Alpha Ray Image Separaton Method from Alpha and Gamma Ray Mixed Image by Using Imaging Plate

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Introduction

Main problem of an imaging plate (IP) as a radiation detector is that it has sensitivities for many kinds of radiations and it is difficult to separate these radiations with each other. As an example, to measure the radon in air with the IP, the IP feels to the natural gamma rays too, and we can't evaluate the alpha ray dose from the radon and the gamma ray dose separately. Also it can't be used for the in-beam heavy ion experiments in a high gamma ray field such as an irradiation vault. The largest defect of the IP is that the radiated memory in it fades according with elapsed time, which can not be neglected for using the IP as an integral type detector. To use the IP as a radiation detector, this defect must be overcome.

By using this fading phenomenon of the IP, we succeeded to separate an alpha ray image and a gamma ray image from an alpha and gamma ray mixed image.

As a separation method of mixed images, a plural times read out method[1] and a two wavelengths read out method[2] have been proposed, but, these methods are not useful in practical fields.

On the other hand, our method is very easy in a principle and it has a high separation efficiency between alpha and gamma rays and will become a good separation method for a short period measurement within a several days.

Principle of image separation

There are some papers concerned with a fading of photo-stimulated luminescence (PSL) of the IP[3,4], but the fading data reported are not equal owing the luck of severe temperature control. We measured a fading function[5] of ^{60}Co gamma rays at 25°C by use of BAS - UR which is one of the IPs for BAS-3000 image analyzer.

$$F(t) = 0.537\ e^{-0.693 \times t / 2.29} + 0.463\ e^{-0.693 \times t / 24.27}$$

Here, t is elapsed time(days). There are two fading components, one component of 53.7% fades with half life of 2.29 days and the other one of 46.3% fades with half life of 24.27

days. The component ratio changes depending on the kinds of radiation. For ^{60}Co gamma rays, it is 1.16 and for alpha rays it becomes more larger.

The speed of fading is changed largely depending on the temperature and the kinds of radiation; it is not so large at 0°C, but it becomes larger remarkably at 50°C. Here, we call the fading at 50°C as "annealing". By using annealing phenomena we could separate alpha ray and gamma ray images.

The method is very simple; we read out the first image from the IP which has irradiated with alpha and gamma rays, it is annealed for 2 hours in a constant temperature convection oven which is kept at 50°C, and finally the second image is read out from the annealed IP.

An alpha ray image is obtained by subtracting the second image from the first image as following ways. Here we call this method as " Annealing-Ratio Subtract Method (ARS method) ".

On every pixel in the IP image, PSL value irradiated with unit dose equivalent of gamma rays stands for f(t) and that of alpha rays stand for g(t) as a function of annealing time (t). Here, we assume that annealing temperature is constant and fading at room temperature is negligible small.

Before the irradiation of the IP with alpha and gamma rays, one part of the IP is covered with a thin polyethylene film, not to be irradiated with alpha rays and to be irradiated only with gamma rays. The PSL density of the area irradiated by the only gamma ray is shown as follows.

$$P_{\gamma}(t) = R \times f(t), \qquad (1)$$

where, R is the dose equivalent of the IP irradiated by gamma rays.
The PSL density irradiated by gamma and alpha rays is shown as follows;

$$P_{mix}(t) = a \times f(t) + b \times g(t) \qquad (2)$$

Here, a and b are the dose equivalents due to gamma rays and alpha rays, respectively.
Now, we subtract an annealed image from a first measured image as follows;

$$\Delta P = P_{mix}(0) - K \times P_{mix}(t)$$
$$= R\{ f(0) - K \times f(t) \} + a\{f(0) - K \times f(t) \}+ b\{ g(0) - K \times g(t) \}. \qquad (3)$$

Here, P_{mix} (0) is the first measured PSL density of the irradiated IP. We put it in a fixed temperature oven for t hours. P_{mix} (t) is the second measured PSL density of it. K is a constant.

In equation (3), the first part shows the PSL component irradiated by the gamma rays, the second part shows the PSL component irradiated by gamma rays which are emitted accompanied with alpha decay and the third part shows the PSL component irradiated by alpha rays.

Now, we set $K = f(0) / f(t)$, the first and second parts are canceled and the equation is simply expressed as follows.

$$\Delta P = b\{ g(0) - K \times g(t) \}. \qquad (4)$$

Here, K is the annealing coefficient which means the reversed function of annealing ratio ($= f(t) / f(0)$) of gamma ray component. Therefore, we can easily calculate K from measured f(t) and f(0) values of the region of interest (ROI) area which is irradiated with only gamma rays and not irradiated with alpha rays. We call K as an annealing coefficient (AC).

By using the equation (4), we can obtain a pure alpha ray image which will be used for qualitative image analysis. But, this equation does not show an absolute PSL distribution, because ΔP is changed by experimental conditions such as an annealing temperature and an elapsed time.

For obtaining an absolute PSL image, we must calculate the AC of alpha ray component. But, we can not calculate it from the usual IP image, because the IP which is irradiated with alpha rays is usually irradiated with beta and gamma rays too. It is calculated by measuring a PSL value of every alpha particle track of the first and the second images.

$$L = g(0) / g(t). \qquad (5)$$

Here, L means the AC of the PSL component irradiated by alpha rays.
From equation (4) and (5), an absolute alpha ray image is shown as follows;

$$b \times g(0) = \Delta P / (1 - (K / L)). \qquad (6)$$

By using equation (6), we can compare the alpha images which are measured on the different conditions.

Experiment

We used an image analyzing system (Fuji Photo Film Co.,Ltd) which is composed of an image reader (BAS-1000), an analyzer (MacBAS), an image printer (PICTROGRAPHY3000), MO disc drive (Panasonic LF-3200) and printer (Laser Jet4). The type of the IP is BAS-1000III s, of which size is 20 × 40 cm and pixel size is 100μm. The time for image reading per an IP is about 3.5 minutes.

We used a ^{60}Co gamma ray source from which dose was 0.12 mGy at 1m and a ^{238}U alpha source of which size was 5 cm in diameter and its activity density was 10.8 Bq/cm^2. The alpha source is in radioactive equilibrium between ^{238}U and ^{234}U.

The IP is irradiated with a ^{60}Co gamma ray source at 2 meter for 30 minutes. In front of the IP, three lead absorbers are set and the absorber thickness are 5, 10 and 15mm. Next, the IP is irradiated with alpha ray source which is put on the IP directly for 15 ~ 45 minutes. After the IP is cooled for 30 minutes waiting for the disappearance of short life fading component, the first reading is carried out.

After the first reading, the IP was annealed for 2 hours in a convection oven which is kept at 50 ± 0.5 °C and the second reading is carried out.

Result

Measurement of annealing coefficient

On ARS method, it is important to obtain an accurate annealing coefficient.

Figure 1 shows the first IP image which is irradiated with radiations from ^{60}Co and ^{238}U sources. In the Fig. 1, A is the area where ^{238}U is set and C, D and E are the shadows of the lead absorbers of which thickness are 5, 10 and 15 mm, respectively.

Figure 2 shows the PSL/mm^2 distribution on the line of a –a' in Fig. 1. The open circles are the first measurement and the crosses are the second measurement. On comparing the first and second curves, the distance of peak area where is irradiated with ^{238}U source is larger than the other gamma ray irradiated areas.

Table 1 shows the AC obtained in every ROI area. The AC of area A is 2.12 and 1.2 times greater than the other areas. The AC of them show almost same value 1.74 and their standard deviation is calculated to be ± 0.02. It is clear that the AC of gamma ray irradiated areas are not changed even if absorber thickness are changed and that of the alpha ray irradiated area is annealed faster than gamma irradiated areas.

In Fig. 2 , the differences of the open circles and 1.7 times of the crosses are the black circles. The alpha ray irradiated area is emphasized and gamma ray shadows are disappeared.

Separation of images

An operation between image data are carried out by using "LPprocess" which is a image reconstructing software developed by Fuji Photo Film Co., Ltd.

By using LPprocess, We tried to separate an alpha ray irradiated image from a alpha and gamma ray mixed image.

Figure 3 shows the first measured raw image. The IP was irradiated with the same condition as Fig.1, and the area F and G were irradiated with alpha particles from the ^{238}U source for 45 minutes and 15 minutes, respectively. After annealing treatment, the IP was set to the image reader.

Figure 4 is an image subtracted with the second image by a factor 1.7 from the first image. In Fig. 4, the shadows of lead absorbers are almost cleared but many black points (pixels) are remained. This is explained as that two images are not measured at the same position within the length of one pixel and the statistical error due to subtraction are emphasized in view. Before the image subtraction, we smoothed the first and second images by using LPprocess and subtracted the two images with above mentioned method. Figure 5 shows the subtracted image. The gamma background is clearly eliminated and alpha irradiated areas are remained.

The PSL densities of A, F and G are 18.8, 24.0 and 8.8 PSL/mm^2, respectively, and these values are roughly proportional to the irradiation time 30, 45 and 15 minutes, respectively.

Conclution

We have developed a separation method of an alpha ray image and a gamma ray image by using an IP. The IP which has been read out the first image by the image reader is annealed at 50°C for 2 hours in a convection oven and is read once more by the image reader. Subtracting K times of the second image from the first image, we can get the alpha ray image. Here, K is the annealing coefficient which is defined as the PSL density of gamma ray irradiated area of the first measurement to the one of the second measurement area.

References

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Table 2. Annealing coefficient of the area indicated in Fig. 1.

area	AC	radiation, absorber
A	2.12	gamma + alpha
B	1.73	gamma
C	1.76	gamma, lead 5mm
D	1.71	gamma, lead 10mm
E	1.75	gamma, lead 15mm

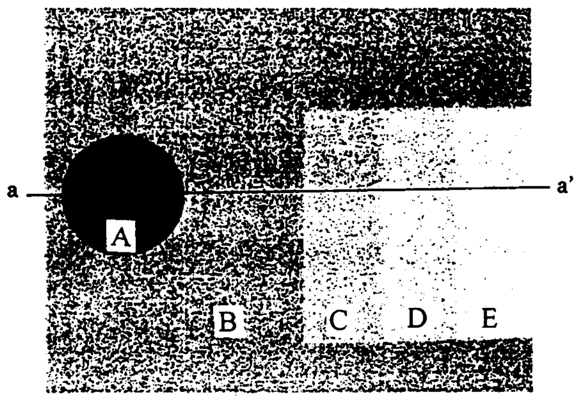

Fig. 1. The first measured image irradiated with ^{60}Co and ^{238}U sources. Circle shows the place irradiated with Uranium source and three rectangles at right side are the shadows of Lead filters (thickness : 5, 10, 15 mm).

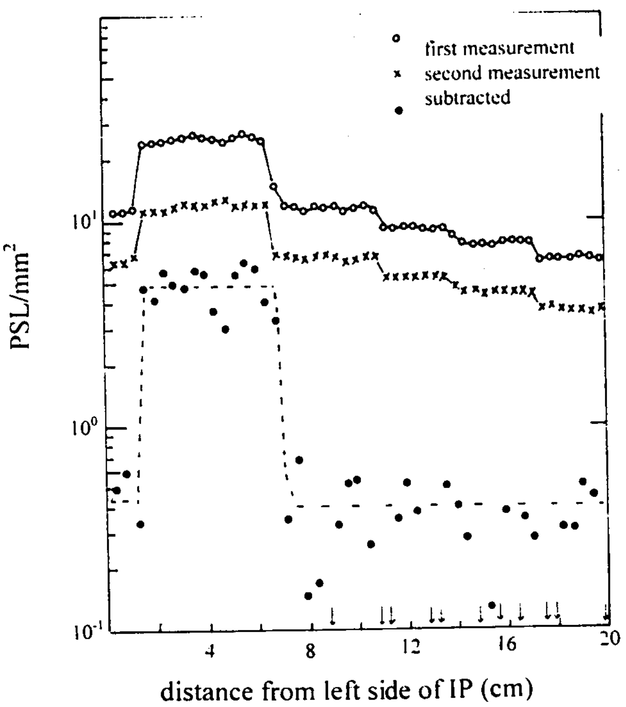

Fig. 2. PSL distribution of the first measurement, the second measurement and subtracted values.

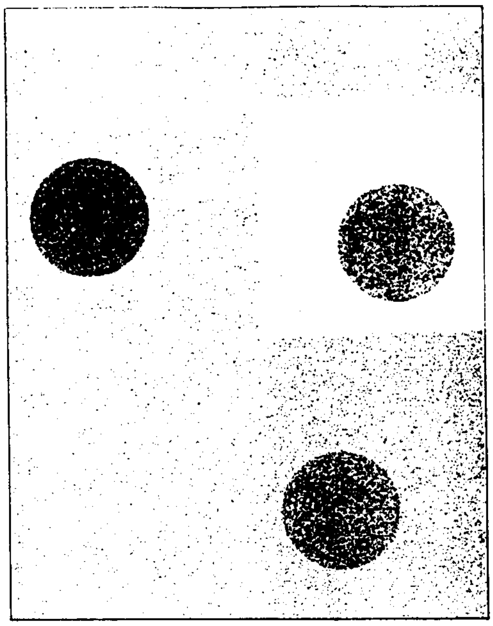

Fig. 3. The first measured image irradiated with ^{60}Co and ^{238}U. Three circles belong to Uranium sources.

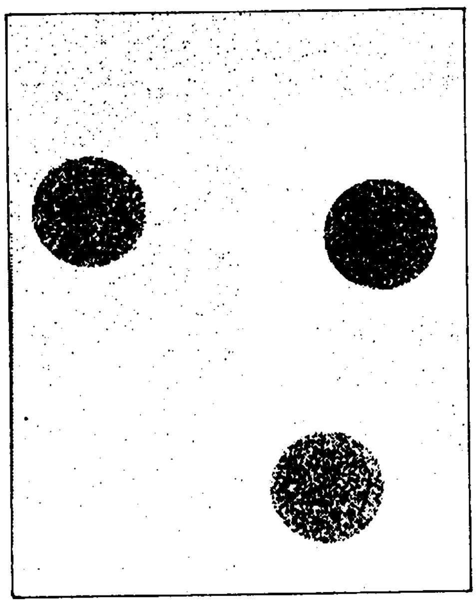

Fig. 4. Subtracted alpha ray image. (no smoothing).

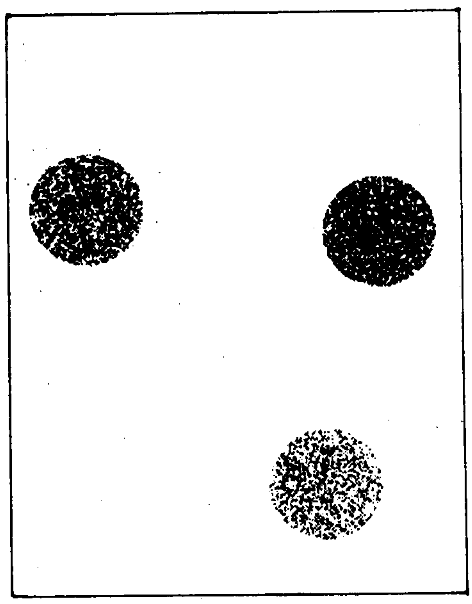

Fig. 5. Smoothed and subtracted alpha ray image.