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Aggregated Transfer Factors for Small Mammals Collected from the Exposed Sediments of a ^{137}Cs Contaminated Reservoir

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Abstract

^{137}Cs transfer factors were computed for small mammals collected from the dried sediment areas of a partially drained, contaminated reservoir. Soil ^{137}Cs concentrations were heterogeneous on small and large spatial scales, with a geometric mean of 253.1 Bq/kg dry weight. About 50% of the variance in cotton rat *Sigmodon hispidus* tissue ^{137}Cs levels was explained by variation in soil ^{137}Cs levels. Soil to animal transfer factors (whole body dry weight) averaged 6.0 for cotton rats and 1.2 for cotton mice *Peromyscus gossypinus*. These values are similar to ^{137}Cs transfer factors for herbivorous, homeothermic animals from other contaminated ecosystems. Site-specific transfer factors can significantly affect the estimation of dose. In the RESRAD-BIOTA dose model, the default transfer factor for ^{137}CS in terrestrial animals is 110 resulting in an estimate of radiation dose to terrestrial biota that is 16 times more than the dose calculated with the actual measured transfer factor.

Keywords: Radionuclides; Transfer Factors; Bio-concentration; Biota Dose

1. Introduction

There is a growing interest in methods for the protection of non-human species and the environment from the effects of radiation (Strand et al. 2000, Pentreath and Woodhead 2001). These methods necessitate the estimation of radiation doses to biota. Radiation doses are strongly dependent upon internal concentrations of radioactive materials, which can be predicted from ratios termed transfer factors that relate internal concentrations to concentrations in the surrounding media (Beresford et al. 2004). Transfer factors (also called concentration ratios, uptake factors, bioconcentration factors, and lumped parameters) subsume a number of behavioral, physiological, chemical, and ecological factors that determine the bioavailability of radionuclides to biota. They have been developed for many types of plants and soils (Frissel et al. 2002) and for aquatic organisms and water (Blaylock 1982, Rowan and Rasmussen 1994) but are not widely available for non-domestic terrestrial animals. Although transfer factors can be derived through biokinetic modeling (DOE 2002), such methods may be subject to greater uncertainty than empirically derived values computed from measurements of radionuclide activity in animals and soil from contaminated environments. Empirical measures, in turn, are subject to site specificity resulting from geographically influenced factors including food web structure, climate, and soil type (Frissel et al. 2002). Most transfer factors for non-domestic terrestrial animals are based on data from northern ecosystems and are for Cs^{137} (Beresford et al. 2004), one of the most commonly occurring and biologically significant radionuclides.

The Savannah River Site (SRS), an 800 km^2 Department of Energy reservation on the upper coastal plain of South Carolina has a warm-temperate climate and sandy,

acidic, soils with low nutrient levels. These factors, which can strongly affect the food chain transfer of radionuclides from soil to animals (Seel et al. 1995), are substantially different from those at higher latitudes. An opportunity to compute soil to animal transfer factors on the SRS occurred when a contaminated reservoir was partially drained and its sediments colonized by terrestrial vegetation and small mammals during the four years they were exposed. Soil and small mammal samples were systematically collected from various locations on the exposed lake bed and analyzed for ^{137}Cs and other radionuclides permitting a detailed characterization of the spatial distribution of soil contamination and the relationship between soil contamination and contaminant levels in animals. The objectives of this study were 1) to characterize radionuclide concentrations and distributions in the exposed sediments and small mammals on the former lake bed, and 2) determine the relationship between soil and small mammal radionuclide levels.

2. Materials and methods

2.1. Study site

PAR Pond is a 1012 hectare reservoir on SRS that was contaminated with radionuclides released mainly from 1958 to 1964. The water level of PAR Pond was artificially maintained at 61 m above mean sea level (msl) until 1991 when it was reduced to 55 m above msl because of a defect in the PAR Pond dam. This resulted in the exposure of contaminated sediments that were rapidly colonized by vegetation, small mammals, and other terrestrial organisms. The sediments were sandy (mean 89%), acidic (mean pH=4.0), and low in clay (mean 5%), organic matter (mean 1.5%), and potassium (mean 20 ug/g) (see Seel et al. 1995 for more details). Sediment and small mammal

samples from PAR Pond were analyzed for a number of radionuclides, metals, and organic contaminants. Results showed that ^{137}Cs was the major radioactive constituent and one of the few constituents consistently elevated compared with background levels (Paller and Wike 1996). The defect in the dam was repaired and PAR Pond was refilled to its previous level in 1995.

2.2. Field Methods

Field work was conducted between January and March 1995. At the start of the sampling period, the surface elevation of PAR Pond was approximately 58 m above msl, approximately 3 m higher than the lowest level reached during drawdown and 3 m lower than full pool.

Soil samples and small mammals were collected from 15 sites on the exposed sediments of PAR Pond and from two reference sites. Sample sites were randomly selected from within each of four major arms of PAR Pond to ensure coverage of the entire lake and avoided bias associated with subjective selection of sample sites. The 15 sample sites were apportioned among the four arms on the basis of the total length of shoreline in each arm. The two reference sites located several km from PAR Pond were uncontaminated except by fallout from airborne releases.

Two 100-m transects were established running approximately parallel to the original shoreline at each site. The lower transect was located near the water line at the time of sampling and the upper transect was located near the old full pool water line. The upper and lower transects were usually offset to maximize spatial separation and independence. Similar transects were established at each of the control sites except they

were at the same elevation and longer (250 m) to collect sufficient numbers of small mammals, which were less abundant at the reference sites.

Soil samples to a depth of 10-15 cm were collected at five evenly spaced locations along each transect. This depth corresponded to the main root zone of most of the herbaceous plants that colonized the PAR Pond sediments after the drawdown. A spade with a blade wrapped with polyethylene was used to collect each sample. The plastic was discarded and replaced after each sample to prevent inter-sample contamination. Each soil sample was homogenized, transferred to appropriately labeled jars, and placed on ice for shipment to an analytical laboratory.

Small mammals were collected from PAR Pond and the control sites with trap lines that corresponded to the soil sampling transects. Two baited Victor snap traps and one baited Sherman live trap were set at each trapping point for a total of 30 traps along each transect. Trapped animals were identified to species; placed in labeled plastic bags; and conveyed to the laboratory where they were sacrificed, weighed, and frozen. Two species, the cotton rat *Sigmodon hispidus* and cotton mouse *Peromyscus gossypinus*, were collected in sufficient numbers for analysis.

Descriptive information about each site included Munsell soil color of each soil sample, a general site description emphasizing floristic composition, and Global Positioning System coordinates corresponding to the beginning and end points of each transect.

2.3. Laboratory methods

To prepare small mammal tissue for radiological analysis, sufficient numbers of individuals (three or more) from each species at each transect were composited to attain a

minimum sample mass of 300 g and homogenized in a blender to produce whole-body composite samples. In addition to these transect samples, cotton rats from five transects that produced large numbers of specimens were dissected to separate the skin, gastrointestinal tract (GIT), and corpus (i.e., the rest of the body) and homogenized to produce a composite sample for each tissue type.

The soil and tissue samples were analyzed directly for gamma-emitting radionuclides using a high-purity germanium detector. The radioanalyses were performed by a subcontracted laboratory (General Engineering Laboratories, Inc.) following standard gamma spectroscopy procedures (DOE 1997). The reported nominal minimum detection limit was 0.01 pCi/g (0.37 Bq/kg) for ^{137}Cs. All results are reported as dry weight.

2.4. Data analysis

Soil ^{137}Cs concentrations are presented as geometric means (calculated by back transforming the average value of the $\log_{10}$ transformed data) because they were lognormally distributed. Confidence intervals for geometric means were calculated as shown in Sokal and Rohlf (1995). Values below detection limits were assumed to be one half the detection limit following US Environmental Protection Agency (EPA) guidance (Gilbert 1987).

Differences in soil ^{137}Cs levels among elevations (i.e., transects), sample sites and lake arms were assessed with a mixed model analysis of variance (ANOVA). Lake arm and elevation were fixed effects, and sample site was a random effect nested within lake arms. Variance component estimates for random effects were calculated as shown in

Sokal and Rohlf (1995). Data were $\log_{10}$ transformed to better meet the assumptions of ANOVA for homoscedascity and normality.

Differences in ^{137}Cs concentrations among different soil types were tested with a one-way factorial ANOVA. Three basic soil types (clay, organic, sand) were identified based on field observations and Munsell soil color. Soil samples were assigned to each category based on the predominant component.

Species specific transfer factors from soil to small mammal tissues were calculated for each sample site by dividing the ^{137}Cs concentration in the composited tissue sample from the transect (which was equivalent to an average) by the geometric mean ^{137}Cs concentration in the soil samples from the transect (both values expressed as dry weight). The average ^{137}Cs concentration in the composited tissue samples was used as the numerator in the few cases where two composite tissue samples for the same species were collected from a transect. The relationship between soil and small mammal tissue ^{137}Cs levels was also investigated by regressing small mammal tissue ^{137}Cs concentrations on geometric mean soil ^{137}Cs concentrations at each sample site.

3. Results

Soil concentration data were characterized by a preponderance of comparatively small values with a few large ones (Figure 1), a pattern characteristic of lognormal distributions (Chi square goodness of fit to a lognormal model was 15.03, P=0.240). The geometric mean soil ^{137}Cs concentration at the control sites was 10.4 Bq/kg (95%CI=7.8-13.8) compared with 253.1 Bq/kg (95% CI=215.8-296.8) at the PAR Pond sample sites. The mixed model ANOVA of the PAR Pond soil data (excluding the control sites)

indicated that log transformed soil ^{137}Cs concentrations significantly differed ($p \leq 0.05$) among sample sites but not lake arms (Table 1). Soil ^{137}Cs concentrations were usually higher at the lower transect (geometric mean =355.8) than the upper transect (geometric mean =180.0), but a significant interaction between sample site and transect showed this difference was inconsistent among sample sites. The greatest proportion of the random variation in the ANOVA model was among sample replicates (68.6%), reflecting large differences in ^{137}Cs concentrations at a comparatively small spatial scale (individual replicates were about 20 m apart). However, the proportion of random variance associated with sample sites within lake arms was substantial (31.4%) reflecting variability at large spatial scales as well (average distance between PAR Pond sample sites was 1.5 km).

Factorial ANOVA indicated that ^{137}Cs concentrations differed significantly among the three identified soil categories ($P<0.001$). The highest ^{137}Cs concentrations occurred in sediments that were primarily organic (geometric mean of 396.7 Bq/kg), followed by sediments that were predominantly sand (216.7 Bq/kg), and sediments that were predominantly clay (68.9 Bq/kg).

Cotton rats were collected in sufficient numbers for analysis from 18 transects in PAR Pond (out of 30 possible) and both control transects. Failure to collect sufficient numbers of animals from the other locations was probably the result of poor habitat. A Kolmogorov-Smirnov test indicated that ^{137}Cs concentrations in the cotton rat samples from Par Pond did not deviate significantly from a normal distribution. This finding differs from the highly non-normal distribution reported for ^{137}Cs in mice and voles collected from the Chernobyl exclusion zone (Taras et al. 2002), probably because the

PAR Pond samples were composited and the Chernobyl samples were from individual animals. Composited samples represent averages, which are often normally distributed, even if the underlying data from which they are derived are not (Sokal and Rohlf 1995).

The average ^{137}Cs concentration in the tissues of composite cotton rat samples collected from the control sites was 14.2 Bq/kg dry weight compared with 2626.5 Bq/kg dry weight (95% CI=1897.9-3355.2) in the tissues of cotton rat samples collected from PAR Pond (Figure 1). Assuming a mean cotton rat weight of 125 g, the average PAR Pond cotton rat whole body burden was 328.3 Bq of ^{137}Cs. Variability among cotton rat samples from PAR Pond was high as indicated by a coefficient of variation (CV=mean/SD) of 65.7%. Analysis of cotton rat skin, corpus, and gastrointestinal tract samples indicated ^{137}Cs concentrations of 180.2, 2000.0, and 3667.0 Bq/kg, respectively.

Soil to cotton rat aggregate transfer factors ranged from 0.0 to 58.8 (Table 2). However, the maximum value of 58.8 was atypical since the next highest value was 16.2. The average transfer factor was 8.6 (95% CI =2.7-14.6) if 58.8 is included and 6.0 (95% CI =3.8-8.2) if it is excluded. ^{137}Cs concentrations in composited cotton rat tissue samples were significantly (P=0.004) related to the geometric mean soil concentrations at each transect (Figure 2, the outlier site, “P3 upper” (Table 2), was excluded from this analysis). The y-intercept for this relationship did not differ significantly from zero (P=0.433) indicating that the slope of the regression line constituted an appropriate estimate of the soil to cotton rat ^{137}Cs transfer factor. This value (4.6, 95% CI=1.7-7.5) was similar to the average transfer (6.0) factor computed by averaging the individual transfer factors (Table 2).

The regression of cotton rat ^{137}Cs levels on soils ^{137}Cs levels from each transect produced a comparatively low R^2 (0.39). However, the two transects at each site were closely spaced compared with the home range of cotton rats (<0.5 hectare, Fleharty 1972) suggesting that cotton rats may have foraged over an area that included both transects at a sample site. If so, the relationship between average cotton rat tissue concentrations and average soil concentrations should be stronger on a sample site scale (which included both transects) than a transect scale. This hypothesis was supported by a regression of average ^{137}Cs concentrations in cotton rats on average ^{137}Cs concentrations in soil at each sample site, which produced a R^2 of 0.50.

Cotton mice were collected in sufficient numbers to produce composite samples for analysis from six transects in PAR Pond and one control transect. The ^{137}Cs concentration in cotton mice from the control site was 29.6 Bq/kg compared with an average of 470.9 (95% CI=115.8-826.0) Bq/kg in cotton mice from the PAR Pond sites (Table 2). Transfer factors for cotton mice ranged from 0.2-17.5 (Table 2), although 17.5 was an outlier since the next highest value was 3.3. The average soil to animal transfer factor for cotton mice was 3.6 (95% CI =-2.2-9.3) if 17.5 is included and 1.2 (95% CI =0.1-2.4) if it is excluded. The average ^{137}Cs concentration in cotton rats collected from the same PAR Pond sites as the cotton mice was 2198 Bq/kg compared with 471 Bq/kg reflecting somewhat greater bioaccumulation of ^{137}Cs in the cotton rats.

4.0 Discussion

Higher levels of ^{137}Cs in the GIT (which included GIT contents) than in the skin and corpus suggested that PAR Pond cotton rats became contaminated from their diet.

Our limited examination of cotton rat GIT contents revealed only plant material, which agrees with the findings of more extensive studies showing that cotton rats primarily consume the stems, shoots, and leaves of grasses and sedges (Golley 1962, Randolph et al. 1991). Although ^{137}Cs levels in potential cotton rat forage were not measured in our study, Whicker et al. (1993) reported a mean ^{137}Cs concentration of 2300 Bq/kg dry weight in native plants growing on the PAR Pond lake bed, a value generally similar to the 2627 Bq/kg observed in cotton rats. These numbers suggest a little over a 1:1 plant to whole animal transfer factor, which is generally similar to the plant to muscle transfer factors reported by Rosen et al. 1995 for lambs and Pedersen et al. 1998 for ptarmigan in Chernobyl fallout areas (if their estimates are converted to dry weight).

Cs^{137} concentrations in PAR Pond cotton rats were likely in equilibrium with ambient Cs^{137} concentrations since habitat conditions were generally stable prior to sampling and cotton rats are relatively sedentary (Fleharty 1972). Garten (1979) reported that cotton rats continually exposed to ^{137}Cs in contaminated food attain equilibrium body burdens after five biological half-lives of about 8.4 days each. He also reported that ^{137}Cs concentrations in cotton rats inhabiting the bank of a radioactive liquid waste pond varied by a factor of about 100 on a seasonal basis. He attributed this variability to a seasonal change from foraging in a relatively narrow band of contaminated vegetation growing along the shoreline to foraging in uncontaminated areas farther from the shoreline. Temporal variations in ^{137}Cs concentrations in PAR Pond cotton rats are unknown but are unlikely to have been as great as observed by Garten (1979). The exposed PAR Pond lake bed was large (1012 hectares) in relation to the home range of cotton rats (0.5 hectares or less, Fleharty 1972), and it is unlikely that most cotton rats from the study

sites had access to uncontaminated vegetation. However, temporal variations could also arise from seasonal dietary changes to plants with different ^{137}Cs concentrations as observed by Johanson et al. (1994) in moose from Sweden.

Cotton rats from different locations in PAR Pond exhibited large variations in ^{137}Cs concentration (Table 2). This result agrees with the findings of Chesser et al. (2000) who observed large variations in ^{137}Cs levels among small mammals collected from as little as 100m apart in the Chernobyl exclusion zone. Although many factors can contribute to such differences (e.g., diet, physiological state, movement patterns), this was at least partly attributable to variations in the ^{137}Cs concentration in PAR Pond soils (and subsequently in plants) as indicated by a significant relationship between ^{137}Cs concentrations in soil and cotton rats (Figure 2). Variations in ^{137}Cs soil concentrations likely resulted from several factors including the differential association of ^{137}Cs with certain soil types and the heterogeneous distribution of these soils. This heterogeneity was conspicuous on a scale of several meters as a result of erosion following the drawdown and possibly biological and physical processes operating when the reservoir was full. Spatial heterogeneity on the larger spatial scales represented by the sample site and transect was also significant. The higher soil ^{137}Cs concentrations usually occurring at the lower transect may reflect original patterns of deposition or the erosion and downslope transport of contaminated sediments following the reservoir drawdown. Heterogeneity on the sample site scale is harder to explain since it did not correspond with the original flow path followed by the contaminated discharge (Halverson et al. 1997). It may have been caused by processes of redistribution when the reservoir was operating or erosion and redeposition following drawdown.

The mean whole body ^{137}Cs concentration in PAR Pond cotton rats of 2467 Bq/kg can be compared with ^{137}Cs concentrations in rodents from other contaminated environments. It exceeds the approximately 0 - 16 Bg/kg ^{137}Cs observed in the muscle tissue of rodents from fallout areas in Nevada and Utah in the years following nuclear testing (Romney et al. 1983) but, when converted to a whole body burden of 309 Bq, is less than the 1647 Bq whole body burden in cotton rats that inhabited the banks of a radioactive waste pond in Oak Ridge Tennessee (Garten 1979). All of these values are but a small fraction of the 3200000 Bq/kg of $^{134, 137}Cs$ in small mammals (primarily rodents) residing in the Chernobyl exclusion zone approximately a decade after the Chernobyl accident (Chesser et al. 2000). In spite of these high levels, Chesser et al. (2000) observed seemingly normal populations of small mammals in the Chernobyl exclusion zone as did Baker et al. (1996),who concluded that the diversity and abundance of small mammals at the most radioactive sites near Chernobyl were not reduced. These results suggest that PAR Pond cotton rats were unlikely to have been noticeably affected by the much lower ^{137}Cs levels they were exposed to.

Aggregated transfer factors for ^{137}Cs in the exposed lake bed of PAR Pond, a warm-temperate ecosystem with sandy, low nutrient soils averaged 6.0 for cotton rats and 1.4 for cotton mice. The relatively small difference between the two species could be related to diet or physiology. These value are comparable to the ^{137}Cs aggregated transfer factor of 4 for voles (*Microtus*) and lemmings (*Lemmus*) reported for Arctic ecosytems (Hosseini et al. 2005) and generally similar to the average transfer factor of 1.6 for white tailed deer (*Odocoileus virginianus*) at SRS (Friday et. al. 1996). However, an

aggregated transfer factor of 0.3 for ^{137}Cs in kangaroo rats in Nevada and Utah was substantially lower (calculated from data in Romney et al. 1983).

Aggregated transfer factors can also be expressed on an areal basis as shown in Rosén (1996) where the transfer factor (in m^2/kg) is equal to the ^{137}Cs activity in dry sample matter divided by the ^{137}Cs deposited on ground. PAR Pond transfer factors can be recomputed as areal estimates by calculating the quantity of ^{137}Cs per m^2 assuming an average ^{137}Cs soil concentration of 253.1 bq/kg, ^{137}Cs penetration depth of 15 cm, and a soil bulk density of 1.6 g/cm3. Connor et al. (1997) reported that over 90% of the ^{137}Cs in PAR Pond soils was in the 0-15 cm depth range. On this basis the aggregated transfer factor for PAR Pond cotton rats (whole body) was 0.04 m^2/kg. This value is generally similar to transfer factors reported for ptarmigan (*Lagopus lagopus and L. mutus*) in Norway, 0.01-0.03 m^2/kg (Pedersen et al. 1998), and moose in Sweeden, 0.05 m^2/kg (Johanson et at. 1994) exposed to fallout from Chernobyl. Values for ptarmigan and moose were converted from wet weight estimates in the original papers and represent muscle tissue rather than whole body estimates. In general, transfer factors for small mammals from the exposed lake bed of PAR Pond were surprisingly similar to transfer factors for largely herbivorous, homeothermic animals from a variety of other ecosystems, although additional studies are needed before such factors can be accepted as generic for small mammals from other moderately contaminated ecosystems.

Soil to organism transfer factors are comparatively scarce for wild animals, despite the need for such data to model the movement of radionuclides through ecosystems and determine dosages to human and ecological receptors. The most important parameter in the modeling of terrestrial biota dose is the estimation of internal

tissue concentrations resulting from the movement of radionuclides through the ecosystem. Empirically derived transfer factors that directly relate radionuclide concentrations in soil to concentrations in biota provide the dose assessor with the least uncertain estimation of tissue concentrations. In the RESRAD-BIOTA dose model (DOE 2002), the default soil-to-animal transfer factor for cesium in terrestrial animals is 110. Using this default transfer factor and the ^{137}Cs geometric mean soil concentration (253.1 Bq/kg) measured in the PAR Pond dried sediment, the dose to a terrestrial animal is estimated to be 0.00032 Gy/d. The average transfer factor reported here for cotton rats on the dried lake bed of PAR Pond was 6.0, which is a factor of 18.3 less than the default value. Using this site-specific transfer factor and the same ^{137}Cs soil concentration of 253.1 Bq/kg, the dose to a terrestrial animal is reduced by a factor of 16 and is estimated to be 0.00002 Gy/d (because of the constant dose from external exposure to soil, the reduction in total dose is not direct). These results show that the use of measured, site-specific soil to animal transfer factors can have a significant impact on biota dose estimates.

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Figure 1. Frequency distributions of ^{137} concentrations in exposed sediments and cotton rats collected from PAR Pond.

Figure 2. Relationship between ^{137}Cs levels in exposed sediments and cotton rat tissue.

Table 1. Analysis of variance of ^{137}Cs concentrations in the exposed sediments of PAR Pond between the elevations of 58 and 61 m above mean sea level.

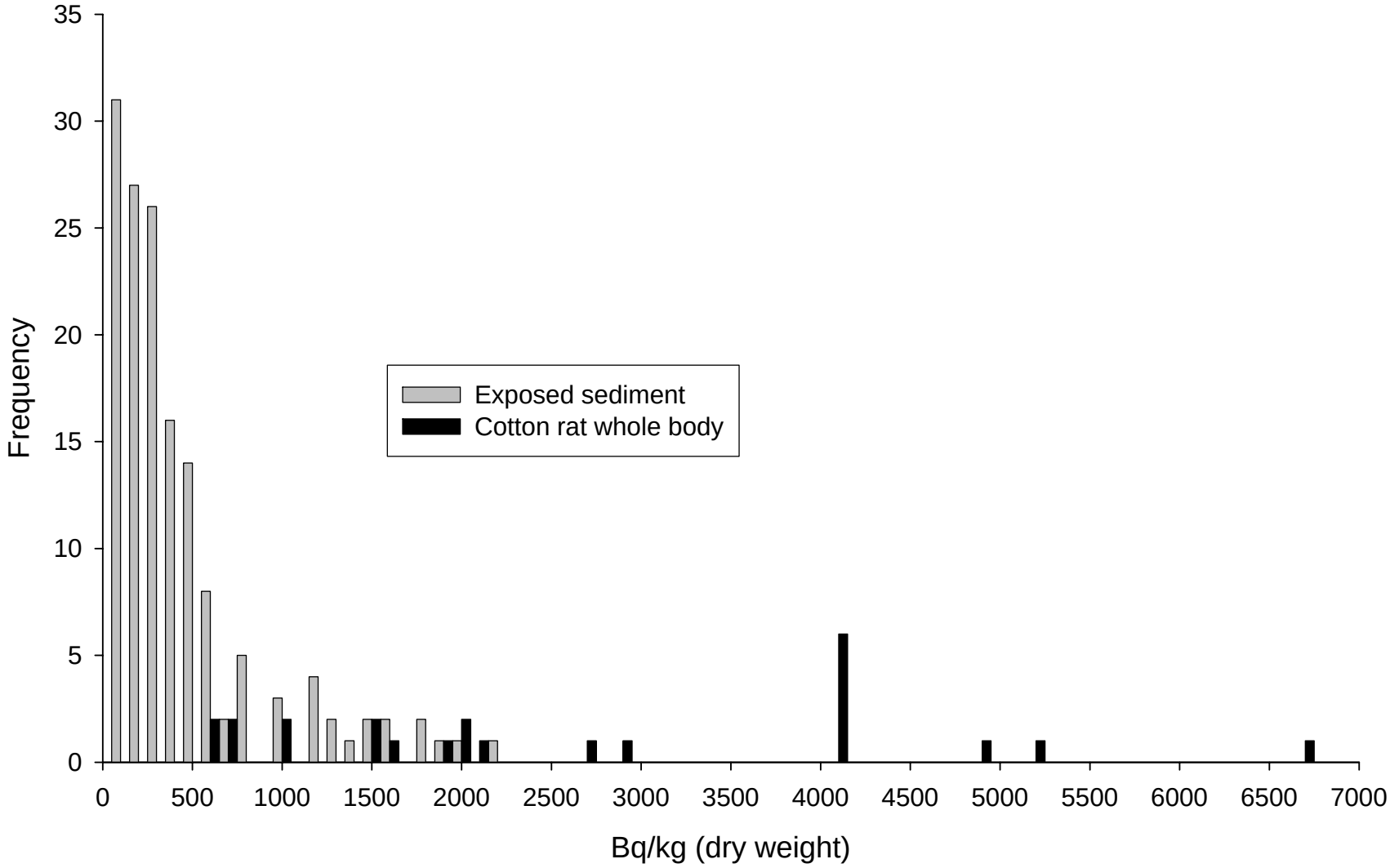
Source of variation	df	Mean square	F ratio	P	Variance component (%)[a]
Lake arm	3	174390	0.55	0.657	
Elevation	1	2 772152	4.82	0.051	
Elevation x lake arm interaction	3	496830	0.86	0.489	
Sites within lake arms	11	315912	2.55	0.006	31.4
Elevation x site within lake arm interaction	11	575663	4.64	<0.001	
Error (variation among replicates)	118	124032			68.6

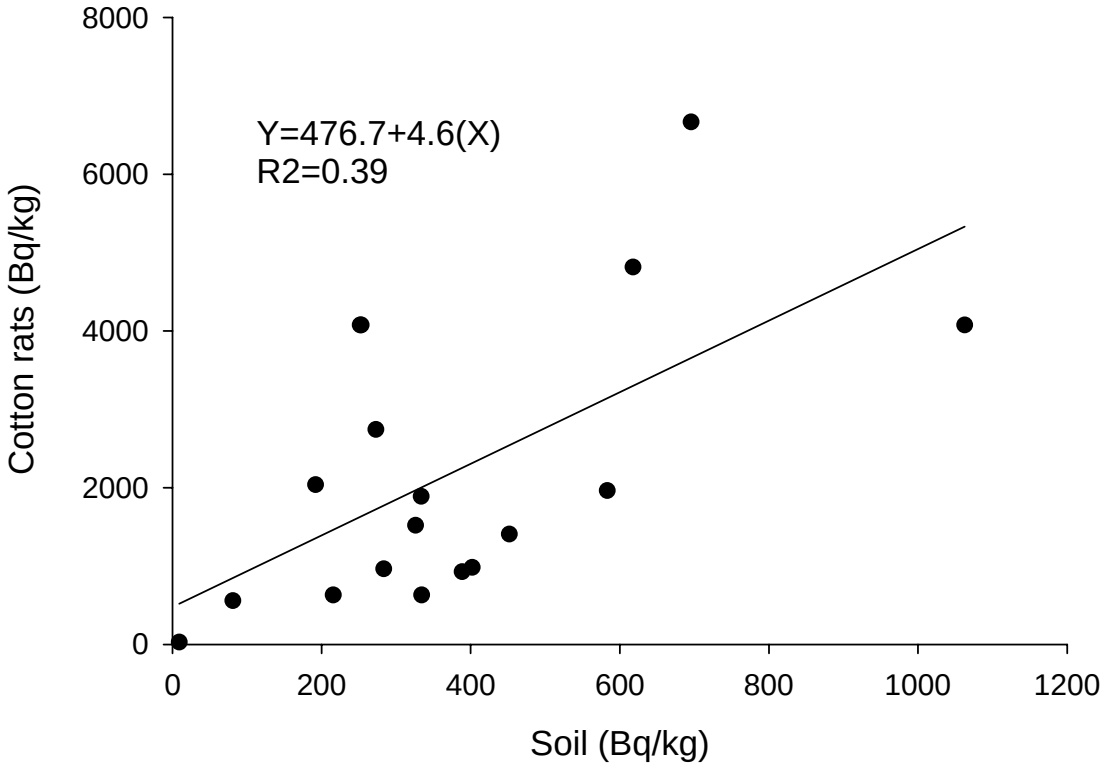
[a] Expressed as a percentage of the random variation in the model

Table 2. ^{137}Cs levels in soil and cotton rat tissues collected from control sites and PAR Pond (PP)

Sample site no.	Location	Elevation	Soil ^{137}Cs (Bq/kg)[a]	Cotton rat ^{137}Cs (Bq/kg)[b]	Cotton rat transfer factor	Cotton mouse ^{137}Cs (Bq/kg)[b]	Cotton mouse transfer factor
C1	Control site		12.0	-0.4	0	29.6	3.3
C2	Control site		9.0	28.9	3.2		
P1	PP cold arm	lower	207.3				
P1	PP cold arm	upper	57.0			1000.0	17.5
P2	PP north arm	lower	442.3				
P2	PP north arm	upper	63.9				
P3	PP north arm	lower	583.2	1963.0	3.4	481.5	0.8
P3	PP north arm	upper	78.8	4629.6	58.8		
P4	PP north arm	lower	334.3	629.6	1.9		
P4	PP north arm	upper	272.9	2740.7	10.0		
P5	PP north arm	lower	251.8	4074.1	16.2		
P5	PP north arm	upper	695.7	6666.7	9.6	963.0	1.4
P6	PP north arm	lower	178.7				
P6	PP north arm	upper	843.7				
P7	PP north arm	lower	326.1	1518.5	4.7		
P7	PP north arm	upper	253.0	4074.1	16.1		
P8	PP north arm	lower	617.6	4814.8	7.8		
P8	PP north arm	upper	128.8				
P9	PP hot arm	lower	388.4	925.9	2.4	407.4	1.0
P9	PP hot arm	upper	87.7				
P10	PP hot arm	lower	1062.6	4074.1	3.8		
P10	PP hot arm	upper	90.6				
P11	PP cold arm	lower	576.0			318.5	0.6
P11	PP cold arm	upper	280.6				
P12	PP intake arm	lower	402.0	981.5	2.4		
P12	PP intake arm	upper	283.4	963.0	3.4		
P13	PP intake arm	lower	81.0	555.6	6.9		
P13	PP intake arm	upper	215.7	629.6	2.9		
P14	PP intake arm	lower	333.4	1888.9	5.7		
P14	PP intake arm	upper	191.8	2037.0	10.6		
P15	PP intake arm	lower	451.7	1407.4	3.1	96.3	0.2
P15	PP intake arm	upper	170.6				

[a] Each value represents a geometric mean (dry weight)
[b] Each value represents a composite of at least three animals (whole body dry weight)


35
30
25
20
15
10
5
0
Frequency
Exposed sediment
Cotton rat whole body
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
Bq/kg (dry weight)


Y=476.7+4.6(X)
R2=0.39
Cotton rats (Bq/kg)
Soil (Bq/kg)
0
2000
4000
6000
8000
0
200
400
600
800
1000
1200