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Distortion of Pulse Height Spectra Due to Absorbers in the Measurement of Low-energy β -rays with a Silicon Detector

Hisao YAMAMOTO, Toshiaki ABE, Toshiyuki NORIMURA* and Akira KATASE**

Radioisotope Research Center, *Department of Radiation Biology and Health,
University of Occupational and Environmental Health, Japan

1-1 Iseigaoka, Yahatanishi-ku, Kitakyushu-shi, Fukuoka Pref. 807-8555, Japan

**Yohshindo Laboratory

4-22-3 Miwadai, Higashi-ku, Fukuoka-shi 811-0212, Japan

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In measurement of β -rays from ^{14}C with a silicon semiconductor detector, pulse height spectra are observed to change by insertion of absorbers between the source and the detector. An obvious broad peak appears in the spectra by the insertion. An increase in the absorber thickness reduces the peak height, and shifts the peak position to the higher energy side in the spectra. On the other hand, the increase in the distance between the source and the absorber also reduces the peak height, but does not move the position of the peak. The absorption curve derived from these results shows its particular shape corresponding to the respective position of the absorber. Therefore, the distortion of the pulse height spectrum for low-energy β -rays depends not only on the thickness of the absorber but also on its position between the source and the detector.

Key Words : carbon-14, beta ray, spectrum distortion, absorption curve,
silicon detector, absorber

1. Introduction

In the relative measurement of the intensity of β -emitting radioisotopes, the absolute efficiency of a detector is obtained by using a standard β -ray source of known activity. The standard sources are usually sealed with thin foils for safe and easy handling. The angular distribution and the energy spectrum of β -rays emitted from the sealed source change by scattering and absorption of β -rays passing through the foils. Information about the effects of the absorber on the emission angle and the pulse height spectrum of β -rays is, therefore, required to precisely obtain the intensity of the samples containing β -emitting radioisotopes.

In the previous measurement, we found the

anisotropy of β -ray emission from the sealed source¹⁾, and proposed a simple method for the calculation of the angular distribution of β -rays for a sealed standard source of ^{14}C ^{2), 3)}. In addition, the effects of the anisotropy were evaluated on the determination of detection efficiency of β -ray detector⁴⁾. A method to correct these effects was also developed.

On the other hand, although the pulse height spectra of β -rays have been described in many articles^{1), 2), 5)-11)}, so far as we know, the distortion of the spectrum due to the absorber was not reported except an estimation¹¹⁾, where the change in the spectrum of β -rays from ^{14}C was calculated only for the absorption in source itself and that in air existing between the source and the detector. Therefore, more

systematic experiments are required to make clear the effects of absorber on the intensity calibration of β -rays.

In this work, β -rays from ^{14}C were measured with a silicon semiconductor detector, and then the distortion of the pulse height spectrum was studied by changing the thickness and the position of the absorber placed between the source and the detector. From these results, the effects of such variation on absorption curves were also studied.

2. Experimental Method

The measurement system was composed of a Canberra 2100A preamplifier, a Canberra 2021 spectroscopy-amplifier and an EG&G ORTEC 7100 multichannel analyzer. The semiconductor radiation detector fabricated from a commercial silicon photodiode^{12), 13)} was used for detection of β -rays. The active area of the detector was 13.2 mm^2 (4.1 mm diameter) and the depth of the depletion layer was estimated to be about $100 \text{ }\mu\text{m}$. The ^{14}C source of about 2 mm diameter was made by dropping a small quantity of aqueous solution (containing 3 % ethanol) of ^{14}C polyethylene glycol onto a Mylar (polyethylene terephthalate, 0.889 mg/cm^2) foil. During the experiment, the β -ray source, the absorber (Mylar) and the detector were placed in an evacuated chamber (Canberra 7400).

The interior dimensions of the chamber were 133 mm in diameter and 90 mm in depth, and the inside surface was lined with polyethylene sheets (0.5 mm thick) to reduce the scattered electrons. The detector was set at the point of half depth in the chamber. Its sensitive surface was placed at 33 mm away from the cylindrical wall and pointed toward the center of the chamber. The source was

located at distance of 26 mm from the detector surface on the central line of the chamber and separated by 74 mm from the opposite wall surface. The absorber (20 mm diameter) was set at one of the position of 1, 7, 13, 19 and 25 mm from the source. All the measurements were performed at room temperature.

Effects of the β -rays backscattered by the wall of the chamber on the counting rate were corrected by using the previous results²⁾ obtained for three lining materials of the wall. These data showed that the counting rate increases almost linearly with the atomic number of the lining materials for various emission angles of β -rays. Relative magnitude of the corrections was 0.8% for the effective atomic number (4.75) of the lining material (polyethylene) used in this experiment.

3. Results and Discussion

Figure 1 shows the pulse height spectra measured for 10 000 s for each thickness of the absorber set at a distance of 1 mm from the β -ray source. The channel number is nearly equal to the energy expressed in keV. For no absorber a small peak with a steep slope appears in the low-energy region, and then it becomes broader by inserting the absorber. This tendency is similar to that calculated by Borg¹¹⁾ for the absorption in air existing between the source and the detector. It is worth to notice that for the two absorber thicknesses of 0.427 and 0.889 mg/cm^2 the pulse height spectra almost overlap with that for no absorber in the region of energy higher than 30 keV. This result means that the energy loss for these thin absorbers is almost negligible in this energy region, since the stopping power for electrons is small.

Figure 2 represents the variation of the

Fig. 1 Pulse height spectra measured for 10 000 s for each thickness of the absorber set at a distance of 1 mm from the β -ray source of ^{14}C .

peak point against the absorber thickness B . Open and closed circles indicate the results for the channel number H_p and the relative count N_p at the peak point, respectively. Solid and broken lines are fitted to these experimental values by applying the least squares method and expressed by the following respective formulas :

$$H_p = -36.4 \exp(-0.409B) + 55.1 \quad (1)$$

and

$$N_p = 0.982 \exp(-0.324B) + 0.079. \quad (2)$$

Thus, with increasing absorber thickness, the peak height decreases and simultaneously the peak channel is shifted to the higher energy side. This phenomenon is attributed to the fact that in the low-energy region the stopping power for electrons decreases with increasing energy¹⁴⁾. Electrons with lower energy are

Fig. 2 Variations of the channel number (open circles) and the relative count (closed circles) at the peak point in the spectra of Fig. 1 against the absorber thickness. Solid and broken curves (expressed by Eqs. (1) and (2), respectively) are fitted to these experimental values by applying the least squares method.

more easily absorbed by increasing the thickness of absorber.

In Fig. 3 is shown the pulse height spectra measured for 10 000 s with the absorber of $B = 1.778 \text{ mg/cm}^2$ put at various distances from the β -ray source. The distance between the source and the detector is fixed at 26 mm. Figure 4 represents the variations of the peak channel and the relative count at the peak point against the distance D between the source and the absorber. Circles and lines have the same meaning as in Fig. 2. The solid and broken lines are expressed by the following respective equations :

$$H_p = 0.0472D + 38.0 \quad (3)$$

and

$$N_p = 0.243 \exp(-0.117D) + 0.394. \quad (4)$$

In this case, the peak channel hardly changes for the variation of the distance. On the contrary, although the peak height decreases with increasing distance, the rate of change is reduced and the shape of spectrum scarcely

Fig. 3 Pulse height spectra measured for 10 000 s for an absorber thickness of 1.778 mg/cm^2 at various distances from the β -ray source of ^{14}C .

varies for the distance more than 13 mm. The qualitative explanation for this tendency is as follows. Two kinds of β -rays impinge on the detector. One of them consists of those which pass through the absorber without scattering and absorption, and hit straight on the detector. The number of these β -rays is nearly independent of the position of the absorber. Beta-rays of the other kind are those scattered in a region of the absorber and deflected to the detector. The region is around the center of the absorber. This center denotes the point at which the line connecting both centers of the source and the detector crosses the absorber surface. The number of β -rays scattered in the region decreases with the increasing distance D between the source and the absorber. On

Fig. 4 Variation of the peak point in the spectra of Fig. 3 against the distance between the source and the absorber.

Circles and lines have the same meaning as in Fig. 2. Solid and broken lines are expressed by Eqs. (3) and (4), respectively.

the other hand, considering the mean free path of electrons in the absorber, forward scatterings are most probable. Then, the ratio of the number of β -rays which enter the detector, to that of scattered ones in the region dose not change appreciably with the distance D . From these two reasons, the number of β -rays that are scattered in the absorber and impinge on the detector is considered to decrease with the increasing D . For further detailed explanation the quantitative estimation is required.

From the measured pulse height spectra, absorption curves were derived for the β -rays from ^{14}C . The counting rates were obtained by integrating these spectra from 10 to 160 keV. In Fig. 5 the results are illustrated for each distance D of the absorber from the source. The ordinate of the figure shows the relative counting rate R expressed on a logarithmic scale. Five lines represent the results calculated from the equation

$$R = a_1 \exp(b_1 B) + a_2 \exp(b_2 B), \quad (5)$$

where a_1 , a_2 , b_1 and b_2 are the coefficients

Fig. 5 Absorption curves for the β -rays from ^{14}C for five distances between the source and the absorber.

Five lines are expressed by Eq. (5). The values of the coefficients a_1 , a_2 , b_1 and b_2 are determined by applying the least squares method to the experimental results, and listed in Table 1.

determined by applying the least squares method to the experimental results, and their values are listed in Table 1. For $D = 1$ mm the line is convex upward. It becomes almost linear for $D = 7$ mm, and is converted into a downward convex curve for the values of D longer than 7 mm. Moreover, when D is longer than 13 mm, the curves nearly overlap with one another. This overlap corresponds to that of the pulse height spectra shown in Fig. 3.

4. Conclusions

When the relatively thin absorber is inserted between the source of the β -rays and the detector, the obvious peak appears in the pulse height spectrum. With increasing absorber thickness, the height of peak is reduced, and simultaneously its position is shifted to the higher energy side. On the other hand, with increasing absorber distance from the source, the height of peak lessens, but its position does not change.

While the absorber is placed near the source, the absorption curve, whose ordinate is expressed on a logarithmic scale, is convex upward, and can not be expressed by a simple exponential function. Moving it away from the

Table 1 Coefficients in Eq.(5) for the absorption curves determined by applying the least squares method to the experimental results

$D(\text{mm})$	a_1	a_2	$b_1(\text{cm}^2/\text{mg})$	$b_2(\text{cm}^2/\text{mg})$
1	1.12 ± 0.06	-0.118 ± 0.057	-0.242 ± 0.016	-2.3 ± 1.7
7	1.00 ± 0.01	—	-0.253 ± 0.006	—
13	0.882 ± 0.073	0.119 ± 0.072	-0.257 ± 0.020	-1.38 ± 0.86
19	0.875 ± 0.022	0.125 ± 0.022	-0.262 ± 0.008	-1.95 ± 0.47
25	0.852 ± 0.052	0.149 ± 0.051	-0.266 ± 0.015	-1.47 ± 0.55

source, downward convex curves are observed. One should also take notice that the distortion of the pulse height spectrum for low-energy β -rays depends not only on the thickness of the absorber but also on its position between the source and the detector.

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要 旨**低エネルギー β 線に対するシリコン検出器からの
波高スペクトルの吸収体による変形**

山本久夫, 阿部利明, 法村俊之*, 片瀬 彬**

産業医科大学アイソトープ研究センター, * 同大学医学部放射線衛生学教室

807-8555 福岡県北九州市八幡西区医生ヶ丘 1-1

** 養真堂研究室

811-0212 福岡市東区美和台 4-22-3

シリコン半導体検出器を用いて ^{14}C からの β 線を測定する際に、線源と検出器との間に吸収体がある場合に、波高スペクトルがどのように変化するかを調べた。吸収体を挿入すると、波高スペクトルには幅広い明確なピークが生じた。吸収体の厚さを増加させるとピークの高さが減少するとともに、ピークの位置は高エネルギー側に移動した。一方、吸収体が線源から離れるに従って、ピークの高さは減少するが、その位置には変化はなかった。また、得られたスペクトルから β 線の吸収曲線を求めたところ、単純な指数関数曲線ではなく、吸収体の位置によってそれぞれ特徴のある曲線となった。以上の結果から、低エネルギー β 線の波高スペクトルは、吸収体の厚さによって変化するだけでなく、吸収体が線源と検出器との間のどの位置にあるかによって違ってくるのがわかった。