An Efficient Detector for Gamma Radiation

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For the purpose of measuring a sharp variation of the intensity of gamma ray beam, an efficient detector having a very sensitive portion is obtained. The detector is a G-M counter which has a tungsten block in the sensitive volume. By assuming the counting efficiency of the sensitive part of the counter as $A\delta(r)$, the one dimensional distribution of gamma photons from a narrow opening is determined.

1. Introduction

For the measurement of photon distribution in detail(1) or precise determination of liquid levels in a thick pipe(2), a G–M counter having a large local counting efficiency is used. In the counter a tungsten block is inserted. The surface of the block is parallel to the direction of gamma ray beam. When gamma rays travel near the surface of the block, most of the secondary electrons produced in the block reach the sensitive volume and the counter gives a large counting efficiency.

2. Experimental Arrangement and Procedures

The experiment was carried out by using a G–M counter. The counter tube is a cylindrical flow type having a brass cathode 3 cm in diameter, 0.1 cm in thickness and an anode wire 0.005 cm in diameter.

A Cs–137 source which emits homogeneous gamma rays ($h\nu=0.66165$ MeV) was used, the intensity being 7×10^{10} Bq. The CsCl gamma source is put into the cylindrical container 0.4 cm in diameter and 0.4 cm in length. The gamma radiation from the source passes through a heavy metal opening 0.05 cm in width, 1 cm in length and 10 cm in depth (see Fig. 1).

The counter tube can be displaced accurately by a screw, and the counting rate is measured at each position with a standard deviation less than a few percent. The distribution of photons is measured at a distance of 5 cm from the opening. (see Figs. 1 and 3)

As shown in Fig. 1, by inserting a tungsten block (0.5 cm × 1 cm × 2 cm) in the counter, a large counting efficiency is given when the gamma ray beam is in contact with the surface of the tungsten block.

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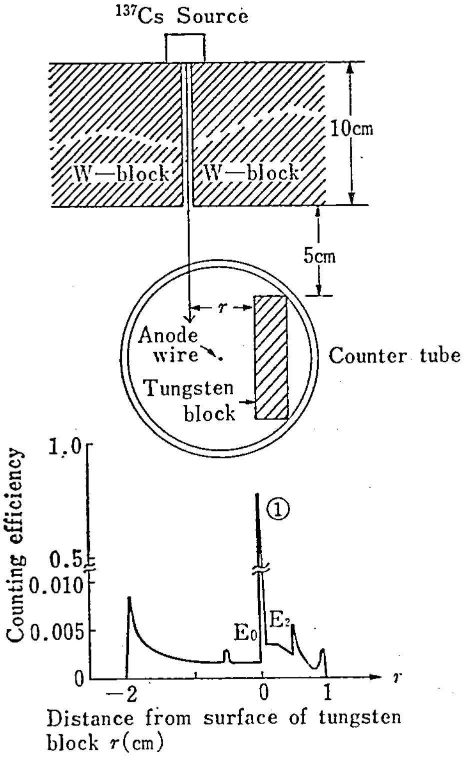

Fig. 1 Schematic diagram of experiment and local counting efficiency of the brass counter having a 0.5 cm×1 cm×2 cm tungsten block for 0.66 MeV gamma radiation.

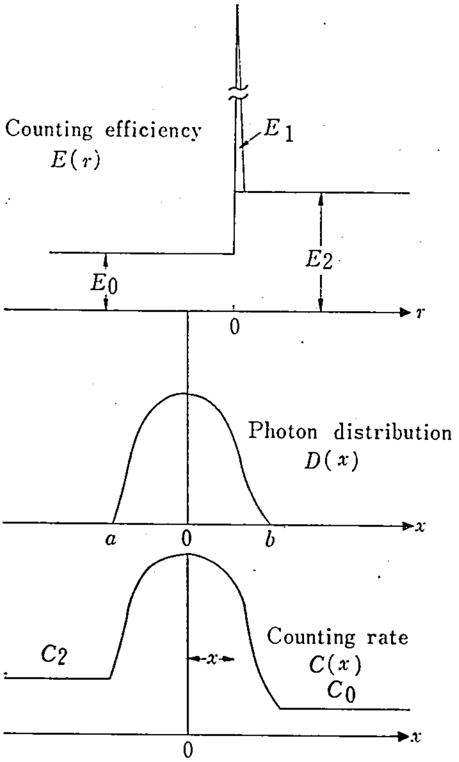

Fig. 2 Schematic diagram of counting efficiency $E(r)$, photon distribution $D(x)$ and counting rate $C(x)$.

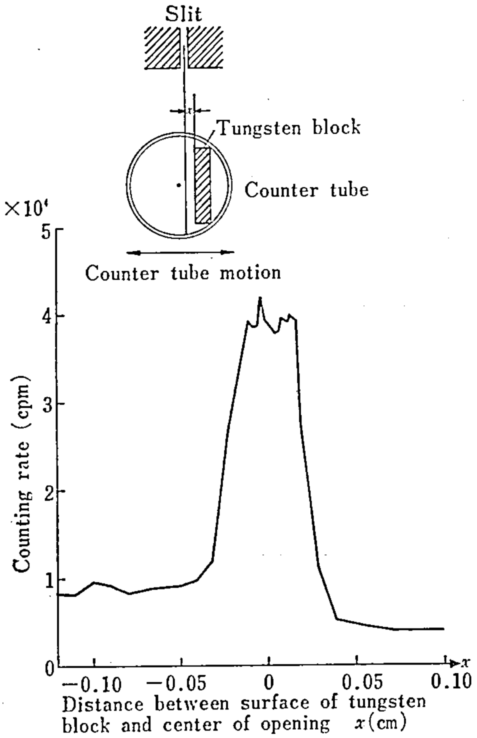

Fig. 3 Counting rate for gamma radiation ($h\nu = 0.66$ MeV) from a narrow opening at a distance of 5 cm.

3. Experimental Results and Discussions

The number of photons emitted from the opening in unit time is determined from the increase of counting rate by platinum anode wire(3). By assuming that all secondary electrons produced in the effective layer(4) reach the sensitive volume and the practical counting efficiency of platinum counter 0.063 and effective layer 0.020 g cm^{-2} for 0.66 MeV gamma rays (4) (5), the number of photons from the opening in unit time N is calculated as

$$N = 2.30 \times 10^6 \text{ photons min}^{-1}. \tag{1}$$

For a given counting efficiency $E(r)$ and a photon distribution $D(x)$, the counting rate $C(x)$ may be written(6) as

$$C(x) = \int_a^b E(t-x)D(t)dt \tag{2}$$

(see Fig. 2).

In this experiment, since the width of gamma ray beam X is very small compared with the diameter of counter tube D, as

$$\frac{X}{D} \approx \frac{0.05\text{ cm}}{1.5\text{ cm}} \approx 0.03, \tag{3}$$

$D(x)$ in Eq. (2) may be considered as

$$D(x)=B\delta(x), \tag{4}$$

except the region ① in Fig. 1 where the variation of counting efficiency is very large. The value B in Eq. (4) is obtained from Eq. (1) as

$$B=2.3\times10^6 \text{ photons min}^{-1}. \tag{5}$$

From Eqs. (2) and (4), we obtain

$$\begin{aligned}C(x)&=B\int_a^b E(t-x)\delta(t)dt\\&=BE(-x)\end{aligned} \tag{6}$$

or

$$E(r)=\frac{1}{B}C(-r). \tag{7}$$

The counting efficiency obtained from counting rate and Eq. (7) is shown in Fig. 1. The counting rate $C(x)$ near $x=0$ in Fig. 2 is given in Table I and Fig. 3.

For 0.66 MeV gamma radiation, the effective layer of tungsten metal is obtained as 0.017 g cm^{-2} or 0.0087 cm, assuming the counting efficiency of tungsten counter is 0.005(4) (5). Since the FWHM of the peak of the counting efficiency curve in the region ① in Fig. 1 is approximately the thickness of effective layer, and then the ratio to the diameter of the counter tube is

$$\text{FWHM}/D\approx6\times10^{-4}, \tag{8}$$

the efficiency near $r=0$ may be divided into three parts as

$$\left.\begin{aligned}&E(r)=E_0 && \text{for } r<0,\\&E(r)\approx E_1+E_2=A\delta(r)+E_2 && \text{for } r=0,\\&E(r)=E_2 && \text{for } r>0.\end{aligned}\right\} \tag{9}$$

(see Fig. 2)

From Eqs. (2) and (9) we obtain

$$\begin{aligned}C(x)&\approx\int_a^x E_0D(t)dt+\lim_{\Delta x\to0}\int_x^{x+\Delta x}A\delta(t-x)D(t)dt+\int_x^b E_2D(t)dt\\&=E_0\int_a^x D(t)dt+AD(x)+E_2\int_a^b D(t)dt-E_2\int_a^x D(t)dt\\&=AD(x)+E_2N-(E_2-E_0)\int_a^x D(t)dt.\end{aligned} \tag{10}$$

From Eq. (10) the n-th approximate value of A_nD_n may be calculated from the $(n-1)$ th value of $D_{n-1}(x)$ as

$$\begin{aligned}A_nD_n(x)&=C(x)-E_2N+(E_2-E_0)\int_a^x D_{n-1}(t)dt\\&=I_n,\end{aligned} \tag{11}$$

where

$$I_n = C(x) - E_2 N + (E_2 - E_0) \int_a^x D_{n-1}(t)\,dt. \tag{12}$$

The values of $C(x)$ and $C(x) - E_2 N$ are given in Table I. Integrating Eq. (11) we obtain

$$A_n N = \int_a^b I_n dx, \tag{13}$$

and A_n is determined from $D_{n-1}(x)$ or I_n in Eq. (12). Consequently $D_n(x)$ is given from Eq. (11) as

$$\begin{aligned} D_n(x) &= I_n / A_n \\ &= \frac{1}{A_n}\left[C(x) - E_2 N + (E_2 - E_0) \int_a^x D_{n-1}(t)\,dt \right]. \end{aligned} \tag{14}$$

In this calculation we assumed that

$$D_0(x) = G \exp\left[-a^2 x^2 \right], \tag{15}$$

where

$$G = 3.6 \times 10^7 \text{ photons min}^{-1}\text{ cm}^{-1} \tag{16}$$

and

$$a = 27.7\text{ cm}^{-1}. \tag{17}$$

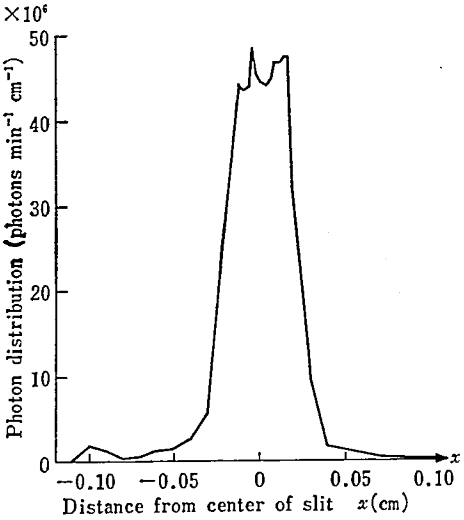

Fig. 4 Distribution of gamma photons 5 cm from the opening.

Values of $D_0(x)$, A_1, $D_1(x)$, A_2, $D_2(x)$, A_3 and $D_3(x)$ are calculated numerically from Eqs. (13), (14), (15) and are given in Table I. The difference between $D_2(x)$ and $D_3(x)$ is negligibly small at each value of x as shown in Table I.

The distribution of gamma photons

$$D(x) \approx D_2(x) \approx D_3(x) \tag{18}$$

is shown in Fig. 4.

For the measurement of the sharp variation of gamma ray beam, it is difficult to get a clear picture by X-ray films. It may be due to the motion of secondary electrons in the emulsion. On the other hand, it is possible to make a precise determination of liquid levels in a thick pipe or to measure gamma photon distributions near a narrow opening by a detector having a very local counting efficiency as this experiment.

Table I. Counting rate and calculated values in Eqs. (12)-(15).

x (cm)	$C(x)$ (cpm)	$C(x)-E_2N$ in Eq. (12) (cpm)	$D_n(x)$ (in units of 10^5 photons $\text{min}^{-1}\ \text{cm}^{-1}$)			
			$D_0(x)$ in Eq. (15)	$D_1(x)$	$D_2(x)$ in Eq. (14)	$D_3(x)$
−0.11	8091	0	0	0	0	0
−0.10	9409	1318	0	18	18	18
−0.09	8992	901	0	12	13	13
−0.08	8175	84	3	1	2	2
−0.07	8459	368	8	5	6	6
−0.06	8900	809	22	12	12	12
−0.05	9062	971	52	15	15	15
−0.04	9837	1746	104	27	26	26
−0.03	11886	3795	178	59	55	55
−0.02	28171	20080	262	288	282	282
−0.01	39023	30932	330	444	439	439
−0.0075	38365	30274	341	437	433	433
−0.005	38461	30370	349	440	437	437
−0.0025	41877	33786	354	489	486	486
0	39307	31216	356	456	454	454
0.0025	38322	30231	354	445	444	444
0.005	37828	29737	349	441	440	440
0.0075	38109	30018	341	447	446	446
0.01	39340	31249	330	466	466	466
0.0125	39093	31002	316	464	466	466
0.015	39502	31411	300	472	474	474
0.0175	39217	31126	281	470	473	473
0.02	27803	19712	262	315	320	320
0.03	11201	3110	178	94	99	99
0.04	5100	−2991	104	14	17	17
0.05	4712	−3379	52	10	12	12
0.07	4084	−4007	8	3	4	4
0.10	3816	−4275	0	0	0	0
0.15	3812	−4279	0	0	0	0

A_n in Eq. (13) (in units of 10^{-3} cm) $A_1=7.31$, $A_2=7.33$, $A_3=7.32$

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References

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

(2) T. Suzuki and T. Urai, J. Atomic Energy Soc. Japan Vol. 5, 22 (1963).

(3) T. Suzuki, J. Atomic Energy Soc. Japan, Vol. 3, 416 (1961).

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

(5) H. Bradt et al., Helv. Phys. Acta, Vol. 19, 77 (1946).

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