Accumulation and Distribution of Selenium in Mussel and Shrimp Tissues

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The natural weathering cycle accounts for most of the selenium mobilized into the environment; however, anthropogenic fluxes originating from fossil fuel combustion and agricultural and industrial usage will add to the levels derived from natural processes (BERTINE and GOLDBERG 1971; GESAMP 1974). Recognition of an anthropogenic component of the total selenium flux in the environment has lead some authors to consider this highly toxic element as a potential pollutant in the marine environment (IDOE 1972; GESAMP 1974; KETCHUM in press).

Recent investigations demonstrate that selenium accumulates in marine organisms to levels commensurate with those of other toxic elements (CHAU and RILEY 1965; ROBERTSON et al. 1972; BERTINE and GOLDBERG 1972; SANDHOLM et al. 1973). Furthermore, the observation that in some species selenium concentrations are strongly correlated with those of mercury and other heavy metals suggests a possible uptake regulating process in the accumulation of these elements by marine organisms (KOEMAN et al. 1973; MACKAY et al. 1975). The processes governing selenium uptake, retention and interaction with other elements in aquatic biota are presently receiving some attention (SANDHOLM et al. 1973; GISSEL-NIELSEN and GISSEL-NIELSEN 1973; BLAYLOCK et al. 1974; FOWLER and BENAYOUN in press); nevertheless, fewer data are available on the distribution of selenium in the tissues of these species. Such information is required for accurate assessment of selenium transport paths and accumulation mechanisms within organisms. The purpose of our study was to examine the tissue distribution of selenium in mussels and shrimp and, with the aid of radioselenium, elucidate selenium bioaccumulation kinetics in the various tissues.

METHODS

Mussels (Mytilus galloprovincialis) and shrimp (Lysmata seticaudata), collected near the Monaco port, were apportioned into several groups. One group of mussels and shrimp was maintained in sea water containing 0.8μCi/liter high specific activity Se-75 (> 160 μCi/μg Se as sodium selenite). Periodically throughout the accumulation period, three to four individuals were dissected and their tissues monitored for Se-75 content. In order to maintain the Se-75 concentration relatively constant, the labelled sea water was changed three times per week. During tracer solution changes, the shrimp and mussels were briefly held in non-

Bulletin of Environmental Contamination & Toxicology,
Vol. 16, No. 3 © 1976 by Springer-Verlag New York Inc.

radioactive sea water and fed chopped mussel and mixed phytoplankton, respectively.

Another group of shrimp, maintained in flowing sea water, were fed ad libitum mussels that had previously accumulated Se-75 from sea water for several days. Shrimp were periodically dissected to follow tissue accumulation of ingested selenium.

The remaining individuals were dissected and their tissues analyzed for selenium to assess tissue distribution of stable selenium in animals considered to be at equilibrium with this element in their environment. Selenium was measured by non-destructive neutron activation analysis. Bowen's kale was used as a standard, the method being checked by simultaneously analyzing NBS orchard leaves (SRM-1571). Our value was in good agreement with the certified NBS value.

Radioactivity measurements were made with a well-type NaI(Tl) scintillation crystal (7.6 x 7.6cm) connected to a single channel analyzer. Reference standards of the appropriate geometry were counted with the samples in order to correct for Se-75 decay and compensate for any slight changes in instrument calibration. Counting errors associated with samples, backgrounds and standards were propagated and were < 5% at the 1σ level.

Results of the uptake experiments are reported either in terms of nCi Se-75/g wet tissue, or concentration factors (CF) which are defined as Se-75 activity/g wet tissue ÷ Se-75 activity/ml water. Tissue distribution data are given as percentages of either the total Se-75 activity or stable selenium in the dissected tissues.

RESULTS AND DISCUSSIONS

Accumulation of selenium from water by various shrimp tissues is shown in Fig. 1a. The highest concentrations were found in the exoskeleton, presumably due, in part, to the relatively large amount of isotope sorbed to its outer surface. Molts, cast by shrimp at various times throughout uptake, contained from 60 to 90% of the total Se-75 body burden. After day 20, individuals which had molted were of necessity used in the dissection and, as a result, concentration factors in exoskeletons as well as other tissues were somewhat lower thereafter. It is evident that previous molting activity led to the drop in Se-75 concentrations in exoskeletons of individuals accumulating the radioisotope from water, however, the reason for the concomitant drop in the radioactivity level of the other tissues at day 41 is not clear. This could be due merely to statistical variation inherent in samples containing tissues from only a few individuals; nevertheless, the possibility of selenium translocation among the various tissues leading to an overall loss of Se-75 cannot be ruled out since it is known that trace metal content in crustacean tissues can vary greatly during the intermolt cycle (MARTIN 1975).

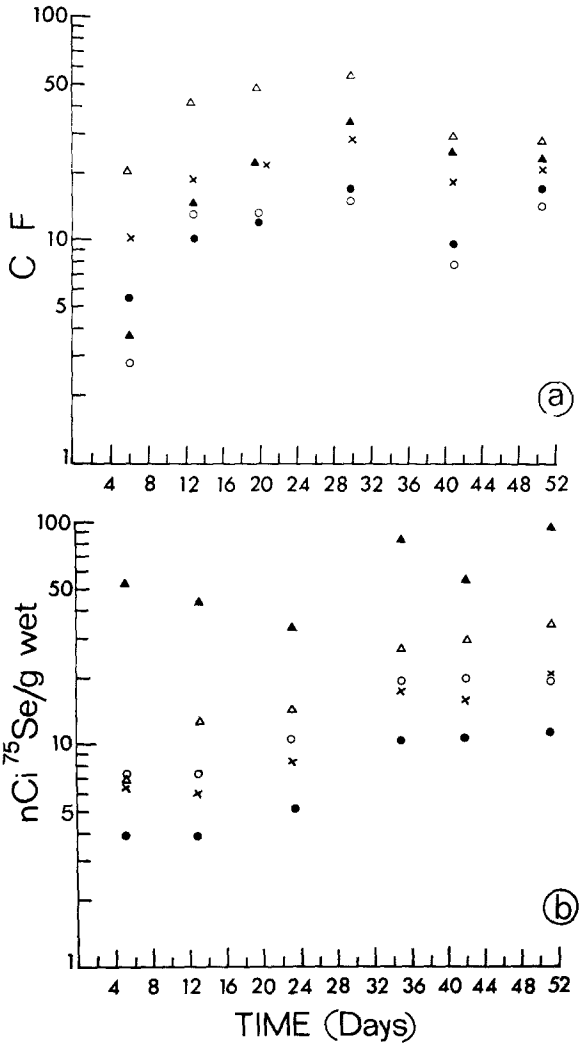

FIG. 1. Accumulation of Se-75 in the tissues of the shrimp, Lysmata seticaudata, after uptake from a) water, b) food. Eyes (○), muscle (●), exoskeleton (△) viscera (▲), whole body (X).

When uptake occurred via the food chain, the highest activity was found in the visceral tissues which first come in contact with the assimilated isotope; however, the relatively

high level of Se-75 associated with the exoskeleton attests to the fact that ingested selenium is readily translocated from internal to external tissues (Fig. 1b). During uptake molting did not significantly affect the Se-75 concentration in exoskeleton, since the percentage of the Se-75 body burden retained in molts was relatively low, viz. about 6%.

Gross tissue distributions of Se-75 in shrimp as a function of time are presented in Fig. 2. Direct uptake from water led to

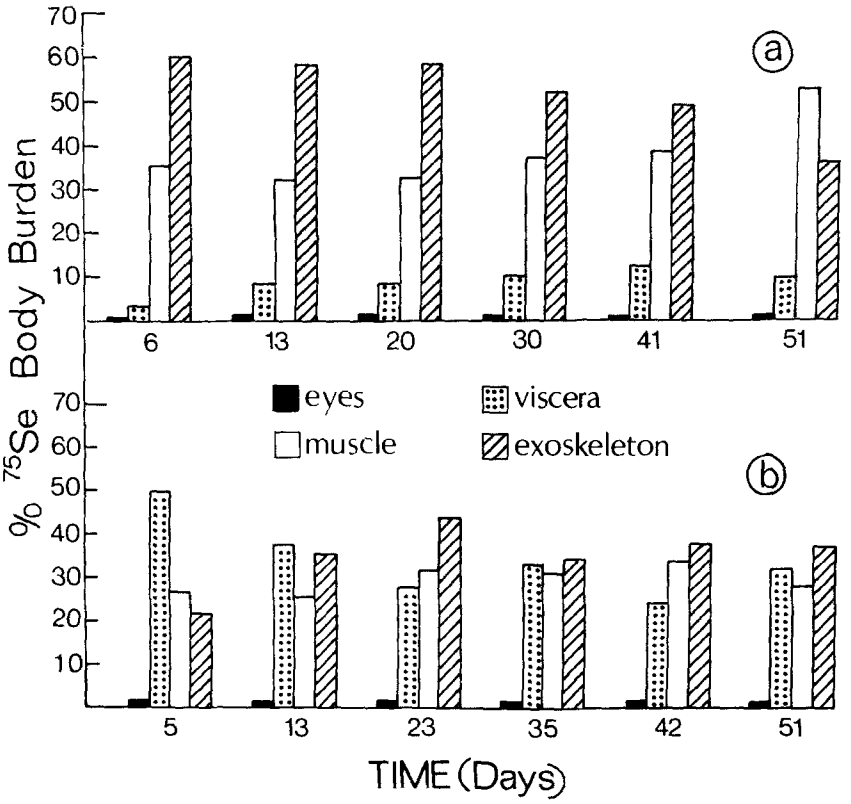

FIG. 2. Tissue distribution of Se-75 in the shrimp, Lysmata seticaudata, after uptake from a) water, b) food

initially small fractions in internal tissues such as muscle and viscera compared to the relatively large fraction associated with the exoskeleton (Fig. 2a). With time percentages in internal tissues gradually increased relative to that in the exoskeleton. When Se-75 was accumulated through the food chain an opposite trend was noted with the Se-75 fraction in exoskeleton slowly increasing and that in viscera decreasing during the course of the experiment (Fig. 2b).

The accumulation of Se-75 from water by Mytilus tissues is shown in Fig. 3. All tissues examined readily accumulated the

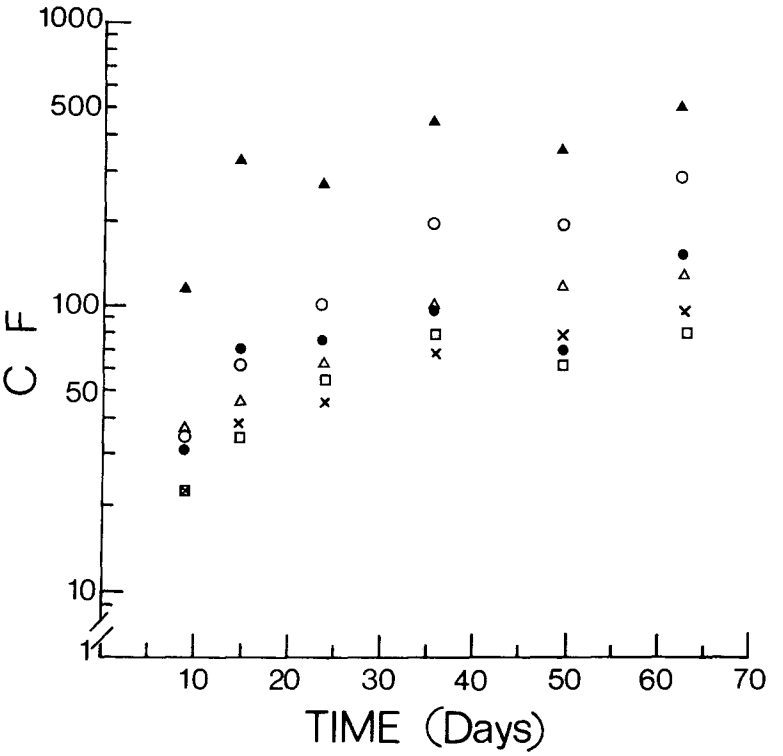

FIG. 3. Accumulation of Se-75 in the tissues of the mussel, Mytilus galloprovincialis, after uptake from water. Gills (○), muscle (●), shell (△), viscera (▲), mantle (□), whole body (X).

isotope and, in general, did not appear to have reached a steady state concentration after 63 days. The highest Se-75 concentrations were found in the visceral mass with lesser amounts in gills, muscle and mantle, in that order. PENTREATH (1973) has reported similar trends in heavy metal concentration in tissues of Mytilus after accumulation from water. Examination of the data on relative tissue distribution of incorporated Se-75 indicates that, in general, the Se-75 fractions in tissues remained relatively constant throughout the 63 day uptake period (Fig. 4).

Stable selenium concentrations as well as computed tissue distributions of this element in tissues of organisms considered to be at equilibrium with selenium in their environment are presented in Table 1. The relative order of stable selenium in

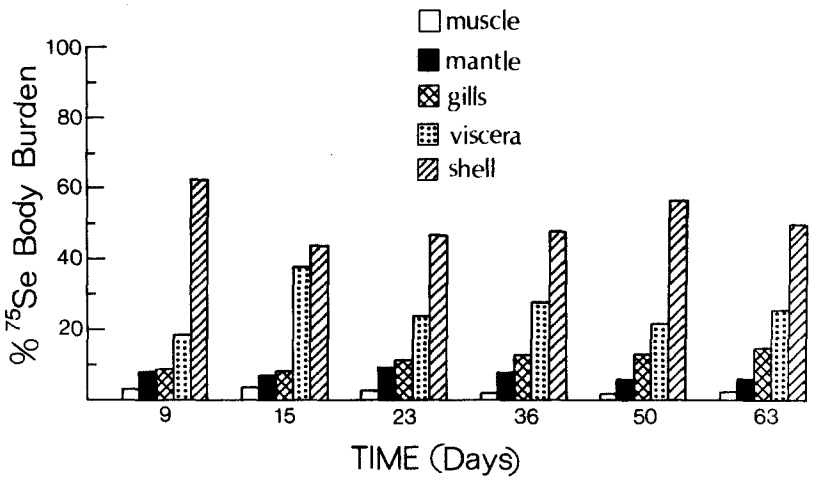

FIG. 4. Tissue distribution of Se-75 in the mussel, Mytilus galloprovincialis, after uptake from water.

TABLE 1

Tissue distribution of selenium in mussels and shrimp in terms of element concentration and percentage of total tissue content

Tissue	µg Se/g dry	µg Se/g wet	% total tissue wet weight†	% total Se in tissue
Lysmata seticaudata (whole)	*2.69	*0.65		
Viscera	7.06	2.26	8.2	31.6
Muscle	1.98	0.40	62.8	42.8
Eyes	4.86	1.22	1.8	3.8
Exoskeleton	1.51	0.47	27.2	21.8
(Molts)	0.32	0.07	19.0	2.1
Mytilus galloprovincialis				
Shell	< 0.05	< 0.05	65.2	< 10.4
Mantle	5.26	0.95	13.8	41.8
Gills	7.08	0.78	9.1	22.7
Viscera	3.22	0.77	8.7	21.4
Muscle	1.91	0.36	3.2	3.7
(whole soft parts)	*6.10	*0.89	34.8	> 89.6

* measured value, not reconstructed
† based on total weight of dissected tissues

shrimp tissues agrees fairly well with that noted for Se-75 in tissues after 51 days uptake via the food chain (Fig. 1b), i.e. viscera displayed the highest, eyes and exoskeleton intermediate, and muscle the lowest concentrations of stable selenium and Se-75. As mentioned earlier a different order of tissue accumulation was found when Se-75 was taken up directly from water (Fig. 1a). Selenium-75 in viscera and eye tissue was low relative to the sequence of tissue levels based on stable selenium measurements; this fact suggests that achieving equilibrium selenium concentrations in shrimp viscera and eyes solely by direct uptake from water would be a relatively slow process. In addition, comparison of the shrimp tissue distribution of stable selenium in Table 1 with those computed from the Se-75 uptake experiments (Fig. 2) shows that a somewhat nearer approximation of the natural selenium distribution is achieved when Se-75 is ingested with the food.

It is interesting to note that cast molts only account for about 2% of the total selenium in Lysmata whereas the entire exoskeleton holds approximately 22% of the body burden (Table 1). Simple calculation shows that molts, representing 70% of the exoskeleton's biomass, contain only about 10% of the exoskeleton's selenium content; hence, much of the selenium in exoskeleton is located in deeper tissues which are not lost at molt. Although only relatively small fractions of the shrimp's selenium content are lost with the molt, crustacean molting will play a role in redistributing selenium in the aquatic environment as has been suggested by BERTINE and GOLDBERG (1972) and FOWLER and BENAYOUN (in press).

The relative order of stable selenium levels in Mytilus tissues (Table 1) were quite different from that achieved by tissues accumulating Se-75 from water (Fig. 3). For example, mantle, having the highest stable selenium concentration in any tissue examined, showed the lowest degree of uptake in the tracer study indicating that the water route may be relatively unimportant in attaining equilibrium concentration factors in this tissue.

At present we have no information on the selenium concentration in Monaco sea water; however, recent reports indicate that 0.1 to 0.5 µg Se/l may be considered as a representative range for unpolluted marine waters (CHAU and RILEY 1965; IDOE 1972; GESAMP 1974). If concentration factors based on these water levels are computed for shrimp and mussel tissues using the stable selenium data in Table 1, it becomes apparent that concentration factors measured in the tracer experiments (Figs. 1a, 3) are substantially less than those in corresponding tissues estimated from stable isotope measurements. We believe this difference is a reflection of the relatively slow rate of uptake from water and that in nature selenium accumulated via the food chain is instrumental in rapidly achieving equilibrium levels of this element in organisms. The overriding importance of the food chain in the bioaccumulation of selenium has been shown to hold true for certain zooplankton and fish (SANDHOLM et al. 1973; FOWLER and BENAYOUN in prep);

nevertheless, this hypothesis remains to be verified for shrimp and mussels such as those used in this study.

ACKNOWLEDGEMENTS

The International Laboratory of Marine Radioactivity operates under a tripartite agreement between the International Atomic Energy Agency, the Government of the Principality of Monaco and the Oceanographic Institute at Monaco. Support for the present work is gratefully acknowledged. We also wish to thank the IAEA Seibersdorf Laboratory for performing the stable selenium analysis.

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