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AnaComp Program application to calculate ^{137}Cs transfer rates in marine organisms and dose on the man

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Laboratory experiments using radioactive tracer were performed to study the uptake and elimination of ^{137}Cs by the *Abudefduf saxatilis*. A compartmental model (AnaComp Program) has estimated the transfer rates of the radioactivity through the sea-water and fish compartments as well as the dose caused by the consumption of a contaminated fish.

Introduction

The knowledge of the radionuclide behavior in the organisms is of great importance in order to estimate its distribution in the ecosystem. Cesium-137 a critical radionuclide from the ecological point of view, may be introduced into the marine environment by global fallout, nuclear discharges from reprocessing units or nuclear reactors and nuclear accidents, and be accumulated by the biota. The radionuclide uptake by marine organisms may be evaluated by the bioaccumulation factor which relates the ratio of the equilibrium activity in the organism and the sea-water.[1]

The compartmental analysis is useful to define the quantitative distribution of the elements in different compartments, in function of time.[2,3] The AnaComp Program[4] employed here is a computational code to the analysis of kinetic data that allows the interpretation of the experimental results of a quantitative and kinetic way.

In this paper, the ^{137}Cs uptake from sea-water by the fish *Abudefduf saxatilis* and its elimination were studied. AnaComp Program was employed to estimate the transfer rates of ^{137}Cs radionuclide through the sea-water and fish compartments as well as the dose received by the man from the ingestion of the contaminated fish.

Although the extrapolation of results obtained under experimental conditions to situations occuring in the marine environment may be restricted, this paper contributes to the understanding of the ^{137}Cs distribution released into the marine environment.

Experimental

Fish acclimation

Fish were collected along the Brazilian coast (São Paulo State), maintained in aerated glass aquarium at 21 °C and fed three times a week with cultures of *Artemia* sp and a comercial food (Tetra-Marine). After seven days of acclimation, the fish were exposed to ^{137}Cs tracer.

Cesium-137 uptake and elimination

The uptake and elimination of ^{137}Cs by the fish were carried out in aerated vessels (2 liters of filtered sea-water). The ^{137}Cs tracer (10^3 kBq) was mixed in the sea-water for several hours in order to establish the equilibrium between the solution and the vessel walls. Then, two fishes were introduced in each vessel. During the experiments, the fishes were fed three times a week in a vessel with tracer free sea-water. All experiments were carried out at 21 °C. The radioactivity of each fish (whole body counting) and the sea-water (25 ml aliquot) were measured at different time intervals for the determination of bioaccumulation factor (FC), i.e., the ratio of the radioactivity of ^{137}Cs in the fish (cps/g) and in sea-water (cps/ml).

Gamma-activity was measured by using a calibrated NaI detector, until accumulation equilibrium has been reached. After 11 days, fish were transferred to vessels (2 liters of tracer free sea-water) and counted in different days to estimate the ^{137}Cs elimination. Radionuclide elimination is indicated as the percentage of the initial radioactivity remaining in the fish.

Results

Table 1 shows the ^{137}Cs uptake by the fish. The results show that ^{137}Cs is concentrated by the *Abudefduf saxatilis*. The equilibrium was reached in 264 hours (11 days) and the accumulation factor was of 5.63±0.21. After this time, the experiment of ^{137}Cs elimination was measured.

Table 2 indicates the ^{137}Cs percentage eliminated by the fish as a function of the time.

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Table 1. ^{137}Cs uptake by the *Abudefduf saxatilis*

Time, h	Experiment A Sea-water, cpm/ml	Experiment A Fish, cpm/g	Experiment B Sea-water cpm/ml	Experiment B Fish cpm/g	Medium value of FC
3	1028.3	149.7	1024.2	158.2	0.15±0.05
7	1023.6	246.9	1018.8	224.5	0.23±0.07
24	1041.9	906.2	1040.9	701.4	0.78±0.13
48	1039.2	1822.7	1032.2	1817.5	1.76±0.04
96	1031.1	3143.0	1024.2	3004.7	2.99±0.10
144	1019.5	3475.7	981.4	3267.0	3.37±0.12
192	963.7	4379.7	962.0	4158.6	4.44±0.17
200	965.6	4573.0	961.6	4318.2	4.62±0.16
224	902.7	5019.4	946.9	4661.9	5.25±0.42
264	911.6	5046.4	879.3	5038.3	5.63±0.21

In Experiments A and B, the values of counting represent the medium value obtained in 4 experiments.

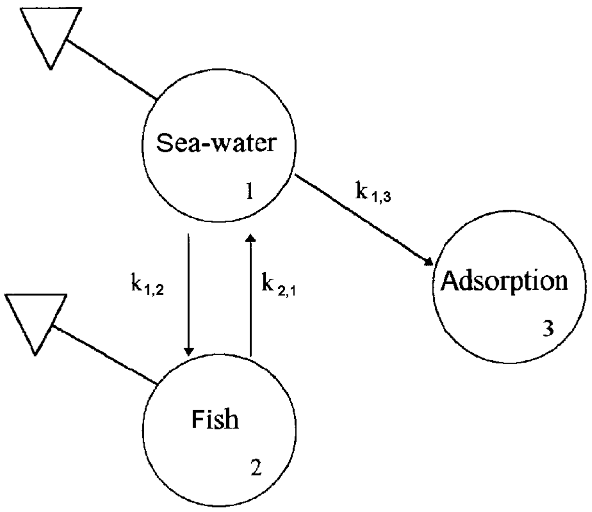

Fig. 1. Schematic representation of ^{137}Cs distribution through compartments

Table 2. ^{137}Cs elimination by the fish

Time, h	Elimination, %
0	0
16	10.6
40	21.4
64	25.0
112	42.1
160	46.8
184	55.6
232	62.8
264	69.1

After 184 hours (7.7 days), the fish has eliminated more than the half of incorporated ^{137}Cs. The biological half-time, obtained by plotting the elimination % versus time (h), was of 187 hours. The values of FC and biological half-time are very important to predict the toxicological risk assessment.

Based on physico-chemical characteristics of the ^{137}Cs radionuclide that may influence its uptake and elimination through the sea-water and fish compartments, a compartmental model was proposed to explain the cesium distribution (Fig. 1). Fish accumulates and eliminates radioactivity at the $k_{1,2}$ and $k_{2,1}$ rates, respectively. The third compartment represents the radionuclide adsorption in the vessel walls. In the marine environment this corresponds to the ^{137}Cs uptake by other organisms or sediments present in the ecosystem.

The AnaComp Program was used to calculate the transfer coefficients (k_{ij}) of the model, that represent the transfer rates through the 1 and 2 compartments. This program was feeding with data obtained at the ^{137}Cs uptake experiment: fish countings (cpm/g) and sea-water countings (cpm/ml), both in function of time (Table 1).

Then, the AnaComp Program was again feeding with the data obtained in the ^{137}Cs elimination experiment (Table 2). It was assumed that in the zero time, the radionuclide was totally present in the sea-water compartment, and in the elimination experiment, 100% of ^{137}Cs was in the fish compartment.

The equation system (f_i) in function of time (t) obtained by the AnaComp Program was:

$$f_1 = 2054628.4e^{-1.99 \cdot 10^{-4}t} + 1971.6e^{-4.7 \cdot 10^{-3}t}$$

$$f_2 = 1887.2e^{-1.99 \cdot 10^{-4}t} - 1887.2e^{-4.7 \cdot 10^{-3}t}$$

$$f_3 = 2056515.5(1 - e^{-1.99 \cdot 10^{-4}t}) + 84.5(1 - e^{-4.7 \cdot 10^{-3}t})$$

These equations describe the rate of change of the radionuclide activity over the time. The concentration in the organism increases with time until equilibrium is reached, then it gradually decreases.

The transfer rates (k_{ij}) are:

$$k(1,2) = (0.000004 \pm 0.00006)\ \text{h}^{-1}$$
$$k(2,1) = (0.004664 \pm 0.000001)\ \text{h}^{-1}$$
$$k(1,3) = (0.0002 \pm 0.0022)\ \text{h}^{-1}$$

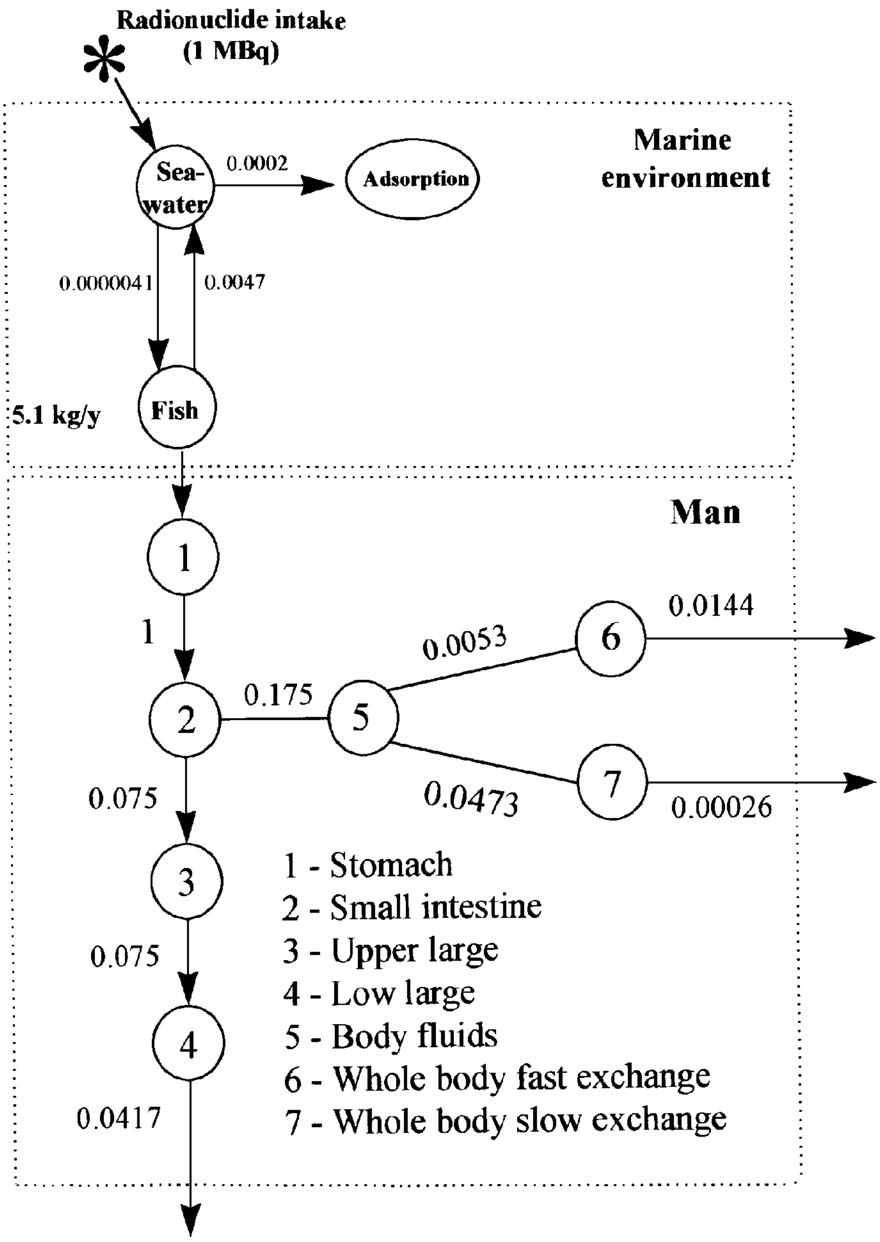

Fig. 2. Kinetic model for ^{137}Cs incorporated by ingestion

The k_{ij} values are necessary to evaluate the ^{137}Cs distribution in different compartments as a function of time. They are useful in the case of radioactive contamination to estimate the potential risks of radionuclide releases in the marine environment as well as the contamination of food-chains leading to man.

Although these experiments were performed in a reduced number of days, these constants can be used for predicting long-term consequences of ^{137}Cs uptake by the fish in the system studied.

The experimental values for FC and biological half-time were of 5.6 and 187 hours, and the values obtained by the AnaComp Program were of 7.9 and 146 hours, respectively. The results show that the model adjusted by the Ana Comp Program provides data in good agreement with the experimental values.

Based on the transfer rate values obtained in this paper and by taking into consideration the data of a ^{137}Cs metabolism in the man,[5,6] the AnaComp Program has estimated the dose that a man would receive by ingestion of ^{137}Cs contaminated fish.

Figure 2 shows the distribution of ^{137}Cs in the marine environment and in the man's body as well as the transfer rates obtained by the AnaComp Program.

Results indicate that the dose would be of 0.000174 mSv, less than the permissible limit recommended by the International Commission on Radiological Protection (ICRP)[5,6] to protect the public (1 mSv·y^{1}).

Conclusions

The compartmental analysis is a useful tool to quantify the radioactivity transferred to different trophic levels in the ecosystem, to evaluate the potential risks of radionuclide releases in the environment and to estimate the dose received by the man by ingestion of the contamined organisms.

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