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A REVIEW OF THE ECOLOGICAL PARAMETERS OF RADIONUCLIDE TURNOVER IN VERTEBRATE FOOD CHAINS¹

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Abstract. Ecological studies of radionuclides in the environment have a long tradition in developing the capability to identify and predict movement and concentration of nuclides in agricultural food chains leading to man. Food chain pathways and transfer coefficients for the nonagricultural portions of natural and managed ecosystems characteristic of affected habitats adjacent to nuclear facilities have not been adequately characterized to establish reliable models for radionuclide releases. This information is necessary in order to assess the impact that such installations will have on the biota of natural ecosystems. Since food chains are the major processes transferring elements from one trophic level to another in terrestrial ecosystems, information is needed on the (a) food-chain transfer pathways, (b) bioconcentration by each trophic component and (c) turnover rates by receptor organisms. These data are prerequisite inputs for food-chain transport models and can be correlated with species characteristics (e.g., body weight and feeding habits), to provide indices for predictive calculations. Application of these models for radionuclide transfer can aid in the assessment of radioactive releases from nuclear reactor facilities to terrestrial nonagricultural food chains.

Key words: Radionuclide cycling; metabolism; bioconcentration factors; nonagricultural food chains.

INTRODUCTION

Passage of the National Environmental Policy Act (1969) has provided impetus to understanding the ecological consequences of many problems associated with environmental pollutants. This is particularly true of the radioactive effluents associated with nuclear power generating facilities. Chronic releases of small quantities of radionuclides to natural biotic communities requires knowledge of their subsequent accumulation, and the effects of low levels of pollutants on the plant and animal components of ecosystems. This concern and the responsibility of providing safeguards for human and environmental health has fallen to both the electrical utilities and federal government.

Basic ecological research on radionuclides in the environment has a 25-yr history resulting in sophisticated models for identification and prediction of the movement and concentration of specific radionuclides, i.e., releases of ⁹⁰Sr, ¹³¹I, ³H, ⁶⁰Co and ¹³⁷Cs

from nuclear establishments and power stations (Booth et al. 1971).

The mathematical description of elemental movement through nonagricultural food chains is more complex because of the intricate feedback among the many components of natural ecosystems and by the numerous ecological processes controlling the pathways and rates of transfer. Evaluation of radionuclide transfer to humans via agricultural food-chains, however, has developed a coherent theory as well as predictive models for radionuclides released from both reactor operations and fallout (Kaye and Ball 1967 and Booth et al. 1971). It has not been lack of mathematical techniques which has restricted the development of predictive models of natural ecosystem transport (Gist et al. 1971, Thomas and Eberhardt 1971, Eberhardt 1971 and O'Neill 1971); but the fact that neither sufficiently detailed nor widely representative (taxonomically) radioecological data have been collected. The problem involved in building models to approximate radionuclide movement in ecosystems is in extrapolating the results of lab and field studies to species and/or habitats other than those observed directly. Obviously, equations correlating radionuclide metabolism (biological half-life or elimination coefficients) to taxonomic groupings, to physical parameters such as body weight, and physiological

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similarities in metabolism of radionuclides, can greatly enhance our predictive capabilities.

Analyses of the environmental behavior of radionuclides and their potential uptake and transport in vertebrate populations must consider three steps:

1. Identification of critical environmental food-chain pathways.
2. Assimilation at each link in the pathway.
3. Turnover rates by the successive receptor populations or trophic levels.

Mathematical descriptions of the transfer of radionuclides from a release source to successive trophic levels typically consist of a series of equations identifying the fractional input and outflow from trophic compartment to compartment (O'Neill 1971, Eberhardt 1971). The derivation of the appropriate coefficients for each compartment (species population in a trophic level) is complicated by the fact that very little data on turnover and uptake are available for a wide variety of species or radioisotopes.

In this report we have attempted (1) to summarize the food-chain parameters used in these models and to formulate relationships which describe cycling and distribution of radionuclides in nonagricultural mammalian food-chains, and (2) to compile, from reliable literature sources, the data needed to define process model inputs and fractional transfer coefficients that reflect both species and isotope variations.

Bioconcentration Factors

Food chains are typically conceptualized as successive links (trophic levels) in the acquisition of foods (Fig. 1) by animal populations. Food-chain dynamics and elemental distribution are dependent on a number of environmental factors, i.e., geochemical characteristics of the system, nutrient

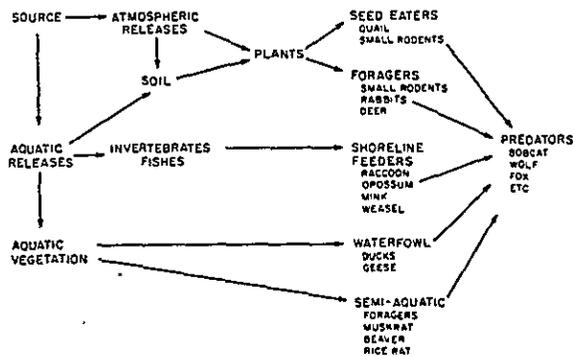


Fig. 1. Radionuclide transfer pathways in an ecosystem.

levels in the food material and physiological demands of the consumer. Historically, the principal reason for determining the bioconcentration factors (BCF's) for terrestrial biota was to calculate the internal radiation dose to the animal at an equilibrium body burden from radionuclides assimilated from foodstuffs.

The BCF of an organism is the ratio of radionuclide concentration in the organism to that in the food base:

$$BCF = \frac{RE_i}{RE_f}$$

where

- BCF = bioconcentration factor (at equilibrium) of radionuclide RE in organism i,
- RE_i = radionuclide concentration (μCi/g) in i, and
- RE_f = radionuclide concentration in the food base (μCi/g).

For the most part, BCF's for mammals have been collected from fallout studies under widely varied habitat conditions (arctic, desert, temperate zone and laboratory) and, consequently, there are few consistent generalizations. Concentration factors for ¹³⁷Cs typically show an increase from plant to mammalian herbivores (Table 1) as well as increases at the higher trophic levels. Ninefold increases in ¹³⁷Cs through plant → mule deer → cougar food-chain were demonstrated in the work done by Pendleton et al. (1965). Also an increase of approximately 2-5 at each link in the lichen → caribou → wolf chain has been reported by Hanson et al. (1967).

Less comprehensive data are available for the other radionuclides, but it is evident that not all radionuclides are concentrated in food chains and that different food chains may exhibit markedly different concentration patterns for the same nuclide. Strontium-90 accumulation for the plant → herbivore chain ranges from 0.02 to 8.4 (Table 1); while the BCF's for ³H, ⁶⁰Co and ¹³¹I are less than 1.0 with the exception of 2.4 for seed, water → quail for ⁶⁰Co movement (Auerbach 1973).

BCF's derived from fallout studies or from any one point in time are not realistic because of the dynamic processes characteristic of food chains. The transfer of material between trophic levels is not an instantaneous process but rather is a series of time-lag responses from one trophic level to another (Reichle and Van Hook 1970, Reichle and Crossley 1967). Therefore, even though equilibrium concentrations of radionuclides under chronic release conditions can be predicted very accurately from bioconcentration estimates, little knowledge is

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TABLE 1. Vertebrate food-chain bioconcentration factors ^a

Element	Species	Food base	Bioconcentration factors	Reference
¹³⁴⁻¹³⁷ Cs	Cottonrat	grass	3.4	Kitchings et al. 1969
	Kangaroo rat	grass	1.0	Romney et al. 1971
	Cottontail	grass	1.9	Romney et al. 1971
	White-tail deer	forage items	0.4	Plummer et al. 1969
	Quail	seeds + water	2.4	Auerbach et al. 1973
	Caribou	lichen		Garner 1972
	muscle		2.3	
	liver		1.7	
	kidney		3.2	
	bone		0.5	
	Grayfox	cottonrat	2.0-5.7 ^b	Jenkins et al. 1969
	Redfox	cottonrat	1.4-2.0 ^b	Jenkins et al. 1969
	Bobcat	cottonrat	6.9-18.7 ^b	Jenkins et al. 1969
	Grayfox	rabbit	1.8-4.8 ^b	Jenkins et al. 1969
	Redfox	rabbit	0.9-1.7 ^b	Jenkins et al. 1969
	Bobcat	rabbit	6.1-15.9 ^b	Jenkins et al. 1969
	Cougar	mule deer	2.9	Pendleton et al. 1964
	Redfox	caribou	1.0-2.0	Hanson et al. 1967
	Wolf	caribou	2.0-5.0	Hanson et al. 1967
	Wolverine	caribou	5.0-7.0	Hanson et al. 1967
	Herbivores		0.3-2.0	Reichle et al. 1970
	Omnivores		1.2-2.0	Reichle et al. 1970
	Carnivores		3.8-7.0	Reichle et al. 1970
⁹⁰ SrC	Cottontail	grass	8.4	Romney et al. 1971
	Kangaroo Rat	grass	4.4	Romney et al. 1971
	Mule deer	grass		Farris et al. 1969
	(0-12 mo)		0.19	
	(12-24 mo)		0.16	Farris et al. 1969
	Columbia black-tail deer	grass	0.30	Goldman et al. 1965
	White-tail deer	grass		Plummer et al. 1967
	1.5 yr		0.47	
	2.5 yr		0.41	
	3.5 yr		0.40	
	Caribou	lichen		Garner 1972
	muscle		0.02	
	bone		7.00	
Herbivores		0.5-4.5	Reichle et al. 1970	
³ H	Kangaroo rat	Russian thistle	~1.0	Koranda 1969
	Deer mouse	Russian thistle	~1.0	Koranda 1969
	Herbivores	grass	0.6	Reichle et al. 1970
⁶⁰ Co	Herbivores		0.3	Reichle et al. 1970
	Quail	seeds + water	2.4	Auerbach et al. 1973
	Quail	4 food sources lumped		
		seeds, seeds + water, water, crickets, lichen	0.2	Auerbach et al. 1973
	Caribou	lichen		Garner 1972
	muscle		0.02	
	liver		0.9	
	kidney		0.4	
bone		0.05		
¹³¹ I	Herbivores		0.5	Reichle et al. 1970
	Omnivores		0.2	Reichle et al. 1970
	Carnivores		0.1	Reichle et al. 1970

^a Unless otherwise noted, data refer to whole body concentration.^b BCF dependent upon region (soil type) where data was collected.^c BCF = (bone pCi ⁹⁰Sr/S Ca)/diet pCi ⁹⁰Sr/S Ca.

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gained about the temporal dynamics of radionuclides in food chains where equilibrium conditions do not prevail.

Radionuclide Metabolism

To understand the dynamics of radionuclides in food chains, additional parameters of radionuclide metabolism must be known. Radionuclide residence times in organisms are functions of biological half-time (T_b) as well as radionuclide decay and are, thus, related to the species physiology. The rate constant (λ_b) describing radionuclide excretion is dependent upon (1) internal (body weight, sex, age and species biochemistry) and (2) external (temperature, chemical form of nuclide, etc.) environmental factors. Radionuclide turnover rate coefficients may be applied for comparative species retention studies as well as calculations of radionuclide body burdens in specific trophic levels. This variable allows predictions of concentrations in a dynamic nonequilibrium system, provided that intake rates of the radionuclide are known.

Because it has not been possible to measure the metabolism of all radionuclides in every species, similarities in nuclide metabolism among related species provide practical formulations with which to extrapolate from a limited data base. We have identified several radionuclides present in the effluents of nuclear power plants of special radioecological concern (^{90}Sr , ^{131}I , ^3H , ^{60}Co and ^{137}Cs) and have developed correlations of the turnover rates of these

nuclides in different mammalian species with body weight. Because metabolism is a function of the 0.75 power of body weight in homeotherms (Kleiber 1961), a few authors have attempted to establish relationships between body weight and radionuclide metabolism (biological half-life T_b). The mathematical relationship for whole-body metabolism follows a linear power function ($Y = aX^b$) where Y is equal to biological half-life and X is the weight of the organism.

Cesium

The data collected on the excretion of radiocesium by many rodents and other small mammals (Table 2) indicate a relationship for body weight regressed against the longest component half-life for ^{137}Cs (Fig. 2):

$$Y = 3.5X^{0.24}, r^2 = 0.93$$

Reichle et al. (1970) also demonstrated a weight/half-life relationship for radiocesium in various vertebrates and invertebrates. The relationship for insects and warm-blooded vertebrates was $Y = 3.5X^{0.21}$. Stara et al. (1971) demonstrated a similar relationship for various vertebrate species and showed that the relationship of biological half-life to organism size (body weight) for monogastric animals is different from that for ruminants. However, these authors did not publish equations describing these curves and so to compare their results with

TABLE 2. Whole-body biological half-life for $^{134-137}\text{Cs}$

Element	Species	Weight (g)	T_{b1}^a	P_1^b	T_{b2}	P_2	Reference
^{134}Cs	Cottonrat	126.0	6.2D		8.4D		Kitchings et al. 1969
	Cottonrat	129.0			8.1D		Baker and Dunaway 1969
	Lab mouse	20.0	19.2H	33.7	2.2D	32.7	Taysum et al. 1968
	Lab rat	187.0	20.5H	32.9	6.3D	67.1	Lengemann 1970
	Mule deer	~28,000	1.1D	20.6	14.9D	79.4	Hakonsen and Whicker 1968
^{137}Cs	Harvest mouse	9.7			3.7D	87.0	Baker et al. 1970
	Whitefooted mouse	21.2			3.5D	57.1	Baker et al. 1970
	Lab mouse	22.0	13.1H	40.1	6.0D	25.4	Furchner and Richmond 1963
		20.0	16.8H	35.6	5.6D	25.1	Taysum et al. 1968
		20.0	1.1D	34.8	6.6D	23.1	Taysum et al. 1968
	Lab rat	225.0			4.5D		McPeak et al. 1966
	Dog	~19,300			28.0D	84	Boecker 1969
	Redfox	~10,000			29.3D		Jenkins et al. 1966
	Mule deer	~28,300			15-21D		Goldman et al. 1965
	Caribou				21-35D		Hanson, 1967

^aBiological half-life for first component (T_{b1}) or second component (T_{b2}) in days (D) or hours (H).
^bProportion of ingested isotope associated with the corresponding T_b .

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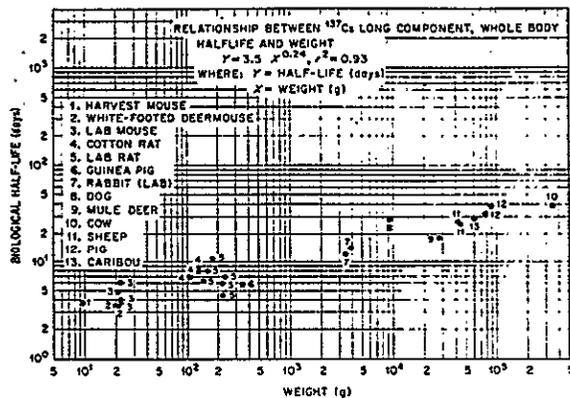


Fig. 2. Relationship of body weight and the long component half-life (T_{b_2}) of ^{137}Cs in mammals.

ours and those of Reichle et al., we have combined values of monogastrics and ruminants and have used approximate values (read from the published graph) to calculate the power function relationship, $Y = 7.1X^{0.15}$.

The discrepancy between the classic metabolism/weight exponential proportionality of 0.75 and the ^{137}Cs /weight coefficients determined above can be explained by remembering that the ^{137}Cs /weight relationship is a function of only a part of the total radionuclide metabolism. The more rapid "intestinal" component (T_{b_1}) largely representing unassimilated isotope is not included in the calculation. The intestinal contribution to the overall loss of the isotope ranges from 20%-40% of the total ingested radioactivity, substantially increasing the whole-body rate loss coefficient. The intestinal component of radionuclide turnover varies substantially with

digestibility of the food consumed and is highly variable, depending upon the diet; for this reason, this component is not included in the turnover regressions. The high degree of correlation ($r^2 = 0.93$) for the metabolic (T_{b_2}) component makes this comparison (^{137}Cs turnover/unit body weight) a useful tool in approximating of Cs elimination for species where this information is lacking.

Strontium

Strontium-90 is of interest to the ecologist assessing the terrestrial movement of the effluent from nuclear power facilities, because radiostrontium contributes significantly to the total dose received by organisms exposed to the reactor effluents (Kaye 1973). Strontium is a long-lived isotope which accumulates in the slowly exchanged bone pool (Reichle et al. 1970). Thus, whole-body retention data reflect the dominance of this bone pool. Limited information is available on the whole-body retention of strontium in small native mammals; however, Reichle et al. (1970) calculated a body weight/ ^{90}Sr turnover whole-body half-life power function of $Y = 107.4X^{0.26}$ for 11 various species from arthropods to man. The literature data that we have collected, including Reichle's (Table 3) references, do not show a significant correlation between weight and half-life for this isotope ($r^2 = 0.28$). On the basis of the wide taxonomic groupings included in this calculation we suggest that the equation of Reichle et al. (1970) is valid only as an approximation of the strontium turnover rates in small mammals.

Iodine

Similar whole-body half-life data for radioiodine have been collected for ten species of mammals

TABLE 3. Whole-body biological half-life for $^{85-90}\text{Sr}$

Element	Species	Weight (g)	$T_{b_2}^a$	p_2^b	Reference
^{85}Sr	Lab mouse	33.0	10D	56	Fujita and Iwamoto 1965
	Lab rat	220.0	10D	45	Fujita and Iwamoto 1965
	Lab rabbit	370.0	10D	45	Fujita and Iwamoto 1965
	Dog	10,000.0	18D	67	Clad et al. 1960
	Mule deer	69,600.0	229D	8	Schreckhise and Whicker 1970
^{90}Sr	Lab mouse	~30.0	25D		Bair et al. 1961
	Lab mouse	~30.0	75D		Bair et al. 1961
	Lab rat	~200.0	593D	6425	Moskalev and Buldalov 1968
	Dog	10,000.0	530D	100.0	Moskalev and Buldalov 1968

^aBiological half-life for second component in days (D) or hours (H).

^bProportion of ingested isotope associated with the corresponding T_{b_2} .

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(Table 4). Iodine-131 and other iodine isotopes (132, 133 and 135) can contribute a substantial portion of dose received by terrestrial biota under certain conditions, i.e., criticality accidents. Other than for the grass-cow-milk pathway, substantial food chain data for radioiodine are lacking. This is because previously only ¹³¹I was recognized as a significant contaminant and it decayed out before significant food chain exchange could occur. Iodine-129, in the liquid effluent from fuel-processing plants, has a very long half-life (1.7×10^7 yr) and will require consideration as a long-term contaminant in terrestrial food-chains.

The thyroid acts as a major physiological pool for all iodine isotopes and the whole-body biological half-life of mammalian species is affected by this rapidly metabolized pool. As in the case with strontium the literature data we have collected do not show highly significant correlation between weight and half-life ($r^2 = 0.57$). The equation for body weight/¹³¹I relationship expressed by Reichle et al. (1970) as $Y = 6.8X^{0.13}$ based on data for 25 species, including insects, fish and mammals. Despite the statistical imprecision, this expression covers such a wide variety of species it should be useful in estimating the T_b for vertebrates where experimental data are lacking.

Cobalt

Cobalt is relatively poorly assimilated by mammalian species. Mathies (1971) found that only 18.3% of ⁶⁰Co ingested by whitefooted mice was associated with body tissues; most was found in the contents of the gastrointestinal tract. Willard (unpublished) found that heart and lungs had the highest concentration of cobalt in several small mammal species trapped from a waste-disposal seep area. The turnover/body weight regression calculated from the five species listed in Table 5 is $Y = 2.64X^{0.24}$, $r^2 = 0.67$.

Tritium

Approximately 90% of the body burden of tritium in the mammalian species is associated with the body-water, with the remaining fraction organically bound in tissues (Elwood 1971). Tritium turnover data for six species are listed in Table 6. Turnover of tritium in body-water as related to body weight was calculated as $Y = 0.82X^{1.55}$, $r^2 = 0.90$ for five of the six species. The sixth species, the Kangaroo rat, exhibited a longer half-life than the horse. This comparatively slower turnover time is characteristic of desert dwelling organisms which must conserve body-water. This species characteristic serves to illustrate that many special cases do occur and that

TABLE 4. Whole-body and thyroid biological half-lives for ¹³¹I

Element	Species	Weight (g)	Organ	T_{b1}^a	P_1^b	T_{b2}	P_2	Reference
¹³¹ I	Deer mouse	~20.0	Thyroid			3.7D	30.0	French 1967
	Cotton rat	108.0	Whole-body			8.0D		O'Farrell and Dunaway 1967
			Thyroid			6.7D		O'Farrell and Dunaway 1967
	Lab mouse	21.0	Whole-body	3.9H	91.1	5.2D	5.0	Furchner and Richmond 1963b
	Lab rat	208.0	Whole-body	6.5H	77.7	2.5D	16.3	Furchner and Richmond 1963b
	Kangaroo rat	~95.0	Thyroid			5.0D	39.0	French 1967
	Guinea pig	500.0	Whole-body	6.5H		26.4D		Nelson et al. 1969
			Thyroid	6.0H		26.7D		Nelson et al. 1969
	Jack rabbit	1,900.0	Whole-body			5.0D		French 1960
	Lab rabbit	3,700.0	Whole-body			13.0D		French 1960
			Thyroid			4.2D	3.0	French 1960
	Dog	11,500	Whole-body	1.3D	54.1	17.4D	46.3	Furchner and Richmond 1963b
	Mule deer	69,600	Whole-body			229D	8.0	Schreckhise and Whicker 1970
		60,000	Whole-body	2.2D	76	6.3D	24	Gist 1969
	Mule deer		Thyroid					
Winter	69,600			6.0D	32	0.8D	Gist and Whicker 1971	
Spring	61,800			7.0D	22	0.8D		
Summer	51,300			6.3D	20			

^aBiological half-life for first component (T_{b1}) or second component (T_{b2}) in days (D) or hours (H).
^bProportion of ingested isotope associated with the corresponding T_b .

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TABLE 5. Whole-body biological half-life for ^{60}Co

Element	Species	Weight	T_{b_1} ^a	P_1 ^b	T_{b_2}	P_2	Reference
^{60}Co	Whitefooted mouse	20.0	9.3H	86.7	5.2D	8.3	Mathies 1971
	Lab mouse	~25.0	4.1H	76.0	4.8D	20.0	Hodges et al. 1969
	Lab rat	395	4.8H	8.6	10.5D	26.0	Smith et al. 1971
	Guinea pig	470	12.0H	72.0	20.7D	10.0	Gibbs et al. 1969
	Lab rabbit	~3000=	9.6H	60	12.7D	6.0	Gibbs et al. 1969

^aBiological half-life of first components (T_{b_1}) or second component (T_{b_2}) in days (D) or hours (H).

^bProportion of ingested isotope associated with the corresponding T_b .

TABLE 6. Body water half-life for ^3H

Element	Species	Weight	T_b	Reference
^3H	Lab mouse	21.4	0.1D	Richmond et al. 1962
	Lab rat	298.0	3.5D	Richmond et al. 1962
	Kangaroo rat	93.0	11.8D	Richmond et al. 1962
		~90.0	12.5D	Koranda 1969
	Lab rabbit	3,160	3.9D	Richmond et al. 1962
	Dog	10,600	5.1D	Richmond et al. 1962
Horse	399,000	8.4D	Richmond et al. 1962	

the body weight/isotope half-life curves represent only approximations, useful only when actual data are lacking.

Food-Chain Transfer

Movement of radionuclides throughout the biotic components of natural systems involves many variables such as feeding habits, seasonal changes in diet and selective feeding on tissues (Kitchings et al. 1969, Willard unpublished, Auerbach et al. 1973, Cummings et al. 1971 and Brisbin 1973). The food-chain transfers to predators from small prey species such as cotton rats differ according to feeding habits of the predators. Carnivores such as foxes, bobcats and snakes which swallow all of the prey will be exposed to the radionuclides in digestible tissues, including the nuclides available as radionuclide particles on skin and fur and in the digestive tracts of the prey. Shrews, on the other hand, mostly ingest soft tissues such as brain, heart, liver and certain muscles (i.e., those of the appendicular skeleton), but normally do not eat the intestines, bones or skin. Hawks and owls ingest most of such small prey, but indigestible parts such as hair, bone and teeth are regurgitated in pellets. Thus, it seems likely that body burdens in predators will depend greatly

on feeding habits of the predators as well as on the isotope concentrations in various tissues of the prey, including the GI-tract contents.

The niche preferences of individual species have been demonstrated to play an important role in the dissemination of radioactive materials. In a study conducted on the White Oak lake bed in 1958-1959 Willard (1960) found that song sparrows, field sparrows, water thrushes and chats, species which occupied the zone closest to the lake bed and fed close to the ground, exhibited the highest tissue levels. In contrast, radioactivity was only about 0.10 as high in goldfinches and indigo buntings, which ranged between the canopy and the understory vegetation, and only about 0.05 as high in thicket birds such as catbirds, vireos, cardinals and Kentucky warblers. Additional work done by Willard (unpublished) on ^{60}Co distribution around a waste seep demonstrated that the area affected by the transfer of this isotope from the aquatic system to the terrestrial components was limited to the stream bank (Fig. 3). The position of certain receptor organisms with regard to living and feeding habits certainly determined the amount of ^{60}Co taken up by the various components.

The preceding discussion points out that considerable diversity of radionuclide concentration in mammalian species should be expected because of the various feeding habits of individual species. Likewise, because of the chemical form of the radionuclide, gut retention time, type of food and age of the animal, radionuclide assimilation efficiency (assimilated/ingested) will not be equal for all nuclides or species (Reichle et al. 1970). The P_2 values as given in Tables 2-6 are good estimates of the percentage of ingested material assimilated by the particular species (Table 7). Under chronic contamination conditions when the organism and food-base are in isotopic equilibrium the combining of equilibrium body burden (Q_e), assimilation (a), and turnover rate (λ_b) can be used to predict the intake

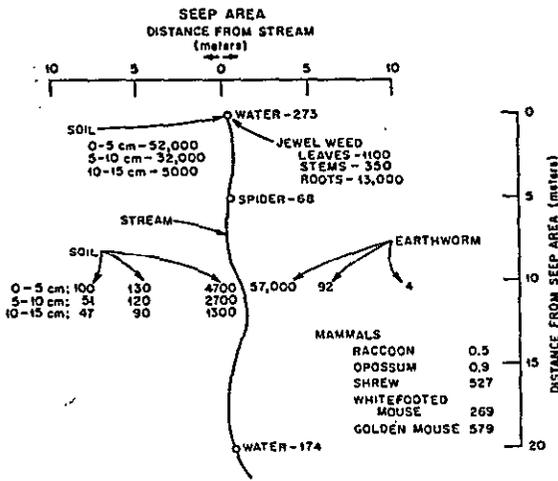


Fig. 3 Distribution of ⁶⁰Co in terrestrial organisms along a contaminated stream. Numbers are pCi/g (wet weight).

TABLE 7. Assimilation efficiencies for selected radionuclides for mammalian species

Radionuclide	Assimilation Efficiencies ^a
¹³⁴⁻¹³⁷ Cs	0.25-0.85
⁸⁵⁻⁹⁰ Sr	0.50-1.00
¹³¹ I	0.03-0.40
⁶⁰ Co	0.05-0.25
³ H	~1.00

^aap₂ values taken from Tables 2-6 (Y-intercept values calculated for the long component regression analysis for the various radionuclides).

(radionuclide unit/unit time) of the particular food-base (r)

$$r = \frac{\lambda_b Q_e}{a}$$

DISCUSSION

As pointed out by Brisbin (1973), until recently the disposal of radioactive waste materials occurred in areas where there is restricted public access and therefore very little human contact with these materials. The possibility now exists, however, that not only will radionuclides move through the nongame small mammal communities but certain species of wild game will gain access to these areas and thus

serve as potential vectors to human food chain. The information which we have gathered on bioconcentration assimilation and turnover should provide the basic data for models of potential food-chain dispersion of the major radionuclides released from nuclear facilities. Additional knowledge on radionuclide intake and assimilation coefficients for indigenous species needs to be gathered and synthesized to achieve the accuracy on food chain mobility now available for agronomic systems.

The current impact assessment activities include estimating radiation doses to humans and limited biota (muskrats and waterfowl) received from internal exposure via inhalation and ingestion and external exposure via contaminated gaseous releases (Kaye 1973). Our ultimate need is to be able to provide the data and to develop the capacity to assess the potential impacts from radionuclides and toxic elements released from all sources in the fuel cycle, i.e., nuclear power generating stations, fuel fabrication and reprocessing plants, on the wide spectrum of mammalian species inhabiting the areas affected by these discharges. Parameterization of existing food-chain transport models reflecting the nuclide transport from compartment to compartment needs to be achieved utilizing quantitative data on ecological variables, e.g., life history parameters, seasonal feeding habits, and niche preferences deemed important to the animal.

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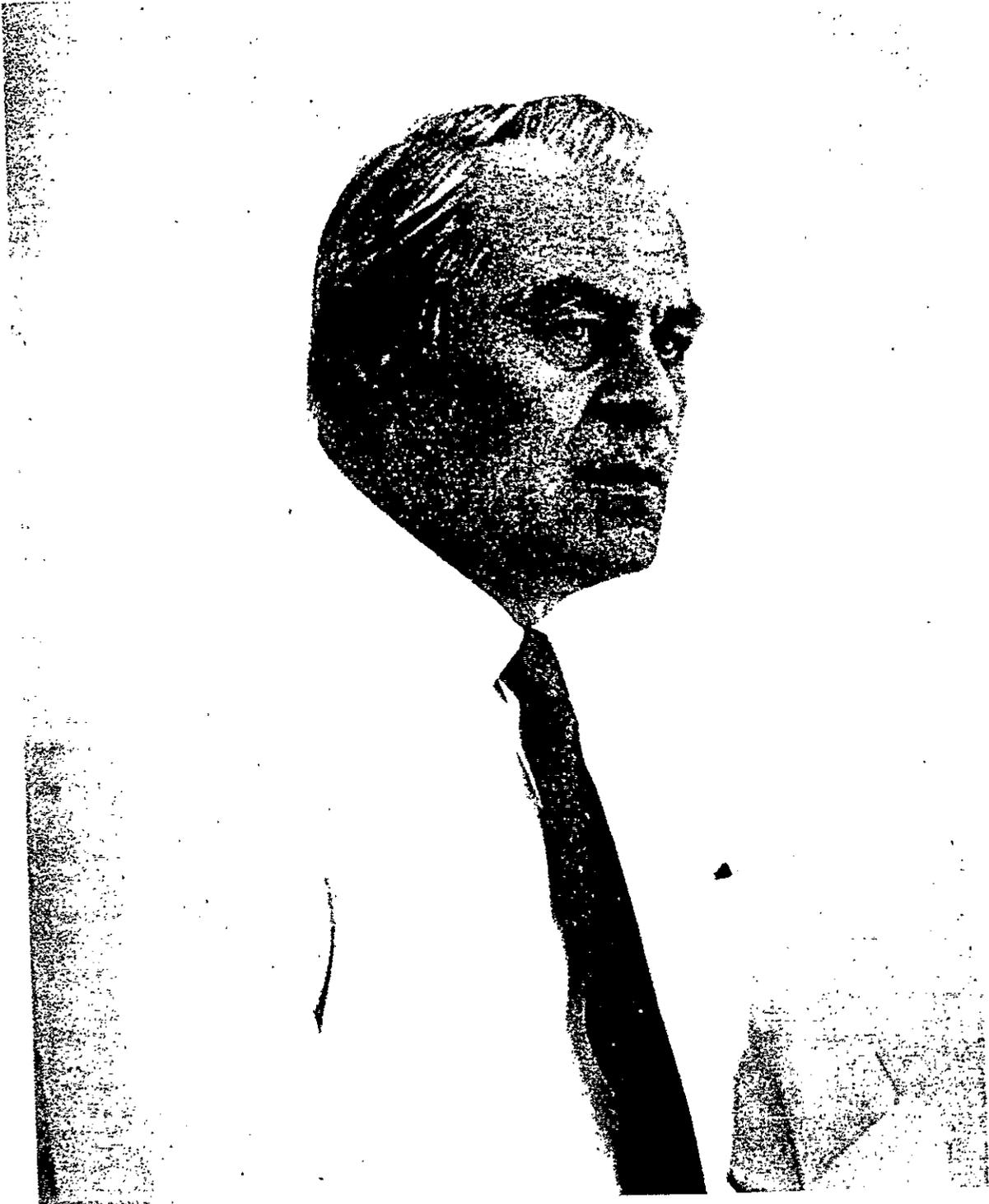
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