Accumulation of ^{60}Co by Marine Organisms under Reduction of Radioactivity in Sea Water

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In order to know the effect of topography on the contamination of marine organisms by radionuclides, the accumulation of ^{60}Co was observed under the reducing level of ^{60}Co in rearing sea water. The level of ^{60}Co in sea water was exponentially reduced by 90% in 1, 7 and 14 days assuming the dispersion patterns of radionuclide from nuclear facilities. The radioactivity in organism was expressed by an exponential model which involved biological parameters (uptake and excretion rate) and the reduction coefficient of radioactivity in sea water. On the 10th day after the start of the experiment, the radioactivity in the fish under the reduction of ^{60}Co in sea water by 90% in 1 day was lower with a factor of 7 and 12 than that of under the reduction in 7 and 14 days, respectively. In this way of thinking, theoretical change in the time of level of ^{60}Co in various marine organisms was illustrated under the reduction of ^{60}Co in sea water by 90% in 7 days. The highest radioactivity was calculated around the 10th day.

In order to estimate the radiation dose to human beings through sea food, we have studied the contamination of marine organisms. In series of the study, we described three destinies of radionuclides released into the coastal sea from nuclear facilities, that is, the adsorption by sediments, the uptake by marine organisms in the coastal sea and being carried away to the open sea by current.¹⁾ The amount of the radionuclide resided in the coastal sea depends mainly on the topography of the coastal sea and the released radioactivity is considered as constant in the closed type coast, while it is rapidly reduced in the open type coast.²⁾ In this article, the effect of the topography on the accumulation of radionuclide by marine organisms is investigated for the change in the time of radioactivity in organisms by rearing experiments with radioisotope tracer. The exponential model has been applied for the explanation of accumulation of radionuclides by aquatic organisms³⁻⁶⁾ and also for the determination of permissible concentrations of radioactive nuclides in air or water.⁷⁾ The exponential model involves biological parameters (uptake and excretion rate) and reduction coefficient of radioactivity in rearing sea water. The radioactivity in rearing sea water was exponentially reduced by 90% in 1, 7 and 14 days assuming the exponential reduction of radioactivity released into various topographies of the coastal sea.

Materials and Methods

The radioactivity in organisms under the constant level of radioactivity in sea water can be expressed by the following equation:

$$X_1(t) = -\frac{Wu}{\beta}(1 - e^{-\beta t}) + X_0 e^{-\beta t} \quad (1),$$

Under the reducing level of radioactivity in sea water, the following equation is used.

$$X_2(t) = -\frac{Wu}{\alpha - \beta}(e^{-\beta t} - e^{-\alpha t}) + X_0 e^{-\beta t} \quad (2),$$

where

$X_1(t), X_2(t)$: radioactivity in organism at time t

X_0 : initial radioactivity in organism

u : uptake rate (1/t)

β : excretion rate (1/t)

α : reduction coefficient of radioactivity in sea water (1/t)

W : radioactivity in sea water at time t_0

Then we carried out the following experiments to estimate the accumulation of radionuclide by organisms under the reducing level of radioactivity in natural marine ecosystems.

Organisms Brown algae (Arame in Japanese; *Eisenia bicyclis*), fish (Dorome in Japanese; *Chasmichthys gulosus*, average weight: 3 g) and

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Fig. 1. System to reduce ^{60}Co level in sea water in Tank 1 exponentially.

bivalve (Kotamagai in Japanese; *Gomphina melanaegis*, average weight: 38 g) were collected from the seashore off our Institute. Abalone (Kuroawabi in Japanese; *Haliotis discus*, average weight: 16 g) was supplied by Fisheries Experimental Station of Ibaraki-Ken.

Radioisotope The specific activity of $^{60}\text{CoCl}_2$ used was 93 mCi/mg Co.

Experiment 1. The accumulation of ^{60}Co by algae and fish in sea water with reducing level of ^{60}Co by 90% in 1, 7 and 14 days, respectively.

Three tanks were prepared for the experiments. To each tank, 10 l of sea water and 16 μCi of ^{60}Co was added.

Tank 1. Organisms were reared as in Fig. 1. The radioactivity in the tank was gradually reduced by 90% in 1 day by continuous addition of non-radioactive sea water from a reservoir. The sea water volume in the tank was regulated to be 10 l by a siphon. The radioactivity in the sea water in the tank reduced exponentially and the reduction coefficient (α) was calculated as 2.3.

Tank 2. The radioactivity was stepwisely reduced by 90% in 7 days by exchanging a calculated portion of rearing sea water with the same volume of non-radioactive sea water every day. The reduction coefficient of radioactivity in sea water was 0.33.

Tank 3. The radioactivity was reduced by 90% in 14 days in the same manner as tank 2 with the reduction coefficient of 0.16. The reducing patterns of ^{60}Co in the rearing sea water are shown in Fig. 2.

The radioactivity in the sea water was measured with an auto-well γ -ray counter (Aloka, JDC-752). In each of the three tanks, five fishes and three pieces of algae (wet weight of a piece: 0.2–1.9 g)

Fig. 2. Patterns of reduction of ^{60}Co in rearing sea water.

α : reduction coefficient: 2.3 corresponds to reduction to 1/10 in 1 day (Tank 1), 0.33 in 7 days (Tank 2) and 0.16 in 14 days (Tank 3).

were reared. The radioactivity of ^{60}Co in organisms was measured with a whole body counter (Oyokoken Co.).

Experiment 2. The accumulation of ^{60}Co by various organisms in sea water with reducing level of ^{60}Co by 90% in 7 days.

Each five individuals of fish, bivalve and abalone and three pieces of algae (wet weight of a piece: 0.4–1.9 g) were reared in sea water with the reduction coefficient of 0.33 as mentioned above in Experiment 1. The radioactivity in organisms was measured with the whole body counter.

The experimental sea water was kept at 15°C and the rearing tank was equipped with culturing light to maintain algae alive.

Results

Experiment 1. The accumulation of ^{60}Co by algae and fish in sea water reducing level of ^{60}Co by 90% in 1, 7 and 14 days.

Fig. 3 shows the observed radioactivity in algae under the reducing level of ^{60}Co in sea water together with the theoretical curve. Radioactivity in the three tanks was decreased to 1/10 in 1, 7 and 14 days, respectively. The theoretical value was calculated by the equation (1) and (2) using the uptake rate (u) and excretion rate (β) from our previous report on algae,³⁾ that is, u is 20.7 and β is 0.0190. The observed value is the average of the experiments repeated 3 times. The relative standard deviation was 80% at maximum. On the 10th day after start of the experiment, the radioactivity in algae under the reduction of ^{60}Co in sea water by 90% in 1 day was 1/7 and 1/12 of that under the reduction in 7 and 14 days.

In Fig. 4, the observed and theoretical levels of

Fig. 3. Observed and theoretical level of ^{60}Co in algae under reducing level of ^{60}Co in sea water.

Curves show the theoretical ^{60}Co level of algae reared in the sea water, ^{60}Co level of which is constant and reduces to 1/10 in 1, 7 and 14 days. Marks show the observed ^{60}Co level of algae in the experiment performed under the condition corresponding to the reduction of ^{60}Co level of the sea water in 1 ($\times$), 7 ($\circ$) and 14 days ($\bullet$).

Fig. 4. Observed and theoretical level of ^{60}Co in fish under reducing level of ^{60}Co in sea water.

Curves show the theoretical ^{60}Co level of fish reared in the sea water, ^{60}Co level of which is constant and reduces to 1/10 in 1, 7 and 14 days. Marks show the observed ^{60}Co level of fish in the experiment performed under the condition corresponding to the reduction of ^{60}Co level of the sea water in 1 ($\times$), 7 ($\circ$) and 14 days ($\bullet$).

^{60}Co in fish are shown. To obtain the theoretical value, 0.1340 and 0.0042⁴⁾ were used for u and β , respectively. To the averaged radioactivity on experiments repeated 3 times, 75% of standard deviation at maximum was observed. On the 10th day after start of the experiment, the radioactivity in fish under the reduction of ^{60}Co in sea water by 90% in 1 day was lower with a factor of 7 and 12 than that under the reduction in 7 and 14 days. The lowest was observed under the condition of the reduction in 1 day and this was about 1/73 of that in the case of the constant

level in sea water on the 28th day.

Experiment 2. The accumulation of ^{60}Co by various organisms in sea water with reducing level of ^{60}Co by 90% in 7 days.

The results are shown in Fig. 5. The uptake and excretion rates are cited from our previous reports.⁸⁻¹⁰⁾ The observed radioactivity in marine organisms rather well agreed to their theoretical value, likely in Experiment 1.

From these results, it could be said that the equation (2) is applicable for the estimation of the change in the time of level of ^{60}Co in organisms

Fig. 5. Level of ^{60}Co in marine organisms reared in sea water with reduction of level of ^{60}Co in 7 days.—: theoretical level, $\circ$: observed level.

under the reducing level of ^{60}Co in sea water.

Discussion

The authors previously illustrated the change in the time of radioactivity released into various topographies of the coastal sea.²⁾ As seen in Fig. 6. (A), imaging an extremely closed type bay which has no outlet to ocean, there is no loss of the re-

leased radionuclide from the bay except that by the physical decay. This can be presented by the line (closed type) parallel to the X-axis meaning time. On the contrary, in an open type coast, the released radionuclide goes down to 0 at once along the Y-axis owing to dispersion by current. In a semi-closed type coast such as shown in Fig. 6. (A), the released radionuclide decreases along the line (semi-closed type) shown in Fig. 6. (B). In a more open type coast (semi-open type) in Fig. 6. (A), the radionuclide decreases faster than in the semi-closed type coast, along the line (semi-open type) in Fig. 6. (B). This reducing radioactivity could be regarded to correspond to the reducing radioactivity in sea water by 90% in 1 day with reduction coefficient of 2.3 in Experiment 1. Similarly, for the closed type coast, α of 0.16 can be used and α of 0.33 for the semi-closed type coast. Thus, the change in the time of radioactivity in marine organisms due to an acute release of radionuclide can be estimated by the equation (2) using the uptake and excretion rate from radioisotope tracer experiments, while the concentration factor is available for the estimation of radioactivity in organisms at the constant level of released radioactivity.

The ratio of radioactivity in algae under reducing radioactivity in sea water by 90% in 7 (semi-open type) and 14 (semi-closed type) to that in 1 day (open type) is 7 and 12. These figures show that the contamination of organisms by radionuclides is affected by the topography.

In Fig. 7, the theoretical radioactivity in several marine organisms is shown on the assumption that these organisms contact with sea water containing 1 pCi/l of ^{60}Co and the level of ^{60}Co in sea water

Fig. 6. Radioactivity released into various topographies of coastal sea.

Fig. 7. Theoretical level of ^{60}Co in marine organisms living in sea water with reduction of ^{60}Co level in 7 days.

Japanese and scientific names A to I are as follows; A: Umitoranoo, *Sargassum thunbergii*; B: Arame, *Eisenia bicyclis*; C: Kotamagai, *Gomphina melanaegis*; D: Kuroawabi, *Haliotis discus*; E: Madako, *Octopus vulgaris*; F: Hotategai, *Patinopecten yessoensis*; G: Sazae, *Batillus cornutus*; H: Dorome, *Chasmichthys gulosus*; I: Buri, *Seriola quinqueradiata*.

decreases to 0.1 pCi/l of sea water in 7 days. The uptake and excretion rates are cited from our previous reports.⁸⁻¹⁴⁾ The algae (A, B) are highly contaminated after contact with radioactivity and then rapidly lose their radioactivity. The radioactivity in molluscs (C-G) follows to algae and that in fish (H, I) is lower than them. But the decrease of radioactivity from both molluscs and fish is very slow. The highest radioactivity in organisms was calculated around the 10th day after contact with radioactive sea water.

The figure like this can be available for the estimation of the change in the time of level of ^{60}Co in organisms due to an acute release of the radionuclide into the coastal sea and river also. In the case of radionuclides, for example Zn, food chain is the main pathway of the accumulation by organisms except algae. Then further investigation should be performed.

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