Bull. Environm. Contam. Toxicol. 24, 752-758 (1980)

Model Ecosystem, Toxicity, and Uptake Evaluation of ^{75}Se-Selenite

P. A. Nassos*, J. R. Coats†, R. L. Metcalf, D. D. Brown, and L. G. Hansen
Department of Entomology, Institute of Environmental Studies, and College of Veterinary Medicine, University of Illinois, Urbana-Champaign, Illinois 61801

Selenium is a nonmetallic trace element with a dual importance in nature. At low levels it is an essential nutrient, but is toxic at concentrations only slightly higher. In areas where adequate selenium is present in the soil, people experience only one-third the number of heart-related diseases as people living in selenium-poor areas (ANONYMOUS 1976). Selenium may provide protection against some types of cancer (CLAYTON & BAUMANN 1949, SHAMBERGER 1970) and counteracts the effects of mercury and cadmium poisoning. At low dietary levels selenium prevents liver necrosis in rats (SCHWARZ & FOLTZ 1957), exudative diathesis in chicks (NESHEIM & SCOTT 1958, SCOTT 1962), and numerous metabolic and reproductive disorders in livestock (SCOTT 1974).

In the 1930's the alkali disease of livestock in South Dakota brought attention to the toxicity of selenium (FRANKE 1934); the legume Astragalus was responsible for concentrating the element from the soil at levels up to 3000 ppm (TRELEASE et al. 1960). Selenium can inhibit reproduction or cause deformed offspring in chickens and mammals (MOXON & RHIAN 1943), and has been shown to be carcinogenic as well (NELSEN et al. 1943, SCHROEDER & MITCHENER 1971).

The detrimental effects of selenium are thought to result from substitution of selenium for chemically-similar sulfur in the amino acids cysteine and methionine (HAMILTON 1975). Resultant macromolecules are less stable and more reactive than normal, leading to metabolic dysfunctions (STADTMAN 1974).

Selenium is made available to organisms through plant uptake from the soil, through natural weathering processes, and in increasing amounts from the burning of coal. One-third of the selenium released by the combustion of coal is in the vapor phase; two-thirds is in the fly ash which may be trapped in electrostatic precipitators in modern plants; a trace remains in the slag (ANDREN et al. 1975). When fly ash and slag were used as landfill the sweet clover (Melilotus) produced heads containing

*Present address: Radian Corporation, Austin, TX 78766
†Present address: Dept. of Entomology, Iowa State University, Ames, IA, 50011

0007-4861/80/0024-0752 $01.40

up to 220 ppm selenium compared to 21 ppm in the substrate. Aquatic organisms and woodchucks in the vicinity also contained elevated levels of selenium (GUTENMANN et al. 1976, FLEMING et al. 1979).

A recently reported occupational exposure to selenium is xerography rooms in which the air contained about 20-60 ng selenium per cubic meter, about 80,000 times more than baseline values for naturally occurring selenium (HARKIN et al. 1976).

This report will consider the fate of selenium (as selenite) in a terrestrial-aquatic model ecosystem, including rates of uptake and comparative bioaccumulation in two model ecosystems utilizing sand vs. Drummer soil-sand as the substrates.

METHODS AND MATERIALS

Radiolabel and assay. The radioisotope used was ^{75}Se, obtained from Amersham-Searle Corp., Arlington Heights, Illinois, as selenous acid. The isotope strength was assayed at 20.6 Ci per millimole (119 mCi per mg). All samples were counted in a gamma detector and cpm results were corrected by background subtraction.

Toxicity tests. Solutions of sodium selenite (nonradioactive) were prepared in battery jars using 2-L of standard reference water (FREEMAN 1953) to determine an approximate LC_{50} for each of the following organisms: the water flea Daphnia magna, the larvae of the mosquito Culex fatigans, the snail Physa sp., and the mosquito fish Gambusia affinis. No food was provided. Mortality was recorded after 48 h.

Uptake studies. Battery jars containing 1 ppb ^{75}Se-sodium selenite standard reference water were used to measure the rate of uptake by each aquatic species mentioned above. No food was provided. Duplicate samples were removed at 3, 6, 12 and 24 h for weighing (wet weight) and counting to determine Se concentration in the bodies.

Model ecosystem. The methodology of the Metcalf terrestrial-aquatic laboratory model ecosystem has been described (METCALF et al. 1971); adaptation for evaluation of toxic metals has involved incorporation of a salt of the metal into the sand or a soil/sand mixture (LU et al. 1975). The disposition of Se was compared on two substrates: pure silica sand and silica sand containing 10% Drummer soil, a silty clay loam for which the physical-chemical properties have been previously described (LU et al. 1975). Se was introduced onto the sand and sand/soil substrates by pouring a solution of 1.5 ug ^{75}Se (as selenous acid) in 25 mL of distilled water over 1.5 kg of sand or 1.5 kg of Drummer soil. After thorough stirring and shaking, the Se-impregnated sand and soil were each mixed with 13.5 kg silica sand to provide the total 15 kg quantities of substrate for the model ecosystems.

Two 10-gal aquaria were filled at one end with the substrate and Sorghum vulgare seeds were planted. Seven liters of standard reference water were added at the opposite end and aquatic organisms were added: the green alga Oedogonium cardiacum, the water flea D. magna, the snail Physa sp., and a complement of plankton. On the 26th day C. fatigans larvae were added; on the 30th day samples of Culex and Daphnia were removed and 3 mosquito fish G. affinis were added as top predators in the food chain. Sorghum plants were removed at intervals and assayed for ^{75}Se. Water samples were also taken regularly.

RESULTS AND DISCUSSION

Acute toxicity. The data in Table 1 show sodium selenite to be quite toxic to the alga O. cardiacum, the crustacean water flea D. magna, and moderately toxic to C. fatigans mosquito larvae (4th instar).

TABLE 1. Toxicity of sodium selenite to aquatic organisms (48 h).

	LC_{50} (ppm Se)
Oedogonium cardiacum alga	< 0.1
Daphnia magna water flea	0.25
Culex fatigans mosq. larva	3.1
Physa sp. snail	>10.0
Gambusia affinis mosq. fish	> 6.0

Forty years ago Se was used as an insecticide and miticide in sprays and in soil treatments for systemic control (MOXON & RHIAN 1943). It is obviously a broad-spectrum toxin, as only the snail and fish demonstrated significant tolerance to selenite.

Uptake rates. The organisms studied all demonstrated a basically linear response with time for uptake of ^{75}Se label from a solution of 1 ppb Se (as selenite). Figure 1 clearly indicates that the very active daphnia incorporated the selenite most rapidly, the mosquito larvae slightly slower, and the snails more slowly. Although no food was provided, the filter-feeding behavior of the crustacean and the insect larva is the probable reason for their faster uptake rates. This study demonstrates that the organisms can concentrate Se several hundred times the level in the water within a period of 24 h.

Model ecosystems. The distribution of the ^{75}Se in the two model ecosystems is shown in Table 2. The most obvious difference between the two is that more selenite bound to the Drummer/sand substrate than to pure sand, resulting in a Se concentration in the water less than one-half of that in the water of the sand ecosystem.

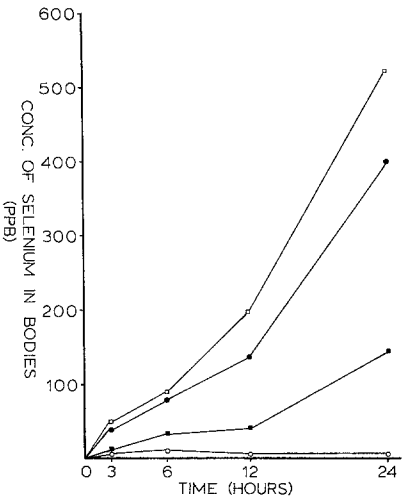

Figure 1. Rate of uptake of ^{75}Se by aquatic organisms from selenite solution containing 1 ppb selenium; (□ - daphnia, ● - mosquito larvae, ■ - snails, o - fish).

The alga did not survive in the sand ecosystem, even with occasional restocking. In the Drummer ecosystem it lived, concentrating the ^{75}Se label 110 times the level in the water, but did not thrive and grow well.

The daphnia and snails concentrated the label more than the mosquito larvae and fish, perhaps owing to the longer exposure times (33 days compared to 4 days and 3 days for the mosquito larvae and fish).

The snails and fish both demonstrate good agreement among the individual samples of each species. For each aquatic species the E.M. values are quite comparable for the two ecosystems despite the 3.3 fold difference in Se concentration in the water. This indicates that the ecological magnification is independent of concentration of the element in the water.

The rates of uptake by the sorghum were very different in the two substrates. Uptake began rapidly in both cases, with significant amounts absorbed the first day after the seeds were planted. As illustrated in Figure 2, the sorghum growing in the pure sand substrate absorbed the ^{75}Se at a much higher rate than that in the Drummer/sand substrate.

TABLE 2. Distribution and ecological magnification (E.M.*) of ^{75}Se-selenite in the components of two terrestrial-aquatic model ecosystems following treatment of the substrates (sand and Drummer soil/sand 1:9) with 1 ppb selenium.

Component	Sand ecosystem		Drummer/sand ecosystem	
	^{75}Se conc. (ppb)	E.M.*	^{75}Se conc. (ppb)	E.M.*
water	0.015	---	0.007	---
alga	**	**	0.051	110
daphnia	32	2100	9.3	1900
mosquito lv.	8.7	580	4.9	970
snail (#1)	48	3200	10	2100
(#2)	40	2600	12	2300
(#3)	30	2000	5.8	1200
fish (#1)	8.9	580	1.8	350
(#2)	8.1	530	3.1	610
(#3)	7.1	460	3.0	600
sorghum	19	1300	3.0	590
substrate	0.027	1.7	0.062	14

*E.M. = ecological magnification = $\frac{^{75}\text{Se conc. in component}}{^{75}\text{Se conc. in water}}$

**Alga could not live at this concentration of Se.

The results parallel closely the findings of a recent study of aquatic organisms in a farm pond near a fly ash land fill site in New York state (GUTENMANN et al. 1976). In that study, analysis of aquatic plants, insects, amphibians, fish and muskrats demonstrated bioaccumulation to levels ranging from 860 times to 26,000 times the concentration of selenium in the water (0.35 ppb). Other workers have reported concentration factors of 20 for shrimp and 100 for mussels, using selenite laboratory trials (FOWLER & BENAYOUN 1976). The ecological magnification values in Table 2 obtained from the laboratory terrestrial-aquatic model ecosystem range from 110 times to 3200 times the level of Se in the water. This is partially due to food chain effects and partially uptake due simply to exposure to selenite ion in the water, as proven by the separate uptake studies discussed above. Model ecosystem studies on lead and cadmium found accumulation of those metals in fish to degrees comparable to Se, and considerably higher than Se in the lower organisms (LU et al. 1975). In that study, lead and cadmium were each concentrated more by the sorghum plants than Se was under similar conditions.

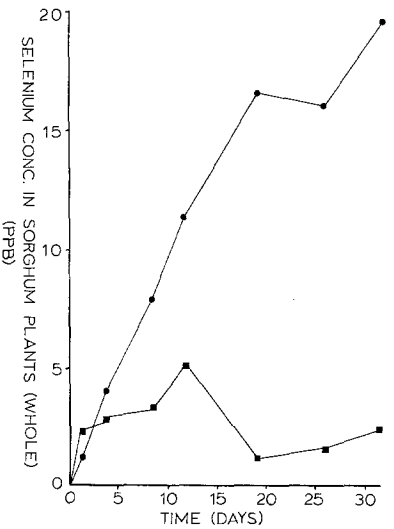

Figure 2. Rate of uptake of ^{75}Se by sorghum plants from substrates containing 0.1 ppb selenium (as selenite); ● - sand substrate, ■ - Drummer soil/sand substrate.

Comparisons with similar model ecosystem studies show that selenium bioaccumulated about as much as the toxic metals cadmium and lead (LU et al. 1975) and the chlorinated pesticides lindane, chlorpyrifos, and hexachlorobenzene (METCALF & SANBORN 1975). In light of the toxicity of selenium and its demonstrated incorporation into tissues of living organisms, selenium from such sources as fly ash and slag or supplementing livestock feed must be regarded as a potential hazard to the environment and appropriate monitoring programs may be advisable.

Acknowledgement

Project was supported by a grant to P. Nassos from the Granite City Steel Fellowship Program and by U.S. Food and Drug Administration Contract FDA-223-74-8251 "Evaluation of the utility of the model ecosystem for determining the ecological fate of substances subject to FDA regulatory authority". The authors thank J. Hassett for providing the Drummer soil.

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