Po-210 distribution image and radioactivity determination in inner organ of fish with nuclear track detector CR-39

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The distribution images of α-emission nuclides in the inner organ of dried sea fish such as sardine were obtained with nuclear track detector CR-39 by exposing for about 3 months. To obtain the radioactivity density in the inner organ from the pit density on the surface of CR-39, the detection efficiency of α-particle emitted in the organ was obtained by the calculation of energy loss of α-particles in the organ and in CR-39 using Bethe formula. The radioactivity densities were 1.3 Bq/cm³ and 85 Bq/cm³ for sardine and the liver of golden threadfin bream, respectively, and the energy absorption doses were 33 mGy/y and 2.2 Gy/y, respectively.

Keywords: sea fish; inner organ; α-emitter; distribution image; CR-39; energy loss; detection efficiency; pit density; radioactivity; absorption dose

1. Introduction

Because of the ingestion intake of α-nuclides in fish, Japanese internal dose is rather high 0.8mSv/y in the total of 2.1 mSv/y [1]. The content of α-nuclide in dried sardine is reported to be about 300 Bq/kg [2]. Inner organ of fish contains fairly large amount of 210Po [3,4]. 210Po is considered to be the most important contributor to the radiation dose received by humans via fish consumption [5,6]. Fish ingest 210Pb and its decay product 210Po through food chain from plankton in sea water. The contents of 210Pb with long half-life (22.3 y, β-emitter) and 210Po with short half-life (138.4 day, α-emitter) in sea water are large [7]. However, because of the intake characteristics of plankton and the food chain, radioactive equilibrium is generally not maintained in fish body [8].

The analytical method of 210Po adopted in the references [9] is generally sophisticated as follows: wet digestion of fish → deposition → dissolution → addition of 209Po as yield tracer → elution through resin-column (or → electroplating on a metal surface) → measurement with scintillation counter (or with Si-detector).

Although there are many reports on the radioactivity density and the ratio of 210Po/210Pb, papers on α-nuclide distribution images in fish body are few.

This paper describes the methods to obtain the images of α-emitter in fish body with nuclear track detector CR-39 and to obtain the radioactivity density of inner organ of fish.

2. Some images of alpha emitter distribution

2.1. Alpha particle distribution image emitted from the inner organ of sardine

Since CR-39 is insensitive to β- and γ-rays, radiation shielding box is not needed at the exposure. The plate of CR-39 is inexpensive and any expensive instruments are not required. Even if radioactivity density in the specimens such as environmental natural materials is very low, long term exposure of the specimens on CR-39 enables us to obtain the images.

Figure 1. (A) Dried sardines, (B) α-particle pits obtained by 89days exposure on CR-39, (C) obtained by 2nd exposure 85days after one year.

Figure 1 (A) shows the flat surfaces of dried sardine obtained by cutting with a knife, (B) α-particle emission image of them obtained with 1st exposure for 89 days on CR-39 and chemical etching with sodium hydroxide of 7.5N, 80°C, for 5 hours and (C) the image obtained with...
the 2nd exposure for 85 days after one year of the 1st exposure. The ratio of the pit density of the 2nd exposure to that of the 1st exposure at the same place of the sardine was about 0.25±30%. When $^{210}$Po was in radioactive equilibrium with $^{210}$Pb, this ratio should be unity. And when only $^{210}$Po with the half-life of 138.4 days was present, the ratio should be 0.16. By taking account of the ratios 0.25 and 0.16, $^{210}$Po seemed not to be fully in the radioactive equilibrium with $^{210}$Pb, although the ratio 0.25 contained large error.

### 2.2. Some other images including each inner organ

**Figure 2.** (A) Fresh water fish: pond smelt (left) and sweet fish (right) and (B) their $\alpha$-particle images in which noticeable etch pits were not seen, because the concentration of uranium in Japanese river is small ~0.041μg/L compared with that ~3.3μg/L in sea water.

**Figure 3** shows (a) golden threadfin bream, (b) each inner organ taken out, (c) dried each organ, and (d) each pit image.

### 3. Determination of radioactivity density and absorption dose

#### 3.1. Calculation of detection efficiency of $\alpha$-particles emitted in inner organ

To obtain the $\alpha$-radioactivity density contained in the inner organ of fish from the pit density on the surface of CR-39, it is necessary to find the detection efficiency of $\alpha$-particles emitted in the inner organ. Here it is supposed that $^{210}$Po is uniformly distributed throughout the related inner organ.

**Figure 4** (a) shows explanatory drawing. The bulk etching thickness was 15.9 μm which was deleted layer by the chemical etching. Alpha-particle emitted at the depth $t_i$ in inner organ with an angle $\theta_i$ loses its initial energy $E_0$ (5.3 MeV) through the length $L_i$ in inner organ and then through $L_c$ in CR-39. The particle with energy $E_b$ enters into the surface which will appear as a pit after chemical etching. Energy $E$ and energy loss ($-dE/dx$) were calculated by Eq. (1).

$$
E_b = E_0 - \int_{t_i}^{t_i+L_c} \frac{dE}{dx} \, dx - \int_{t_i}^{t_i+L_i} \frac{dE}{dx} \, dx
$$

where $L_i = \frac{t_i}{\cos\theta_i}$ and $L_c = \frac{1.59\mu m}{\cos\theta_i}$

($-dE/dx$, and ($-dE/dx$), are the energy losses in inner organ and in CR-39, respectively, which were calculated by Bethe formula [10]. The validity to use Bethe formula was confirmed in the reference [11]. When $E_b$ equals 0.2 MeV, it was considered that the particle was not able to make an observable pit on the surface of CR-39, because the penetration range was only 1.4 μm.

By changing the angle $\theta_i$ in the calculation with Eq. (1), it is easy to obtain $E_b=0.2$ MeV. The angle $\theta_i$ at that case is the maximum detectable angle for $\alpha$-particle emitted at the depth $t_i$ in inner organ. The detection efficiency $\eta_i$ is obtained by Eq. (2).

$$
\eta_i = \frac{1 - \cos\theta_i}{2}
$$

The atomic composition of CR-39 is H:17, C:12, O:7 and the density is 1.31. The composition and the density 1.05 of the inner organ of fish were considered to be the same to human body as shown in Table 110 in ICRP Publication [12]. However, in the calculation, the density of dried fish was estimated to be the same to that of raw fish by the rough measurements of weight and the geometrical volume size. It was also considered that there was no elemental composition change between the dried fish and raw fish, although this is rather rough consideration. Figure 4 (b) shows an example of the energy $E$ and the energy loss ($-dE/dx$) of $\alpha$-particle (5.3 MeV) emitted from $^{210}$Po at the depth $t_i=16$ μm with the angle $\theta_i=29$ degree.
Figure 4. (a) Explanatory picture to calculate detection efficiency of alpha particles emitted in inner organ. The thickness 15.9 μm was a deleted thickness, called bulk etching, of CR-39 by chemical etching. (b) Energy loss (-dE/dx) and energy E calculated by Bethe formula.

Figure 5. Maximum detection angle θi and maximum detection efficiency ηi for α-particle emitted at depth ti in inner organ.

Figure 6. (a) Pit density 27(±20%)/mm² of inner organ of sardine in a small white square shown in Figure 1 (B), and (b) the density 1637/mm² of the liver C in Figure 3 (d) of golden threadfin bream.
organ of fish were obtained with CR-39.
2) The decrease of the etch pit density after one year showed that $^{210}$Po was not fully in radioactive equilibrium with $^{210}$Pb.
3) Fresh-water fish seemed not to contain α-emitters.
4) Detection efficiency of α-particle emitted in inner organ of fish with CR-39 was theoretically obtained and it was 0.12.
5) Absorbed dose of a part of the inner organ of a sardine was 33 mGy/y.
6) Absorbed dose of the liver of a golden thread bream was 2.2 Gy/y.
7) Since CR-39 method is very simple and inexpensive compared with chemical analytical method, anyone is able to obtain the image and measure the radioactivity of α-emitters in fish or in other material, although it needs a few month exposure.

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References