A LOW-BACKGROUND BETA COUNTER

By

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Introduction

There is often a need to determinate small amounts of beta activities in applying isotopes to biological, medical measurements, in radiation protection and in some other cases. A special technique is required to solve this problem.

Low-background counters suitable for measurement of probes possessing small amounts of activities have already been constructed in many forms. GAT and GILAT's paper describes a counter for health physics measurements [1]. The detector arrangement was made up of a gas flow proportional counter tube and of a plastic scintillator shield. PARKER's counter which has been used for medical research consisted of a sample counter tube surrounded by liquid scintillation shield [2]. The low-background counter constructed by VÖDRÖS—GYENGE—MIKLÓS built up of valves has been used for medical purposes too [4]. NOSHKIN and DEAGAZIO used their counter made up of GM tubes for biological researches [6]. In the papers of GABRIEL—SEGAR [3] and of RAGUPATHY [7] the circuits of the low-background counter have also been discussed. An earlier paper of the writer discussed in detail how the lowest detectable activity depends on the efficiency of the counting unit, on the total time of measurement, and on the background [8]. According to the formula given it is advisable to reduce the background counting rate. This is carried out by a detector arrangement and an anticoincidence unit coupled between detectors and scalers.

The present paper describes the transistorized low-background counter made up of GM tubes, which was constructed for our isotope laboratory.

Layout of the low-background counter

A block diagram of the layout of the low-background counter is given n Fig. 1. The counter consists of four parts:

— detectors in shield,
— anticoincidence circuit,
— scalers,
— power supplies.

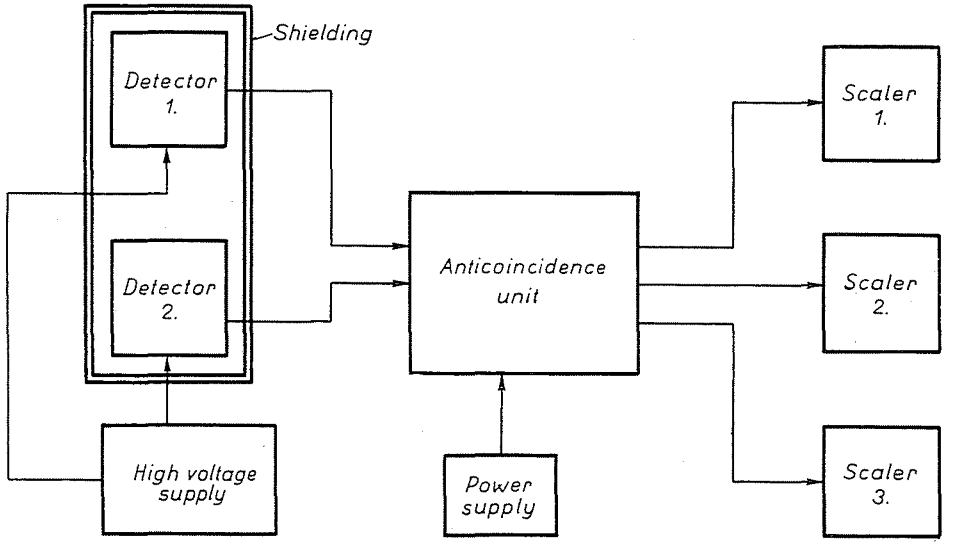

Fig. 1. Block diagram of layout of the low-background counter

The detector arrangement has been built up with two GM tubes produced by the Research Institute for Electronics and Precision Mechanics. One of the tubes has a 1.7 mg/cm^2 thick end-window (Type EFKI-1514) and detects beta particles only emitted from the sample. The other GM tube, having a large bell-shaped form (Type EFKI-1714), covers the small internal GM tube at a solid angle of 2π. The thick wall of bell GM tube is made of chrome-iron, thus beta particles from the sample cannot enter its volume. This tube is sensitive only to high-energy particles of the background radiation. The arrangement of detectors is shown in Fig. 2.

The shielding of the arrangement of detectors has been set up with lead bricks of 50 mm thickness, iron plates and copper plates. At each face of the cubical arrangement, two files of lead bricks gave a shielding of 100 mm thickness. The copper holder with two GM tubes has been placed into an iron tube of 10 mm wall thickness, whose upper part and lower part have been covered with iron plates of 10 mm thickness. The setup of the shielding is shown more exactly in Fig. 3.

Layout and working principle of the anticoincidence circuit will be discussed in the next chapter.

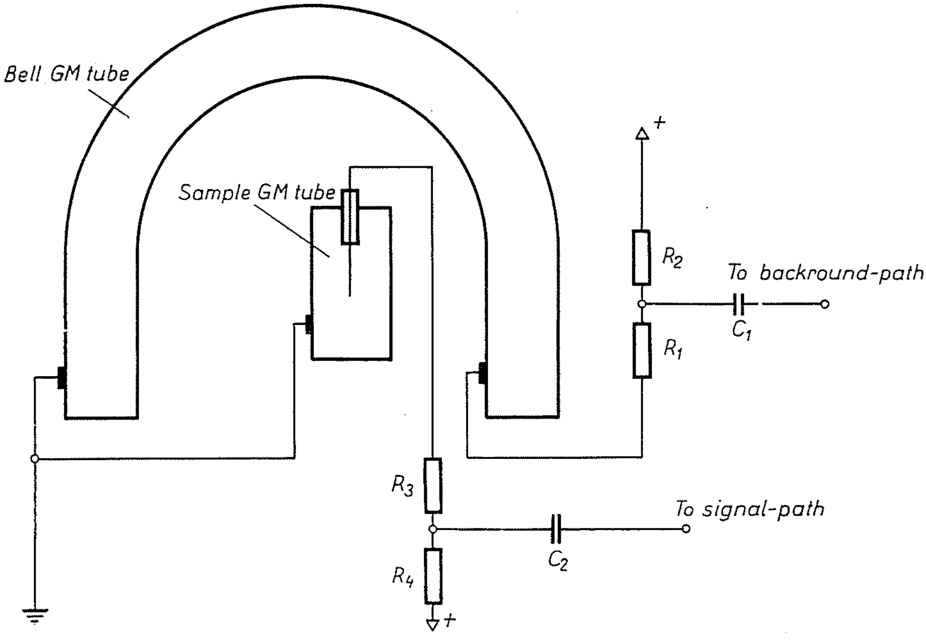

Fig. 2. Arrangement of the detectors

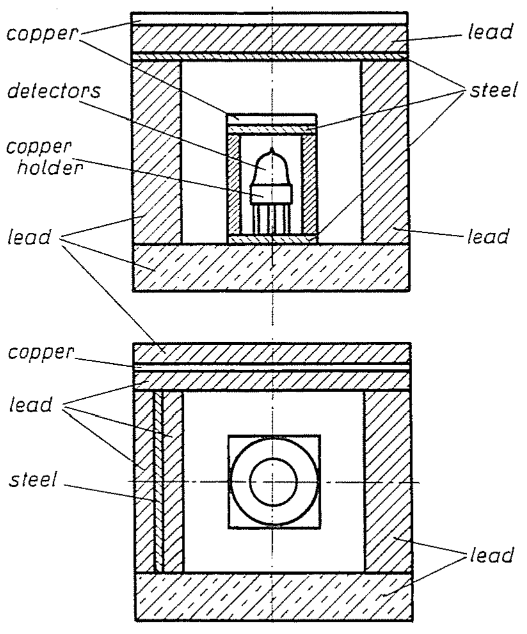

Fig. 3. Scheme of shielding arrangement

There have been used three decimal scalers of the EMG-1872 type in the measurement arrangement, too. The anticoincidence circuit needed a ± 6 V supply which has been ensured by a low-voltage power supply of the Fok—Gyem type (TR-9162). High-voltage power supplies built in the above decimal scalers ensured a proper functioning of the two GM tubes.

Operation of the low-background counter

The working principle of the low-background counter can be studied in block scheme of Fig. 4. The transistorized anticoincidence circuit coupled between detectors and scalers is made up of four parts:

— signal-path,
— background-path,
— gate circuit,
— output circuits.

Regarding the circuit diagram of detectors in Fig. 2, it can be seen that pulses of negative polarity arise, if detecting the tubes, on load resistor R_4 of the sample GM tube as well as on load resistor R_2 of the bell GM tube (Figs 5 and 6). These pulses are fed to inverters I_1 and I_2 on the input of the signal-path as well as on the input of the background-path. Without these pulses the above inverters, made up of transistors T_1 and T_{10}, are in a stable cut-off state. If accepting these pulses on inputs, the inverters produce positive output pulses of short rise-time, which are suitable for triggering univibrators M_1 and M_3.

Furthermore let us see the *signal-path.*

Univibrator M_1 built up of transistors T_2 and T_3 gives a delay of pulses. Delay time can be regulated between 10 and 100 μsec. Univibrator M_2 is made up of transistors T_4 and T_5. The square-pulse of positive polarity at the collector of transistor T_5 is fed to the base of transistor T_6 in the gate circuit on the one hand, on the other hand it is fed to inverter I_2 of the output circuits (Fig. 7).

Let us now have a look at the *background-path.* Pulses of the bell GM tube, being sensitive only to background radiation, are formed by inverter I_3. Univibrator M_3 is triggered by these pulses. The negative square-pulse at the collector of transistor T_{12} is coupled galvanically through resistor R_{16} to the base of transistor T_7 in the gate circuit on the one hand, on the other hand it is led through emitter follower E_2 to the output (Fig. 8). The positive pulse at the collector of transistor T_{13} is led directly to the output.

The *gate-circuit* has been made up of transistors T_6 and T_7. It is necessary to discuss this gate-circuit in detail, because its proper functioning is of great importance concerning the operation of the whole anticoincidence unit (Fig. 9).

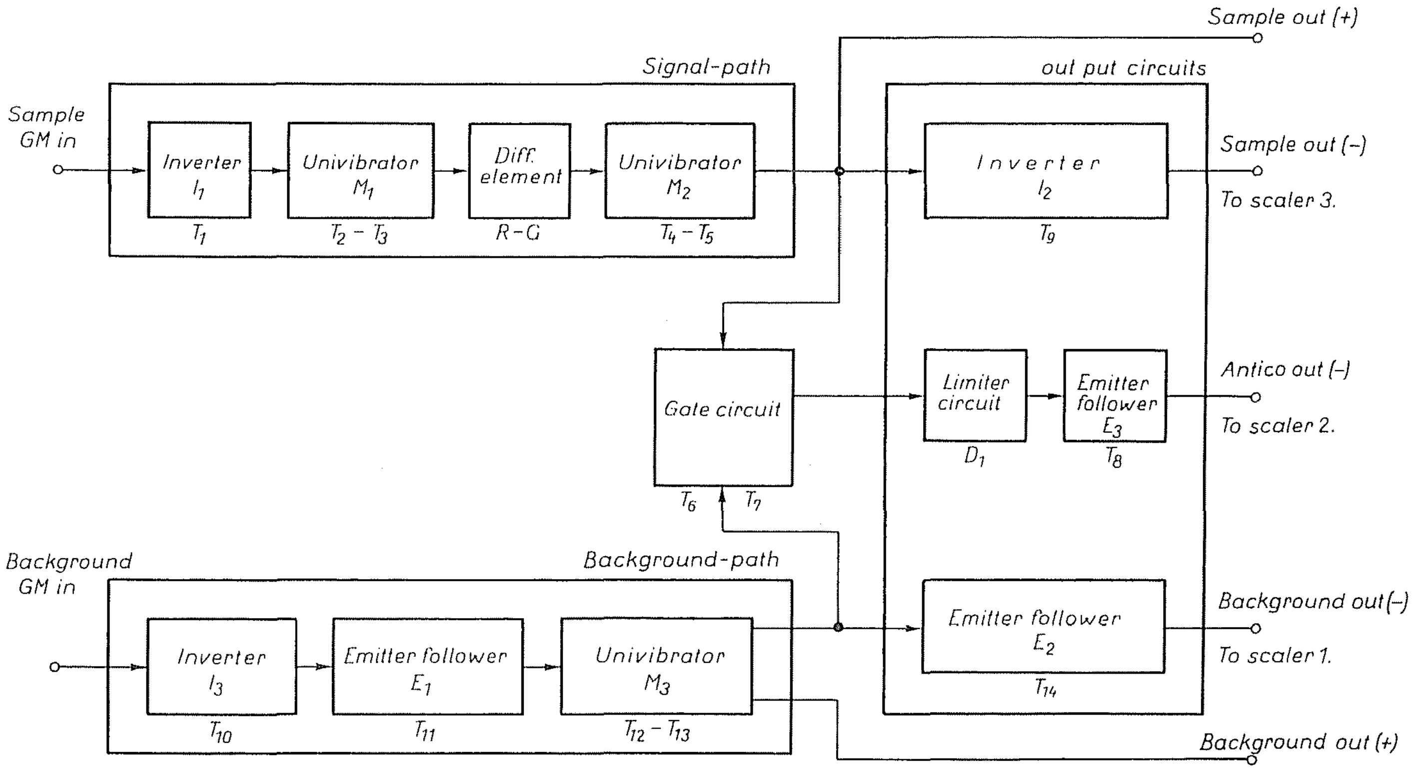

Fig. 4. Block diagram of the functioning of the anticoincidence unit

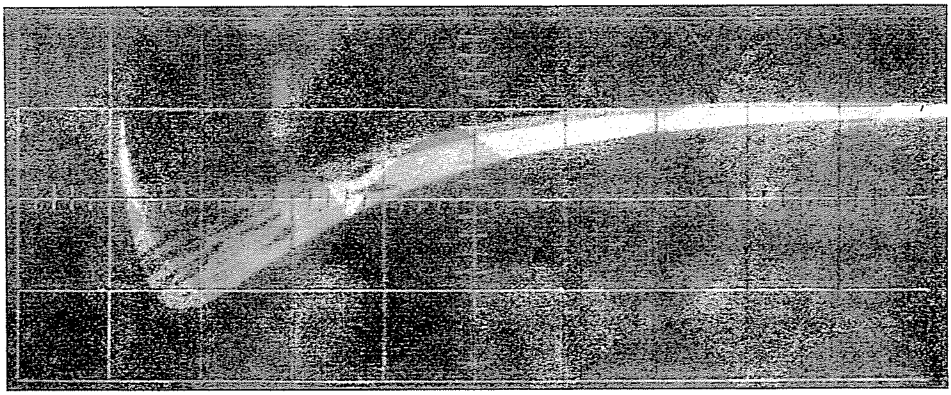

Fig. 5. Pulse form of the sample GM tube. $x = 500\ \mu$ sec/cm; $y = 5$ V/cm

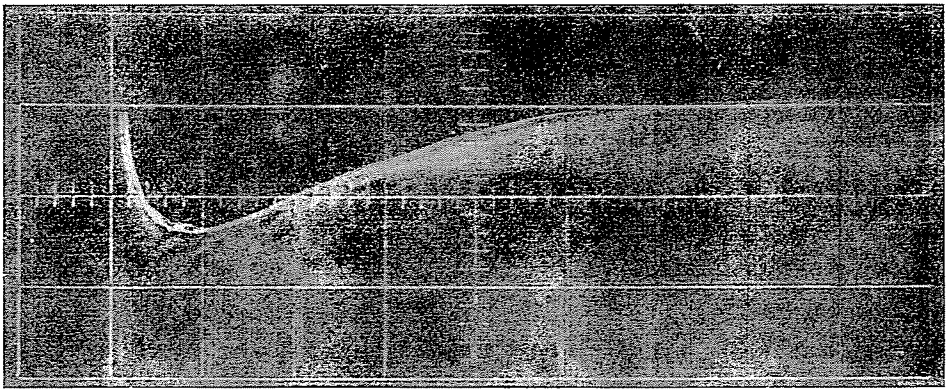

Fig. 6. Pulse form of the bell GM tube. $x = 500\ \mu$ sec/cm; $y = 5$ V/cm

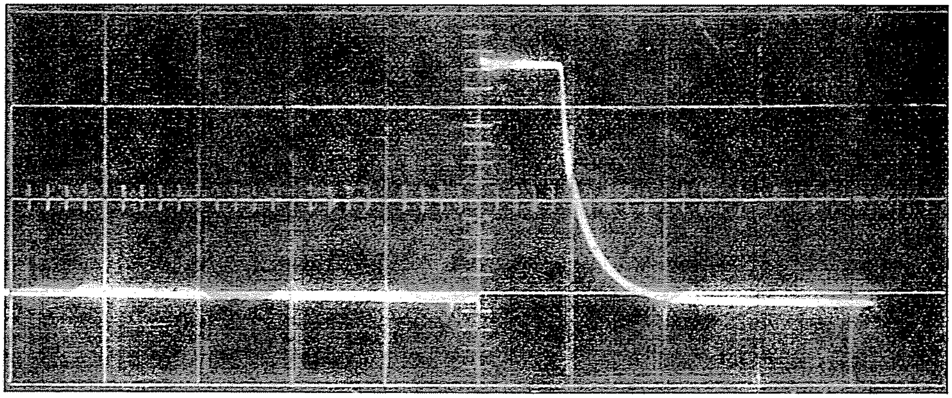

Fig. 7. Square pulse at the collector of T_5. $x = 50\ \mu$ sec/cm; $y = 2$ V/cm

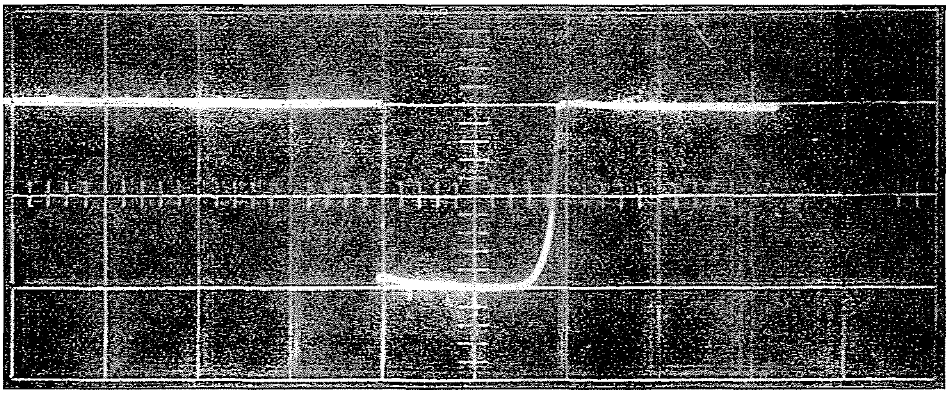

Fig. 8. Square pulse at the collector of T_{12}. $x = 50\ \mu$ sec/cm; $y = 2$ V/cm

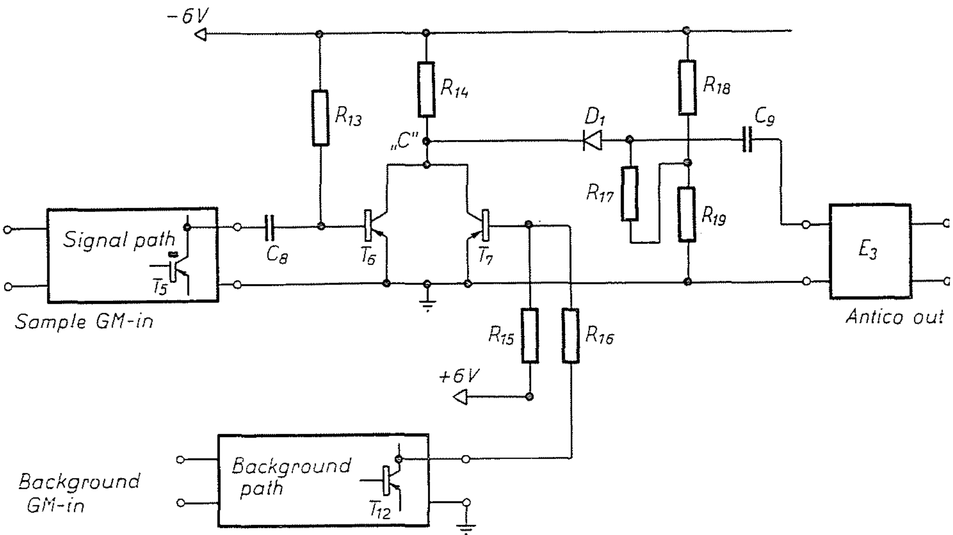

Fig. 9. Scheme to the functioning principle of the gate circuit

In the ground state, transistor T_6 conducts in saturation, which has been achieved by choosing properly the value of resistor R_{13}. The common collector of the two transistors "C" is nearly on zero potential, or, more exactly, it is on a potential of -0.21 V. In the ground state transistor T_7 is cut off, because on its base the potential has been set at $+1.95$ V. This has been achieved by the voltage divider $R_{15}-R_{16}$, where the other end of resistor R_{16} is coupled to the collector of transistor T_{12} being in the conducting state, if, concerning its ground state, $U_{\text{collector}} = -0.12$ V. Now our starting-point is that transistor T_6 is represented by its inner resistance R_{T-6} of low value, while transistor

T_7 is represented by its inner resistance R_{T-7} of great value. Four cases have to be discussed concerning the operation of the circuit:

a) There comes a single pulse on the signal-path.

b) There comes a single pulse on the background-path.

c) There is a pulse on the signal-path, and another one on the background-path, in succession.

d) There is a pulse on the signal-path, and another one on the background-path, but at the same time.

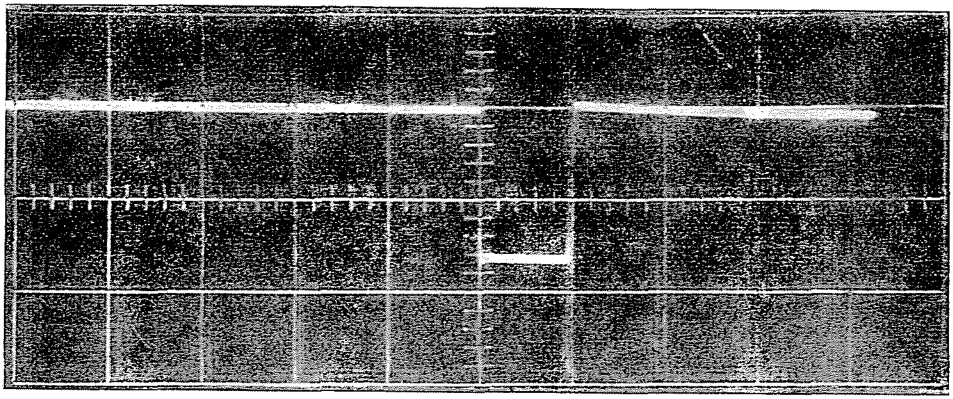

Fig. 10. Output pulse at the collector of T_6. $x = 50$ μ sec/cm; $y = 2$ V/cm

a) Upon input pulses from the signal-path, the univibrator consisting of transistors T_4—T_5 produces two square-pulses of which the one of positive polarity is led to the base of transistor T_6. Transistor T_6 will cut off and a pulse of negative polarity arises at point "C" (Fig. 10). A potential of -1.42 V can be measured at the anode of diode D_1, thus the above pulse is not limited by the series diode limiter circuit, that is being used for reasons to be detailed later on. This negative pulse will appear at the output of emitter follower E_3 consisting of transistor T_8, as well as at the collector of transistor T_9, thus scaler number 2 and scaler number 3 will count simultaneously. This case occurs if a beta particle emitted from the source is detected by the sample GM tube, and the bell GM tube does not operate. But this is the case also if a particle or quantum originating from background radiation, having crossed the shielding and the bell GM tube, will be detected only by the sample GM tube. This phenomenon occurs rarely, but has a deteriorative effect on the background-counting rate.

b) Upon input pulses from the background-path, only the univibrator consisting of transistors T_{12}—T_{13} swings over, thus transistor T_{12} cuts off. On its collector arises a pulse of negative polarity (Fig. 8). Therefore, the other end of resistor R_{16} of resistor divider R_{15}—R_{16}, being not coupled to the base of transistor T_7, gets a potential of -4 V for a duration of 95—100 μsec. The base will have a resulting negative potential for this given duration, so T_7

becomes conducting. Inner resistance R_{T-7} of transistor T_7 is now of low value. It is coupled parallel to the inner resistance R_{T-6} of low value. Theoretically, the resulting resistance lets flow a greater current through common collector load resistor R_{14}. Consequently, there will arise a small pulse of positive polarity at point "C". It was not possible to reveal such a pulse in the realized circuit. But even if such a pulse had appeared, the series diode limiter circuit coupled with proper polarity would have cut it, not allowing it to go to the scaler. Therefore, pulses originating from the bell GM tube cannot let operate the scalers of Nos 2 and 3. These pulses will be counted in scaler number 1 only. (See Fig. 4). Hereby we have got a "shielding" effect, because the particles or quanta, originating from background radiation, which have already been detected by the bell GM tube, cannot fly further, thus they cannot let the sample GM tube operate. The background of the sample GM tube has been diminished.

c) If there are pulses in succession both from the signal-path and the background-path, i.e. both the sample GM tube and the bell GM tube operate separately, then, according to earlier cases a) and b), both scalers of number 2 and 3 will count the signals originating from the beta-source, but the signals from background radiation will be prohibited here.

d) The case is different if both detectors operate simultaneously. This occurs when the particle from background radiation, having been detected in the bell GM tube, does not lose its full energy there, enters the sample GM tube, where it will be detected, too. The background counting rate of the equipment, which is registered by scaler number 2, will be increased by this phenomenon. Thus the above pulses have to be prohibited. The prohibiting of such undesirable pulses is carried out by the gate circuit. The two signals from the two separate GM tubes arrive at the signal-path and the background-path at the same time, because the flying time of particle from the bell GM tube to the sample GM tube is negligible. The positive pulse arriving at the base of transistor T_6 is delayed by 30 μsec by univibrator M_1 compared to the rising edge of the negative square-pulse (prohibiting pulse) arriving at the base of transistor T_7. Therefore, the positive pulse is placed in the "middle" of the prohibiting pulse. In the 100 μsec duration of the prohibiting pulse, transistor T_7 is in the conducting state with maximum current. (R_{T-7} is of low value.) Thus it is in vain that transistor T_6 cuts off, because of accepting on its base a positive pulse (R_{T-6} assumes a great value), since the inner resistance R_{T-7} of low value of transistor T_7 shunts transistor T_6. Consequently, potential of common collector "C" cannot change to such an extent as to produce a pulse. In the realized circuit, neither the inner-resistance R_{T-7} of low value represents a zero value evidently, nor does the inner resistance R_{T-6} of great value have an infinite value, therefore on the common collector "C" there will nevertheless arise a positive pulse of small amplitude, which is of disturbing effect on the proper functioning of the equipment (Fig. 11). The series diode limiter circuit cuts this disturbing pulse, not allowing to transmit it to scaler number 2, which is coupled to the output of the anticoincidence unit. The proper operation of the

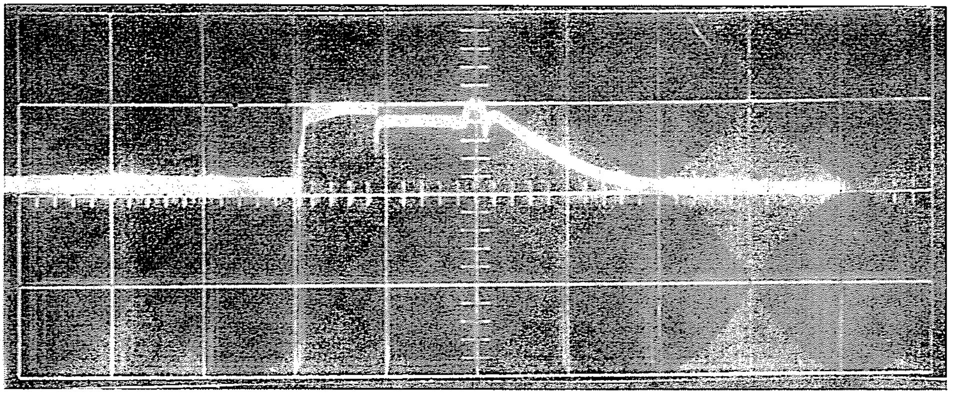

Fig. 11. Disturbing pulse at the collector of T_6. $x = 50$ μ sec/cm; $y = 0.1$ V/cm

series diode limiter circuit has been checked with output pulses — suitable to shift them opposite each other — of a square wave generator with double inputs. Figs 12 and 13 show the pulse arising at the collector of transistor T_6, and at the same time at the cathode of diode D_1, on the one hand, on the other hand, the pulse arising at the anode of diode D_1 (output of limiter), when the coincidence of input pulses is partial. Cutting of the disturbing pulse, and passing of the useful pulse can be illustrated in this way simultaneously (Figs 12 and 13).

Parts of the *output circuits* are diode limiter circuit inventer I_2 and emitter followers E_2 and E_3. Inverter I_2 is built up of transistor T_9 from whose

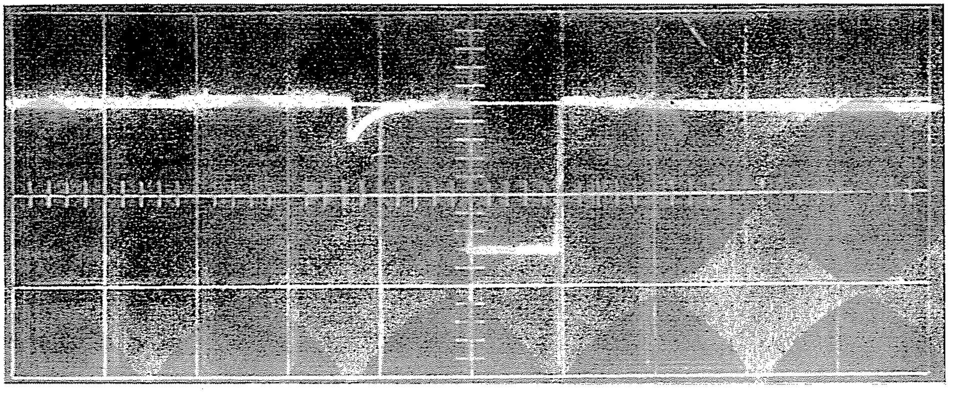

Fig. 12. Pulse form at the cathode of the limiter diode. $x = 50$ μ sec/cm; $y = 2$ V/cm

collector the pulses trigger the scaler number 3. Particles detected by the sample GM tube are counted here only. Emitter follower E_3 consisting of transistor T_8 is coupled to the diode of the limiter circuit discussed earlier.

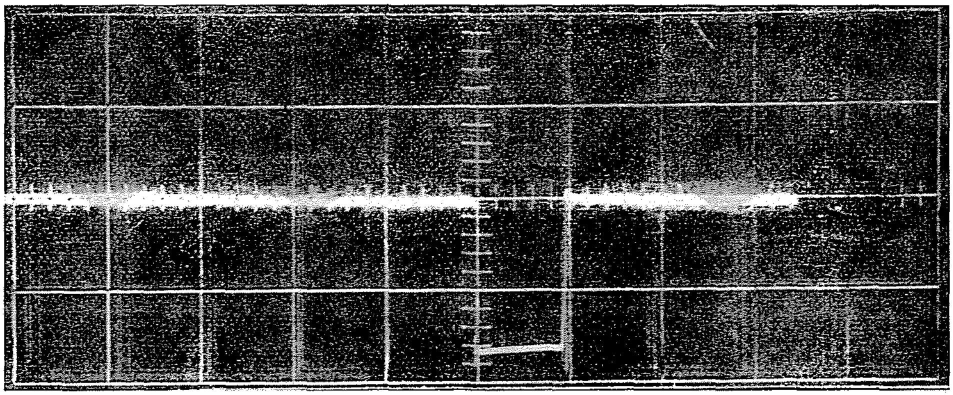

Fig. 13. Pulse form at the anode of the limiter diode. $x = 50\ \mu$ sec/cm; $y = 2$ V/cm

At its emitter there are pulses triggering the scaler number 2, which gives the *reduced background of the sample GM tube*, on the condition that no beta source has been placed under it. Background radiation detected by the bell GM tube is registered by the scale number 1, where pulses are transmitted from the emitter of emitter follower E_2 (consisting of transistor T_{14}).

Measurements, considerations, remarks

A series of background measurements has been carried out by means of the realized equipment. Results are to be found in Table I. It can be seen that the background-counting rate of the detector, being sensitive to the source, is to be diminished by a factor of about 4.3, using only a common shielding.

Table I

Background rates

Arrangement	Background rates [Pulse pro minute]	
	Sample GM tube	Bell GM tube
No shielding	19	230
Under shield	4.4 $\pm$0.2	88.9$\pm$7
Under shield and with anti-coincidence unit	**1.07$\pm$0.1**	

Applying the combited shielding, the diminishing factor became 17.7, thus the anticoincidence shielding resulted in a further factor of 4.1 in diminishing the background-counting rate. The rate of diminishing the background depends not only on the arrangement of mechanical shielding, but also on choosing the concrete type of "Shielding" detector. This is a problem worth studying.

As an informing datum, there has been calculated the lowest detectable activity, taking into account the following data:

- efficiency of measuring unit, $\eta = 10\%$
- total measuring time, $T = 120$ minutes
- background counting rate, $n_b = 1.07$ PPM

$$A_{\min} = \frac{2.934}{0{,}1\,.120} \cdot (1 + \sqrt{1+0.603 \cdot 1.07 \cdot 120}) = 2.4 \text{ pCi} \tag{1}$$

At last, the stability of the low-background counter has been tested. This examination is based on considerations of the probability calculus whose explanation cannot be given here. Reference is only made to the course of stability testing [5]. Measurement groups consisting of 5 single measurements have been made in immediate succession. We have calculated the mean value ($\bar{N}_j$) and expanse (R_j) of these measurement groups, where

$$\bar{N}_j = \frac{\sum_{i=1}^{5} N_i}{5} \quad \text{and} \quad R_j = N_{i\,\max} - N_{i\,\min} \tag{2}$$

Repeating the measurement as above 10 times, the average value of the earlier mean values ($\bar{\bar{N}}$) and the mean value of the expanses ($\bar{R}$) have been calculated, where

$$\bar{\bar{N}} = \frac{\sum_{j=1}^{10} \bar{N}_j}{10} \quad \text{and} \quad \bar{R} = \frac{\sum_{j=1}^{10} R_j}{10} \tag{3}$$

In the knowledge of these two data, the diagram of mean values (Fig. 14) and the diagram of expanses (Fig. 15) have been drawn up. Points represented in these diagrams have to fulfil the following conditions:

1) No points are allowed to be found beyond the extreme limiting line.
2) One or two points are allowed to be found outside the inside limits.
3) No tendency or periodicity is allowed to be manifest in the position of points.

On the basis of the diagrams it can be seen that the points comply with the requirements, therefore temporal stability of the equipment is good, its components work well.

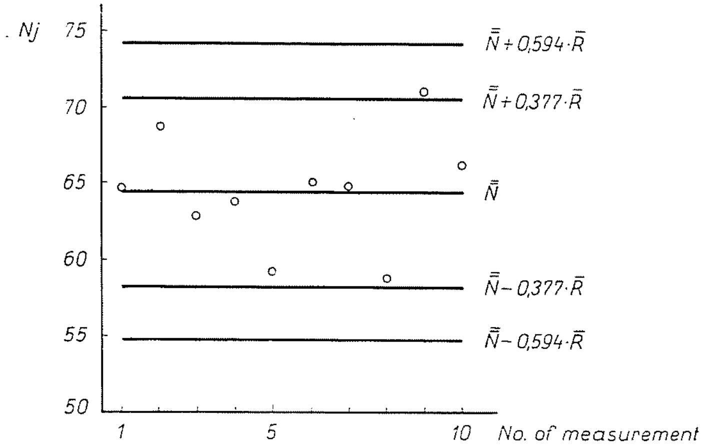

Fig. 14. Diagram of the mean values

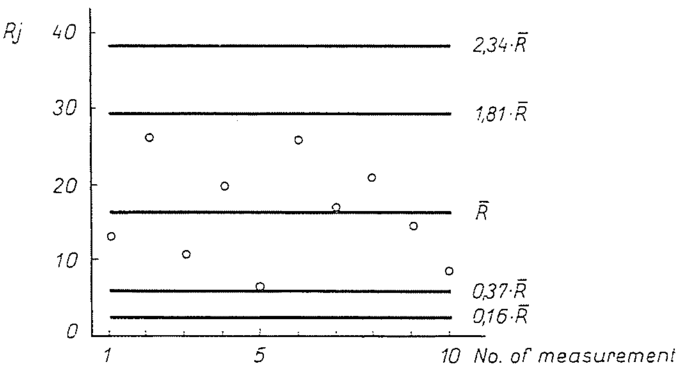

Fig. 15. Diagram of the expanses

Summary

Small amounts of activities can be measured by low-background counters. Layout and operation of a low-background beta counter is described. Working principle of the transistorized anticoincidence unit of this counter is discussed in detail and illustrated by oscillograms. A background of 1.07 ± 0.1 PPM has been measured.

References

1. GAT, J. R.—GILAT, J.: Nuclear Instruments and Methods **8**, 233—235 (1960).
2. PARKER, R. P.: Nuclear Instruments and Methods **8**, 339—343 (1960).
3. GABRIEL, R.—SEGAR, A. M.: Nuclear Instruments and Methods **12**, 307—315 (1961).
4. VÖDRÖS, D.—GYENGE, GY.—MIKLÓS, K.: Orvosi Hetilap **50**, 2380—2381 (1965), (in Hungarian).
5. BUJDOSÓ, E.: Sugárvédelmi Iskola KFKI, 133—134 (1965) (in Hungarian).
6. NOSHKIN, V. E.—DEAGAZIO, E.: Nuclear Instruments and Methods **39**, 265—270 (1966).
7. RAGUPATHY, S.: Nuclear Instruments and Methods **50**, 325—332 (1967).
8. GYÖNYÖR, B.—VIRÁGH, E.: Periodica Polytechnica El. **12**, 467—479 (1969).

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