Comparison of Influences of Sediments and Sea Water on Accumulation of Radionuclides by Worms

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The accumulation and excretion of radionuclides by marine polychaete worms (Nereis japonica) were examined to know the influence of contaminated sediments on the contamination of marine organisms.

The concentration factors of 60Co, 95Zr-95Nb, 106Ru-106Rh and 137Cs for unfed worms were 6, 4, 6 and 6 respectively, and they were similar to the concentration factors for unfed worms.

The biological half lives of 60Co, 95Zr-95Nb and 106Ru-106Rh for fed worms were similar to each other (37, 32 and 35 days, respectively) except that of 137Cs (6 days), and all of them were a little shorter than those for unfed worms.

The transfer ratios of radionuclides from sediments to worms were 5 per cent for 60Co, 0.9 for 95Zr-95Nb, 0.6 for 106Ru-106Rh and 17.9 for 137Cs in cpm/g in regard to initial activity in sediments, and these figures were compared with the concentration factors to estimate the influence of sediments on the contamination of marine organisms. The obtained figures, we call the biological factor of the sediments, were 120, 440, 1000 and 30 for 60Co, 95Zr-95Nb, 106Ru-106Rh and 137Cs, respectively.

INTRODUCTION

Considering the fate of discharged radionuclides to human being via sea, the role of marine sediments is little known in spite of the large accumulation of released contaminants by sediments. To clarify this problem, we have reported the transfer of 115mCd from sediments to polychaete worms in comparison with the concentration factor.

In this study, we have examined the accumulation of radionuclides (60Co, 95Zr-95Nb, 106Ru-106Rh and 137Cs) either from sediments or from sea water by polychaete worms (Nereis japonica) which inhabit on or in sediments to know the relative influence of sediments. Furthermore, the excretion of radionuclides by worms was investigated.
The radionuclides used were $^{106}$Ru-$^{106}$Rh (nitrosylruthenium nitrato complexes), $^{95}$Zr-$^{95}$Nb (Zr[COO]$_2$), $^{137}$Cs (CsCl) and $^{60}$Co (CoCl$_2$). Specific activity of $^{60}$Co was 93 mCi/mg and other radionuclides were carrier-free. For each radionuclide, two acryl cylinders were prepared and each cylinder was supplied with 100 ml of sea water and six individuals (3 g in total weight) of polychaete worm (Nereis japonica). One of the groups was given contaminated food of 0.3 g (fed group) and the other was kept unfed (unfed group). Contaminated food was prepared as follows; 6.5 g of green alga (Ulva pertusa) was kept in 700 ml of sea water containing about 0.2 μCi of a given radionuclide for 5 days and then the alga was rinsed with fresh sea water, dried at 105°C for 24 hours and ground to powder. The radioactivities of thus obtained contaminated food were 46,000, 11,600, 304,000 and 625,000 cpm/g for $^{60}$Co, $^{137}$Cs, $^{95}$Zr-$^{95}$Nb and $^{106}$Ru-$^{106}$Rh, respectively, which were 15, 17, 250 and 380 times higher than the radioactivities of culture media.

Measurement of the radioactivity of worms was made periodically on live specimens with a well type scintillation counter after washing worms and blotting off the sea water by filter paper. The radioactivity was expressed as cpm/g and averages for fed and unfed groups were calculated.

The stable Co content in worms was determined with atomic absorption spectrometry on HCl solution of ashed sample after ion exchange treatment (Dowex 1×8, Cl$^-$ type).

Excretion of radionuclides by worms

Excretion patterns of the four radionuclides were obtained on the contaminated worms following the experiment of accumulation. Twelve individuals of both unfed and fed groups for each nuclide were divided into two groups for the experiment of excretion as there was no difference in accumulated radioactivities between the fed and unfed worms. And one of the two groups was fed with nonactive green alga powder (0.3 g) while the other group was kept without food during the observation period. The nonactive green alga powder (4 g) was obtained from 18 g of fresh alga by drying at 105°C and grinding.

Transfer of radionuclides by worms from sediments

One group (direct group) of worms (six individuals, 3 g in total weight) was reared in a 400 ml capped acryl cylinder with aeration which contained 100 ml of sea water and 10 g of contaminated sediments, and the worms could get in contact directly with the contaminated sediments and with the recycled radionuclides from sediments to sea water as well. The other group (indirect group) of worms was reared in the same manner as the direct group, but was not allowed to get in contact directly with the sediments separated with a net made of Saran. Therefore, they accumulated the contaminants in sea water recycled from the sediments. The rearing sea water was exchanged with fresh sea water every day. To prepare the contaminated sedi-
ments, the four radionuclides (1-10 μCi) were added separately to each of four poly-
ethylene bottles containing sea water (100 ml) and sediments (0.1-0.5 mmφ, 30 g) for
7 days. After discarding sea water, the contaminated sediments were rinsed 3 times
by means of decantation with fresh sea water. In the measurement of radioactivities,
special care was paid on the removal of sediments from the surface of worm. A
portion of the sediments was also measured and the activity was expressed as cpm/g
wet sediment.

In the study, rearing systems were kept at 14±2°C.

RESULTS AND DISCUSSION

Accumulation of radionuclides by worms from sea water

The accumulation of radionuclides by unfed and fed worms are shown in Figs. 1 and 2. In both groups, 10~11 days exposure allowed worms to reach nearly steady
state of radioactivity. The values of concentration factor (CF) after 10~11 days ex-
posure are tabulated in Table 1. CFs for fed group seem to differ little from those
in unfed worms indicating that feeding has little effect on the accumulation of radio-
uclides, although Renfro and Benayoun report that Nereis diversicolor possibly feeds
on algal detritus contaminated by 65Zn.8) The concentration factor from 60Co was
6-7 and that from stable Co was calculated to be about 1,500 by dividing 145 μg/kg

![Graphs showing accumulation of 60Co and 95Zr-95Nb](image)

**Fig. 1.** Accumulation of 60Co (left) and 95Zr-95Nb (right) by unfed and fed worms.
〇; unfed, ●; fed.
of raw worms from our determination by 0.1 μg/l of sea water from Brewer. The latter figure is near to the data from other kinds of worms that were calculated by Mauchline. The difference in concentration factors between 60Co and Co may be mainly due to that in chemical behavior of the nuclide in sea water. The concentration factor for 137Cs is similar to that given by Bryan.

**Table 1**

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Concentration factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>60Co</td>
<td>6 ± 1</td>
</tr>
<tr>
<td>95Zr, 95Nb</td>
<td>4 ± 1</td>
</tr>
<tr>
<td>106Ru, 106Rh</td>
<td>6 ± 1</td>
</tr>
<tr>
<td>137Cs</td>
<td>6 ± 1</td>
</tr>
<tr>
<td>Unfed worms</td>
<td></td>
</tr>
<tr>
<td>60Co</td>
<td>7</td>
</tr>
<tr>
<td>95Zr, 95Nb</td>
<td>3</td>
</tr>
<tr>
<td>106Ru, 106Rh</td>
<td>4</td>
</tr>
<tr>
<td>137Cs</td>
<td>5</td>
</tr>
<tr>
<td>Fed worms</td>
<td></td>
</tr>
</tbody>
</table>

Excretion of radionuclide by worms

The excretion patterns of the radionuclides by unfed and fed worms are shown...
in Figs. 3 and 4. Unfortunately, the observation on unfed worms of $^{60}$Co was not performed because of the death of worms caused by an accident of the aeration system. As is the case in many excretion curves for radionuclides, there is an initial rapid decrease during the first 2 to 3 days, then excretion rate becomes smaller. In Figures, least squares lines were fitted for the semilogarithmic plots of points beginning from the 7th day and ending on the 24th day. The rate of excretion of radionuclides from the slower components of worms is expressed by the equation

$$\ln Y = -aX + b,$$

where $Y=$ the per cent to the initial activity, $X=$ number of days of excretion, $a=$ the slope of the least-squares line, and $b=$ the $Y$ intercept. The biological half lives ($T_{1/2}$) of the slower component were calculated as $0.693/a$ and given in Figures. Although a difference in excretion pattern between fed and unfed worms was observed on $^{106}$Ru-$^{106}$Rh, it was not clear on $^{95}$Zr-$^{95}$Nb and $^{137}$Cs.

Transfer of radionuclides by worms from sediments

In Fig. 5, the accumulation patterns of radionuclides by the direct group worms are shown, and they were similar to those obtained from the indirect group worms, whereas they were different in the case of $^{116m}$Cd. As it is seen in the column of $(B)/(A)$ of Table 2, sediments give little effect on the accumulation by worms through

Fig. 3. The excretion patterns of $^{60}$Co and $^{95}$Zr-$^{95}$Nb by unfed and fed worms. $\times$; unfed, $\bigcirc$; fed.
surface contamination or ingestion for these nuclides. The average transfer ratios [(B)/(A)] from sediments by the direct and indirect group worms were 0.6, 0.9, 5.0 and 17.9 per cent for $^{106}$Ru-$^{106}$Rh, $^{95}$Zr-$^{95}$Nb, $^{60}$Co and $^{137}$Cs, respectively, in relation to the initial activity in sediments, assuming that $^{95}$Zr was transferred at the same rate as $^{95}$Nb in any case.

In order to compare the influences of the sediments with that of sea water on the accumulation of radionuclides by worms, concentration factor was divided by the transfer ratio from sediments as shown in the last column of Table 2. Thus figures which we call the biological factor of the sediments (BFS) are obtained as 1,000, 440, 120 and 30 for $^{106}$Ru-$^{106}$Rh, $^{95}$Zr-$^{95}$Nb, $^{60}$Co and $^{137}$Cs, respectively. These figures imply approximately, for example, that as to the accumulation of $^{106}$Ru-$^{106}$Rh by worms the influence of $^{106}$Ru-$^{106}$Rh in sea water is 1,000 times higher than that of...
Fig. 5. Accumulation of radionuclides by worms from sediments.

Table 2
Accumulation of radionuclides by *Nereis japonica* from sea water and sediments

<table>
<thead>
<tr>
<th>Nuclides</th>
<th>(A) Initial concentration in sediments (cpm/g)</th>
<th>(B) Concentration in worms (cpm/g)</th>
<th>(B)/(A)</th>
<th>(C) Transfer ratio</th>
<th>(D) Concentration factor</th>
<th>(D)/(C)</th>
<th>BFS</th>
</tr>
</thead>
<tbody>
<tr>
<td>^{60}Co</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11,000</td>
<td>Indirect 500 (18)*</td>
<td>0.045</td>
<td>0.050</td>
<td>6</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct 600 (23)</td>
<td>0.055</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>^{92}Zr-^{95}Nb</td>
<td>220,000</td>
<td>Indirect 1,700 (14)</td>
<td>0.008</td>
<td>0.009</td>
<td>4</td>
<td>440</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct 2,100 (21)</td>
<td>0.010</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>^{104}Ru-^{106}Rh</td>
<td>250,000</td>
<td>Indirect 1,200 (40)</td>
<td>0.005</td>
<td>0.006</td>
<td>6</td>
<td>1,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct 1,500 (70)</td>
<td>0.006</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>^{137}Cs</td>
<td></td>
<td>Indirect 1,900 (17)</td>
<td>0.158</td>
<td>0.179</td>
<td>6</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct 2,400 (18)</td>
<td>0.200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Figures in parenthesis are standard deviation (%) of measured activities to the average on six individuals.

this nuclide in sediments. The figure for ^{60}Co is similar to that for ^{115m}Cd, reported previously by us."

The experimental observation for worms was performed on 10 g of sediments
and 100 ml of sea water, and this sediment/water ratio corresponds to 0.4 m depth of sea water with sediments at bottom, by assuming that the specific gravity of sediments is 2 and surface 2 cm of sediments adsorbs radionuclides in sea water.\textsuperscript{12,13} However, different sediment/water ratio gives other BFS, and BFS would be also varied by kinds of organisms. On the variation of BFS for $^{137}$Cs due to different sediment/water ratio, another observation was done using 100 ml of sea water and 10 to 0.25 g of sediments under the same condition. As it is seen in Fig. 6, the transfer of $^{137}$Cs from 10 g of sediments to worms was several times higher than the transfer from 0.25 g of sediments, and this ratio (0.25 g sediments to 100 ml water) corresponds to about 16 m depth of sea. Therefore, the figure (BFS) in Table 2 would be varied depending on the experimental condition (sediment/water ratio). Estimating the role of sediments for the fate of the nuclides released into coastal sea, BFS in 0.1 of sediment/water ratio which corresponds to 0.4 m depth could be considered the maximum influence in relation to water. Coastal sea water would be mixed and turbulated by tide and current. Accordingly, for the application to the field study, the value of BFS in the average depth of coastal sea where organisms inhibit should be used.

\begin{center}
\begin{figure}
\centering
\includegraphics[width=\textwidth]{transfer_ratio.png}
\caption{Transfer of $^{137}$Cs from various weights of sediments to worms.}
\end{figure}
\end{center}

We have investigated the radioecology of Urazoko Bay\textsuperscript{14} where there is a nuclear power station in operation since 1969. In our investigation, the amount of $^{60}$Co in brown alga (Sargassum flavellum) cannot be accounted for regardless of the influence of the $^{60}$Co concentration in sediments which was estimated to be 500-600 pCi/kg wet sediment by Nakamura and Nagaya.\textsuperscript{15} Seymour and Nelson\textsuperscript{16} also observed the contamination of Mytilus by $^{65}$Zn recycled from environment (sediments and biota) after the shutdown of reactor.
Thus, the influences by the contaminated sediments should be considered attentively regarding the contamination of marine organisms by radionuclides to human being via sea although sea water dominates over the accumulation of contaminants by marine organisms, in general.

ACKNOWLEDGEMENT

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REFERENCES