Radiocobalt Cycling in a Small Mammal Food Web¹

William K. Willard²

Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

MAILED

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

ABSTRACT

Cobalt-60 seeping from a nearby radioactive liquid waste trench on the Oak Ridge reservation into a temperate deciduous forest ecosystem provided a source of environmental contamination where its dispersion through a small mammal food web could be studied. Maximum radiocobalt concentrations in the soil were found in the upper 5 cm of 15 cm cores. Transient mammals such as the opossum and the raccoon had small amounts of ⁶⁰Co in their tissues (0.5 and 1.0 pCi/gm, respectively), while the permanent mammal residents including the short-tailed shrew, (80 pCi/g) white-footed mouse (50 pCi/g), golden mouse (50 pCi/g) and the eastern chipmunk (20 pCi/g) had from 27 to more than 100 times that of the transient mammals. The persistent occurrence of ⁶⁰Co in the small mammals tissues indicated its importance in the food web. Of the potential mammalian food items present in the area, only earthworms (Lumbricus rubellus) contained high levels of ⁶⁰Co activity (>56 nCi/gm dry wt.).

¹Work supported by the U. S. Energy Research and Development Administration under contract for the Union Carbide Corporation.

²Permanent Address: Department of Zoology, Clemson University, Clemson, S. C. 29631.

Earthworms collected from the seepage channel eliminated 70% of their body burden (gut contents) of ^{60}Co during the first 24-hour period, but retained the remaining 30% (tissue accumulation) for more than 11 weeks. Tissue retention by earthworms and the utilization of numerous burrows by mammals along the seepage channel during the summer months suggested that earthworms constituted a major link in the small mammal food chain.

Key words: ^{60}Co ; dissemination; mammals; earthworms; food web; accumulation; retention; turnover; adaptive strategy.

Introduction

Although there have been numerous studies on the movement of radionuclides in food webs involving mammals (Neel and Larson, 1963; Kaye and Dunaway, 1963; Jenkins, Monroe and Golley, 1967; Dunaway, Story and Kitchings, 1971; Mathies, et. al., 1972) there have been few terrestrial studies emphasizing ^{60}Co , generally because mammals do not accumulate ^{60}Co and, when ingested, cobalt is rapidly excreted. Also, ^{60}Co seldom occurs in the environment or even in waste disposal areas in significant quantities to warrant scientific attention. Nevertheless, cobalt is a significant element in vitamin B_{12} metabolism and, in large quantities, may induce polycythemia in experimental animals (Underwood, 1971). The human fatalities caused by cobalt in beer illustrate the potential hazard it could pose when introduced into the food web (Schubert, 1973).

The study area was located near a liquid waste trench on the Oak Ridge reservation in eastern Tennessee. The waste trench had received intermediate level liquid waste prior to 1965. Cobalt-60 had seeped

from the trench to a point some 50 meters distant at the foot of the low lying ridge on which it was located. The objective of this study was to characterize the dispersion of ^{60}Co in the environs of the seepage area with special emphasis on the small mammal food web.

Methods

Sherman live traps were used in a 10 x 10 meter grid for collecting small mammals. Tissue samples taken from the mammals for ^{60}Co analysis were divided into the following components: bone, brain, heart, kidney, liver, lung, muscle, fur, stomach, feces, and in the case of Didelphis, young. Water, soil, vegetation, and invertebrates were also collected for ^{60}Co analysis in order to characterize the extent of the contamination as well as the specific activity of the potential mammalian food items. Only those portions of the trees readily available for consumption by the mammals (i.e., that portion in close proximity to the ground) were sampled; therefore, the samples collected represented a mixture of species - dogwood (Cornus florida), red maple (Acer rubrum), and redbud (Cercis canadensis). Tree samples were collected 1) from the seepage channel (roots only), 2) at a distance 5 meters perpendicular to the channel and 3) at a distance of 10 meters perpendicular to the channel. Soil cores were collected to a depth of 15 cm and divided into three equal fractions. Macro-invertebrates (potential mammalian food items) were also collected in the same areas as were the tree samples.

Because of the relatively high levels of ^{60}Co found in earthworms collected from the seepage channel, a laboratory experiment on earthworm (Lumbricus rubellus Hoffm.) uptake and retention of ^{60}Co was

conducted. Earthworms were introduced into three retaining pens each 100 x 100 x 25 cm and allowed to remain for about a week. The earthworms were field-collected from uncontaminated sites (282 to 719 mg/individual wet weight) and placed in pens constructed of treated lumber with screening on the bottom and screen doors on the top; they were then set into the ground to a depth of 15 cm. Three ^{60}Co inoculi using 1) 100 μCi 2) 200 μCi , and 3) 500 μCi were each diluted with water to a volume of 2000 ml and then introduced into the appropriate pen by means of a sprinkling can. The treatments employed were 1) 25%, 2) 50% and 3) 130% of the observed ^{60}Co soil concentrations averaged for the 15 cm depth where the earthworms were collected in the field. Two earthworms were then removed from each treatment at the following time intervals post-tagging: 1, 3, 6, 9, 16, 23, 45, 77, and 108 days. The earthworms were counted immediately after their removal from the pens and periodically (1, 3, 5, 7, 14, 21, and 28 days) thereafter in order to measure ^{60}Co retention. The soil was changed daily in order to preclude re-ingestion of ^{60}Co . All counting was done in an auto-gamma spectrometer coupled to a Nuclear Data 840 computer having a counting efficiency of 20%.

Results and Discussion

Cobalt-60 Concentrations in Mammals

Cobalt-60 followed watershed drainage and was greatly restricted to channel flow (Table 1). Cobalt-60 concentrations were greatest within the seepage channel and decreased with increasing distance away from and perpendicular to the channel (Table 1). In the upper 5 cm of

soil, activity decreased by 98% at 5 meters and by 99% at 10 meters distance from the channel. Transient mammals had relatively low concentrations of ^{60}Co (i.e., raccoon, 1.0 pCi/gm dry wt.; opossum, 0.5 pCi/gm dry wt.) while the permanent mammal residents had comparatively greater concentrations (short-tailed shrew, 80 ± 38 pCi/gm; white-footed mouse, 50 ± 18 pCi/gm; golden mouse, 50 pCi/gm and the eastern chipmunk, 20 ± 23 pCi/gm). The opossum was a female carrying 11 young which were less than 2 weeks of age; no ^{60}Co was detected in the young. These data indicate that the permanent mammalian residents were primarily feeding along the seepage channel and the transient mammals primarily outside the contaminated area.

Analysis of the tissues of the transient mammals (Procyon and Didelphis) for ^{137}Cs and ^{106}Ru revealed concentrations higher than those observed for ^{60}Co (Table 2), indicating the mammals' mobility relative to the seepage area and/or relating their feeding habits to other areas contaminated with ^{137}Cs and ^{106}Ru . Didelphis had a ^{137}Cs concentration averaging 16 pCi/gm dry wt. compared to 6 pCi/gm for Procyon; while the average concentration of ^{106}Ru was 38 pCi/gm for Didelphis and 17 pCi/gm for Procyon. In order to determine if the permanent mammalian residents' were feeding outside the study area several animals were analyzed for ^{137}Cs and ^{106}Ru ; no ^{137}Cs and only trace amounts of ^{106}Ru were present. The total body burdens of ^{60}Co , ^{137}Cs and ^{106}Ru was estimated to be 0.16 μCi for Didelphis and 0.42 μCi for Procyon. It was concluded that the transient mammals were primarily feeding outside the study area and only occasionally from within.

Comparison of the total body burdens of the larger, transient mammals with those of the smaller permanent residents residing in the

seepage age area revealed that the raccoon, for example, had a body burden of ^{60}Co approximately 5 times that of the short-tailed shrew. However, in terms of activity per unit weight, the short-tailed shrew exceeded the raccoon by a factor of more than 68, indicating that Blarina (and the other permanent residents) were feeding on food items having a relatively high activity - possibly earthworms. Cobalt-60 concentrations varied widely both between tissues and within the same tissue, with the greatest activity being found in the heart (710 pCi/gm max) and lungs (626 pCi/gm max). Slightly larger amounts of ^{60}Co (972 pCi/gm max) were found in the feces (Table 2).

Cobalt-60 Dynamics in Earthworms

Of the potential mammalian food items present in the seepage channel, earthworms (Lumbricus rubellus) had the highest concentration (< 56 nCi/gm dry wt.). Earthworms collected from the seepage channel eliminated approximately 70% of their body burden (gut contents) during the first 24-hour period following removal, but retained most of the remaining 30% (tissue accumulation) through 11 weeks (Fig. 1). Crossley et. al. (1971) found that the earthworm Octolasion eliminated about 90% of its accumulated ^{134}Cs the first day while the tissue burden decreased to nearly 0 over a 10 day period. Although total body burdens varied in the earthworms collected, the elimination rate of ^{60}Co from the gut and from the tissues was consistent for all individuals, indicating the earthworms were probably in equilibrium with their environment. A typical curve showing biological turnover of ^{60}Co for a specific earthworm collected from the seep (Fig. 1) followed a two-component model (Reichle and Van Hook, 1970)

$$A_t = A_0(a_1e^{-k_1t} + a_2e^{-k_2t})$$

where A_t is the whole-body ^{60}Co concentration at time t , A_0 is the initial ^{60}Co concentration (at the beginning of the elimination period), and k_1 and k_2 are the elimination rate coefficients associated with the proportions of ^{60}Co in unassimilated gut contents (a_1) and incorporated in tissues (a_2), respectively. The initial 70% decline in whole-body ^{60}Co concentration during the first 24 hours was attributed to gut elimination ($k_1 = 57.7/\text{day}$). The biological half-life (T_b) for ^{60}Co in the gut component was .012 day ($.693/k_1$). Elimination of ^{60}Co from the tissues proceeded at the rate of .036/day ($T_b = 14.5$ days). Using the reciprocal of the elimination rate ($1/k$ of the respective component) after Reichle (1969), the turnover times of ^{60}Co (time required for the turnover of an amount equal to the gut contents and to attain Q_e) were calculated for the gut (25 min.) and tissues (27.8 days). The significance of ^{60}Co retention in Lumbricus rubellus tissues lies in its availability to consumers and its importance in trophic transfer to predators.

The results obtained in the ^{60}Co -earthworm tagging experiment reflected the sporadic and unpredictable feeding behavior of the earthworms (Table 3). Uptake of ^{60}Co by earthworms was generally independent of earthworm size and appeared to be more closely associated with 1) the concentration of ^{60}Co in the soil, 2) the homogeneity of the ^{60}Co -soil mixture, and 3) the feeding and excretion frequency of the earthworms. The body burdens of earthworms collected from the seep were presumed to be in equilibrium with their environment and were also observed to be

independent of earthworm size. After 3 to 4 months posttagging, the percentage of activity retained by the tissues following the initial gut elimination (24 hrs.) varied but approximated the 30% retention values found for field animals (treatment 1, 30%; treatment 2, 36%; treatment 3, 24%). If the field-collected earthworms were in an equilibrium with their environment, then it should have required them about 100 days to equilibrate. The most consistent finding in the uptake experiment was that although the amount of ^{60}Co retained after the 24-hour elimination period varied, the remainder, or tissue burden, remained relatively constant throughout the 28-day elimination study period (Table 3).

The significance in the biomagnification of ^{60}Co by earthworms relative to food chain uptake of ^{60}Co by mammals lies in several findings: 1) the major mast producers (e.g., oaks, hickories, dogwoods), arthropods, and other invertebrates which are routinely considered as mammalian food sources were scarce and/or absent in this ecosystem; 2) earthworms in the seepage area were relatively abundant; 3) a large number of mammals (23) were trapped from an area small in size (ca. 0.1 ha), perhaps indicating that the mammals were gathering to feed on an abundant food resource; 4) bottomland areas throughout the ridge and valley province typically have numerous burrows which are coincident with drainage flow. This suggests that the utilization of the burrows constitutes an adaptive or ecological strategy employed by the mammals in terms of both food and shelter from the hot, dry summer weather. This strategy, therefore, ultimately resulted in the mammals moving into close proximity to a food source which accumulated ^{60}Co , thereby

allowing an increased opportunity for the entry of the contaminant into the food web. Since mammals readily excrete cobalt, the likelihood for the removal of large quantities of ^{60}Co is remote. Because the dispersal of ^{60}Co was greatly restricted in the ecosystem studied, significant food chain transport of ^{60}Co is unlikely. Finally, the study illustrated that radionuclide cycling is an ecosystem process dependent on the interaction of both the physical and biotic aspects of the ecosystem.

Literature Cited

- Crossley, D. A., Jr., D. E. Reichle and C. A. Edwards. 1971. Intake and turnover of radioactive cesium by earthworms (Lumbricidae). *Oikos* 11: 71-76.
- Dunaway, P. B., J. D. Story, and J. T. Kitchings. 1971. Radiation effects and radionuclide excretion in a natural population of pine vales. Third Nat. Symposium on Radioecology, D. J. Nelson, ed., Oak Ridge, Tenn.
- Jenkins, J. H. 137. R. Monroe and F. B. Golley. 1967. Comparison of fallout ¹³⁷Cs accumulation and excretion in certain southeastern mammals. Proc. 2nd Nat. Symposium on Radioecology, Ann Arbor, Mich.
- Kaye, S. V. and P. B. Dunaway. 1963. Estimation of dose rate and equilibrium state from bioaccumulation of radionuclides by mammals. In: Radioecology, V. Schultz and A. W. Klement, Jr., eds. Reinhold Publ. Corp., N. Y. and A. I. B. S., Wash., D.C.
- Lowman, F. G. 1963. Iron and cobalt in Ecology. In: Radioecology, V. Schultz and A. W. Klement, Jr., eds. Reinhold Publ. Corp. and A. I. B. S., Wash., D.C.
- Mathies, J. B., P. B. Dunaway, G. Schneider, and S. I. Auerbach. 1972. Annual Consumption of Cesium-137 and Cobalt-60 Labeled Pine Seeds by Small Mammals in an Oak-Hickory Forest. ORNL-TM-3912.
- Neel, J. W. and K. H. Larson. 1963. Biological availability of Strontium-90 to small animals in fallout patterns from the Nevada test site. In: Radioecology, V. Schultz and A. W. Klement, Jr., eds. Reinhold Publ. Corp., N. Y. and A. I. B. S., Wash., D.C.
- Reichle, D. E. 1969. Measurement of elemental assimilation by animals from radioisotope retention patterns. *Ecology* 50: 1102-1104.
- Reichle, D. E. and R. I. Van Hook, Jr. 1970. Radionuclide dynamics in insect food chains. *The Manitoba Entomologist* 4: 22-32.
- Schubert, J. 1973. Heavy metals -- toxicity and environmental pollution. In: Metal Ions in Biological Systems. S. K. Dhar, ed. Plenum Press, New York.
- Underwood, E. J. 1971. Elements in Human and Animal Nutrition. Academic Press, New York. 430 pp.

Figure 1. Biological turnover of ^{60}Co by an earthworm collected from a seepage area. The earthworm was assumed to be in equilibrium with its environment.

Table 1. Distribution of ^{60}Co in soil, water and biological material emanating from a seepage area near a radioactive liquid waste trench on the Oak Ridge ERDA Reservation in eastern Tennessee.

SAMPLING SITE (Distance From Seep-Meters)	pCi/g									
	SOIL (Depth - cm)			WATER	VEGETATION			INVERTEBRATES	MAMMALS ^a	
	0-5	6-10	11-15		Root	Stem	Leaf			
A. 0	51,970	31,930	4,900	270	Jewel 13,230	Weed 350	1,115		Chipmunk 20	(486) ^b
									White-footed mouse 50	(280)
B. (10 meters down channel)	4,720	2,700	1,300	—	Tree Species 10,400	—	—	Spiders 70 Earthworms 56,735	Short-tailed shrew 80	(304)
B ₁ (5 meters perpen- dicular to channel at B)	130	115	85	—	100	30	30	Earthworms 90	Golden mouse 50	(253)
B ₂ (10 meters per- pendicular to channel at B)	100	50	45	—	15	10	25	Earthworms 5 Millipedes 20 Snails 5	Raccoon 1.0	(1552)
C (20 meters down channel)	12,420	13,090	12,050	175						

^aBecause of their relative mobility, mammals were not categorized to a specific location.

^bNumbers in parentheses indicate total body burden.

Table 2. Activity (pCi/g dry wt.) of ^{60}Co , ^{137}Cs , and ^{106}Ru in the tissues of small mammals inhabiting a seepage area near a radioactive liquid waste trench. Numbers of animals are shown in parentheses.

	^{60}Co		^{60}Co		^{60}Co		^{60}Co	^{137}Cs	^{60}Co	^{106}Ru	^{137}Cs	^{60}Co	^{106}Ru
Tissue	<u>Peromyscus</u> <u>leucopus</u> (6)		<u>Tamias</u> <u>striatus</u> (7)		<u>Blarina</u> <u>brevicauda</u> (8)		<u>Ochrotomys</u> <u>nuttali</u> (1)	<u>Didelphis</u> <u>marsupialis</u> (1)		<u>Procyon</u> <u>lotor</u> (1)			
	Mean	Range	Mean	Range	Mean	Range							
Bone	137	0-337	20	0-62	200	0-697	—	14	—	51	19	—	31
Brain	26	0-110	11	0-30	235	0-613	70	107	—	138	143	—	194
Heart	331	0-564	64	0-140	300	0-710	406	33	23	139	102	—	220
Kidney	115	0-258	4	0-32	96	0-318	—	56	—	171	140	—	235
Liver	46	0-94	14	0-43	125	50-256	8	68	5	92	76	13	252
Lung	195	0-526	33	0-63	149	0-527	322	151	—	230	181	—	343
Muscle	74	0-150	14	0-46	236	0-483	180	130	21	273	132	7	324
Fur	148	0-549	1	0-7	77	0-177	13	43	—	63	14	6	8
Stomach	25	0-87	33	0-118	135	0-410	—	77	—	158	—	—	48
Feces	255	0-972	225	11-882	79	0-196	152	314	—	955	139	265	933
Young	—	—	—	—	—	—	—	30	—	71	—	—	—

Table 3. Earthworm uptake and retention of ^{60}Co . Soil in treatment 1 tagged with 100 μCi ; treatment 2 with 200 μCi ; and treatment 3 with 500 μCi .

Time in Tagged Soil (Days)	Group	Treatment	Avg. pCi Accumulated	Percent Retained Over 28-Day Per				
				1	7	14	21	28
1	A	1	0	--	--	--	--	--
		2	0	--	--	--	--	--
		3	9,270	22	21	20	20	19
3	B	1	4,300	20	21	20	14	14
		2	22,170	26	24	24	23	24
		3	24,110	7	7	6	7	7
6	C	1	3,880	52	28	30	20	32
		2	5,120	52	24	28	36	28
		3	30,900	4	4	4	3	4
9	D	1	9,840	40	32	32	32	32
		2	8,790	54	52	52	52	53
		3	30,160	37	36	34	26	25
16	E	1	3,950	39	30	32	32	32
		2	6,990	64	70	56	68	65
		3	5,520	54	46	52	46	48
23	F	1	5,240	4	2	2	2	2
		2	5,780	15	18	15	15	21
		3	14,740	12	11	11	11	11
45	G	1	13,890	64	53	52	52	52
		2	4,170	34	27	32	30	31
		3	4,990	29	30	26	16	20
77	H	1	4,420	40	40	38	41	39
		2	5,800	31	26	28	30	27
		3	13,800	20	17	19	20	18
108	I	1	2,190	30	23	28	27	28
		2	6,500	36	34	35	32	38
		3	1,420	24	22	24	24	22