Quantum Efficiency of GM Counters for Electromagnetic Radiation of 0.662 MeV Energy

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The absolute local quantum efficiency at different points of Geiger-Müller counters has been investigated. A very thin gamma ray beam emitted from a ^{137}Cs source was used. The counter tubes used in this experiment were of the cylindrical type having 0.8 g cm^{-2} cathode thickness. The efficiency curve of the halogen counter with a thick anode has four maximum peaks. The results were compared with the effective layer theory.

1. Introduction

For the purpose of measuring a fine gamma ray beam from a narrow opening, it is necessary to know the local quantum efficiency of the detector in detail. In this study, the local efficiency of counters was determined from the counting rate and

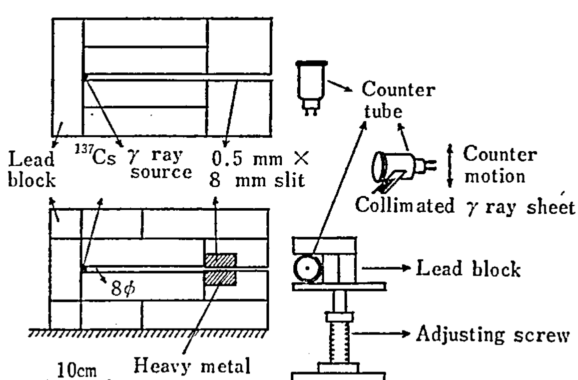

Fig. 1 Experimental arrangement for measuring counting efficiency.

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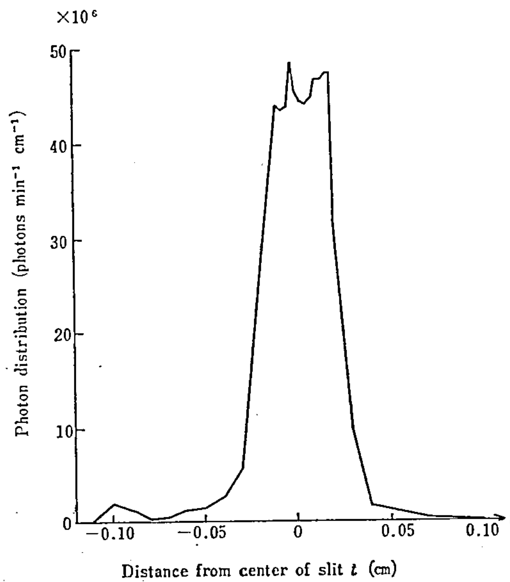
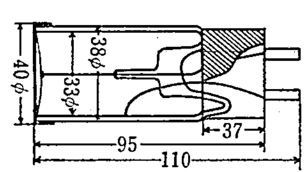


Fig. 2 Distribution of gamma photons 5 cm from the slit.

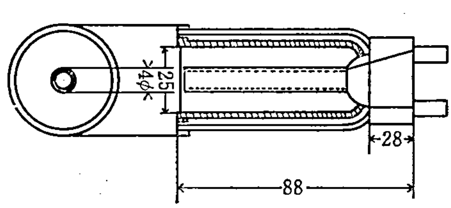
the one dimensional distribution of the gamma ray beam emitted from a slit of 0.5 mm width.

2. Experimental Arrangement and Procedures

The experimental arrangement is shown in Fig. 1. A ^{137}Cs source is embedded in a lead block. The gamma radiation from the source passes through an opening 8 mm in diameter and a narrow gamma ray slit (0.5 mm wide 8 mm long and 100 mm deep) and reaches the counter. The one dimensional distribution of gamma photons from this slit is measured with a GM counter having a very sensitive portion for gamma ray counting and is shown in Fig. 2[1].



(a) Tracerlab TGC-2 type counter



(b) Aloka GM-H-254 type halogen counter

Fig. 3 Counter dimensions.

By moving the counter with an adjusting screw, the counting rate is measured at each position of counters with a standard deviation less than one percent. The counter tubes used in this experiment were of end window type having cylindrical cathodes of 0.8 g cm^{-2} thickness and are shown in Fig. 3.

The Tracerlab TGC-2 type counter is an organic gas quenched counter and is filled with He gas of 720 mm Hg pressure. The cathode is a glass tube with a metal foil.

The Aloka GM-H-254 type halogen counter has a cathode of 25 mm inside diameter and an anode of 4 mm outside diameter and 3.8 mm inside diameter and is filled with Ar gas of 100 mm Hg pressure. The cathode and the anode of the halogen counter are made of iron alloy of 54% Fe, 28% Ni and 18% Co in weight percent.

3. Results and Discussions

The counting rate of TGC-2 type counter is measured at a distance of 30 mm from the slit and is shown in Fig. 4. The counting rate of Aloka GM-H 254 type halogen counter is measured at a distance of 21 mm from the slit and is shown in Fig. 5. The counting rate in Fig. 5 is divided into three parts as cathode counting rate (87.3%), anode counting rate (11.8%) and counter gas counting rate (0.9%). Four maximum values are registered in the counting rate curve of the halogen counter.

As shown in Fig. 6, if the counting efficiency of the cathode is represented by $E(r)$ and the number of photons per unit time per unit length by $D(t)$, the counting rate $C(x)$ can be formularized[2] as

$$C(x)=\int E(t-x)D(t)\,\mathrm{d}t, \qquad (1)$$

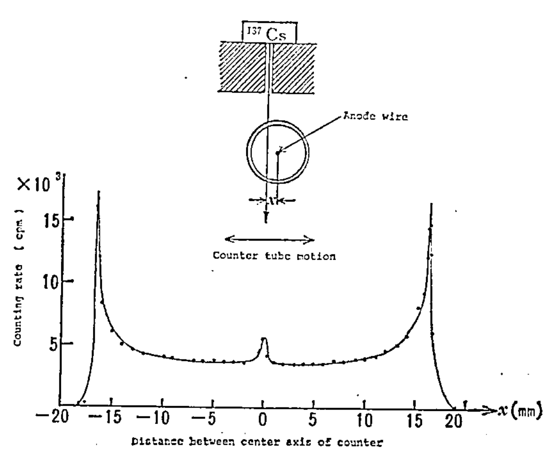


Fig. 4 Counting rate of Tracerlab TGC–2 type counter for gamma radiation of 0.662 MeV energy from a narrow slit at a distance of 30 mm.

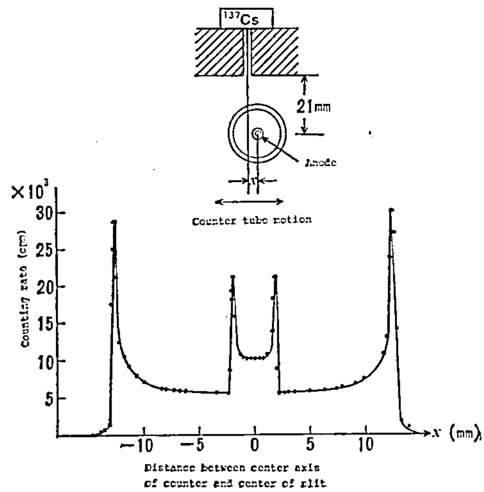


Fig. 5 Counting rate of Aloka GM-H-254 type halogen counter for gamma radiation of 0.662 MeV energy from a narrow slit at a distance of 21 mm.

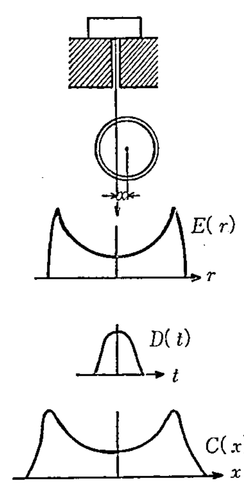


Fig. 6 Relation of counting efficiency $E(r)$, distribution of photons $D(t)$ and counting rate $C(x)$.

where x is the distance between the center axis of the counter and the center of the gamma ray beam.

In this experiment, since the width of the gamma ray beam is very small compared with the diameter of the counter tube, $D(t)$ in Eq. (1) may be written as

$$D(t)=B\delta(t) \qquad (2)$$

except the region where the variation of counting efficiency is very large. B in Eq. (2) is the number of photons emitted from the slit in unit time. From Eqs. (1) and (2) we obtain

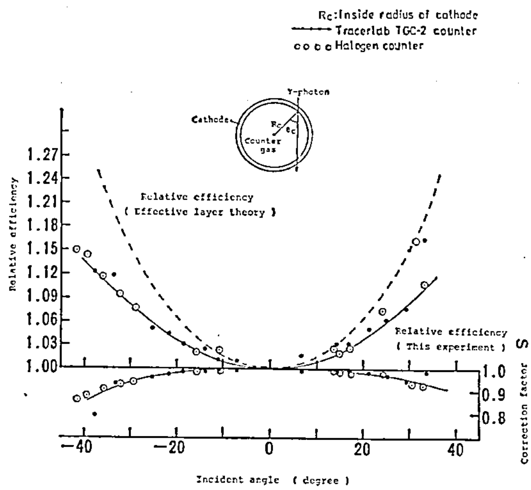


Fig. 7 Relative efficiency and correction factor as function of θ_c.

$$C(x)=B\int E(t-x)\delta(t)\,\mathrm{d}t$$
$$=B(-x) \qquad (3)$$

or

$$E(r)=\frac{1}{B}C(-r). \qquad (4)$$

Where the incident angle of gamma rays θ_c in Fig. 7 is in the region of

$$-40^\circ<\theta_c<40^\circ, \qquad (5)$$

the counting efficiency of the cathode may be obtained directly from the counting rate and Eq. (4). The relative efficiency, the ratio of counting efficiency to the minimum efficiency of $\theta_c=0$, is shown in Fig. 7 as a function of θ_c. The relative efficiency of "effective layer theory"(3)(4) is also shown in Fig. 7.

If the outside radius of the cathode is represented as R_0, the average counting efficiency for infinitely large source distance is given by

$$\langle E\rangle=\frac{1}{2R_0N}\int_{-R_0}^{R_0}C(x)\,\mathrm{d}x \qquad (6)$$

where N is the number of gamma photons strike the counter in unit time.

The effective layer theory is described by assuming that all secondary electrons counted are produced in an "effective layer l_c" of the counter cathode and that all electrons produced in this layer reach the sensitive volume. As shown in Eq. (6), the average efficiency of the cathode may be written as

$$\langle E_c\rangle=\frac{1}{2R_0N}\int_{-R_0}^{R_0}C_c(x)\,\mathrm{d}x, \qquad (7)$$

where $C_c(x)$ is the counting rate due to the cathode. Then the effective layer of the cathode is given as

$$l_c=\frac{\langle E_c\rangle}{\pi\mu}, \qquad (8)$$

where μ is the linear absorption coefficient of gamma rays in the counter cathode.
In this study, the cathode efficiency is assumed as

$$E(r)=S\varepsilon(r)=S\times 2\mu[\sqrt{(R_c+l_c)^2-r^2}-\sqrt{R_c^2-r^2}] \qquad (9)$$

for

$$|r|<R_c$$

and

$$E(r)=S\varepsilon(r)=S\times 2\mu\sqrt{(R_c+l_c)^2-r^2} \qquad (10)$$

for

$$R_c<|r|<R_c+l_c,$$

where $\varepsilon(r)$ is the cathode efficiency obtained from the effective layer theory and S is the correction factor. A part of correction factor S are easily obtained from the experimental values of $C(x)$ and Eq. (9) using Eq. (4) and are shown in Fig. 7. For the region where the efficiency gives a large value, the computed counting rate is obtained from Eqs. (1), (9) and (10). The correction factor S may be given comparing with the experimental counting rate. The quantum efficiency of the cathode of the halogen counter obtained from Eq. (9) or Eq. (10) is given in Fig. 8. (b).

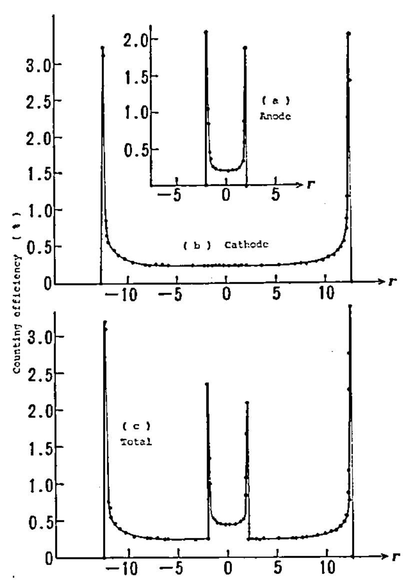


Fig. 8 Variation of the local quantum efficiency across the radius of the Aloka GM-H-254 type halogen counter for 0.662 MeV gamma photon. The solid circles represent the calculated values from the measured counting rate.

The anode efficiency of the halogen counter is obtained as the same procedure of the cathode and is given in Fig. 8. (a). The counter gas efficiency is obtained from the absorption cross section of the gas and the traveling distance of the gamma rays in counter gas. The total quantum efficiency is shown in Fig. 8. (c).

For the GM counters of $_{83}Bi$ cathode, the variation of the local quantum efficiency can be described by assuming an "effective layer[(4)]". The reason for this agreement with the theory may be considered that most of the secondary electrons contribute to the counting are photoelectrons with the same energy and the same range and, therefore, the mechanism is simple. In this study, however, most of the electrons produced in the cathode are Compton electrons with different energy and different range, and the mechanism of counting is very complicated. The local counting efficiency of electrode with low atomic number does not agree with effective layer theory and the correction must be given as this investigation.

References

(1) T. Suzuki, Nucl. Sci. and Tech. Vol. 17, 385 (1980).

(2) T. Suzuki and J. Yuhara, J. Phys. Soc. Japan, Vol. 16, 152 (1961).

(3) H. Yukawa and S. Sakata, Papers Inst. Phys. Chem. Research, Vol. 31, 187 (1937).

(4) R. J. Hart, K. Russel and R. M. Steffen, Phys. Rev. Vol. 81, 460 (1951).