Journal of Environmental Radioactivity 153 (2016) 231–236

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad

The transfer of ^{137}Cs, Pu isotopes and ^{90}Sr to bird, bat and ground-dwelling small mammal species within the Chernobyl exclusion zone

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ARTICLE INFO

Article history:
Received 17 October 2015
Received in revised form
29 December 2015
Accepted 30 December 2015
Available online 22 January 2016

Keywords:
Plutonium
Strontium
Caesium
Chiroptera
Concentration ratio

ABSTRACT

Protected species are the focus of many radiological environmental assessments. However, the lack of radioecological data for many protected species presents a significant international challenge. Furthermore, there are legislative restrictions on destructive sampling of protected species to obtain such data. Where data are not available, extrapolations are often made from ‘similar’ species but there has been little attempt to validate this approach.

In this paper we present what, to our knowledge, is the first study purposefully designed to test the hypothesis that radioecological data for unprotected species can be used to estimate conservative radioecolgical parameters for protected species; conservatism being necessary to ensure that there is no significant impact.

The study was conducted in the Chernobyl Exclusion Zone. Consequently, we are able to present data for Pu isotopes in terrestrial wildlife. There has been limited research on Pu transfer to terrestrial wildlife which contrasts with the need to assess radiation exposure of wildlife to Pu isotopes around many nuclear facilities internationally.

Our results provide overall support for the hypothesis that data for unprotected species can be used to adequately assess the impacts for ionising radiation on protected species. This is demonstrated for a range of mammalian and avian species. However, we identify one case, the shrew, for which data from other ground-dwelling small mammals would not lead to an appropriately conservative assessment of radiation impact. This indicates the need to further test our hypothesis across a range of species and ecosystems, and/or ensure adequate conservatism within assessments.

The data presented are of value to those trying to more accurately estimate the radiation dose to wildlife in the Chernobyl Exclusion Zone, helping to reduce the considerable uncertainty in studies reporting dose-effect relationships for wildlife.

A video abstract for this paper is available from: http://bit.ly/1JesKPc.

1. Introduction

A necessary component of the tools (e.g. Brown et al., 2008; Copplestone et al., 2001, 2003; USDoE, 2002) now established to estimate the exposure of wildlife to ionising radiations is an ability to predict wholebody activity concentrations of radionuclides in a wide range of biota. Although there are alternative approaches to predict transfer to wildlife in development, such as the use of taxonomic relationships (e.g. Beresford et al., 2013, 2015), most of the available tools use concentration ratios ($CR_{wo\text{-}media}$) relating the activity concentrations in plants and animals to those in the appropriate environmental media (soil, air or water) (Beresford et al., 2008a). Whilst databases of $CR_{wo\text{-}media}$ values for wild species have been collated (e.g. Beresford et al., 2008b; Copplestone et al., 2013; Hosseini et al., 2008; Howard et al., 2013; Yankovich et al., 2013), data for many radionuclide-organism combinations are sparse or not available. Where data are unavailable, assumptions such as applying data for a ‘similar organism’ (e.g. mammal data for birds) are often made to provide default $CR_{wo\text{-}media}$ values

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http://dx.doi.org/10.1016/j.jenvrad.2015.12.027

for use in dose assessment tools (Beresford et al., 2008b; Brown et al., 2013).

Protected species are the focus of many assessments (e.g. Copplestone et al., 2005; Wood et al., 2008). For many protected species, transfer data are lacking and there are legislative restrictions on destructive sampling to obtain data (Wood et al., 2011). For some protected species, there are very few data for the overall taxonomic group appropriate to that species. A good example of this is chiroptera (bats), all species of which are protected in the European Union (HMSO, 1994). For some radionuclides there are many $CR_{wo\text{-}soil}$ data for other animals within the class mammalia and the extent to which these data are applicable to bats needs to be established. Similarly, at many ecologically important sites requiring assessment (e.g. Natura 2000 sites), the most prevalent protected organisms are aves (bird) species (Copplestone et al., 2003). However, there are very few $CR_{wo\text{-}media}$ values for birds (e.g. ICRP, 2009).

Previously, we have published data on the transfer of ^{137}Cs and ^{90}Sr to a range of bat species sampled from a variety of sites within the Chernobyl Exclusion Zone (CEZ) (Gaschak et al., 2010). The CEZ, which is the area established around the Chernobyl nuclear complex following the 1986 accident, is increasingly viewed as a natural laboratory, and more recently as a radioecological observatory (https://wiki.ceh.ac.uk/x/NoFsD). It provides an opportunity to study the transfer of radionuclides to different species of wildlife across different taxonomic groups (e.g. Beresford et al., 2005). In this paper we present a study where species of birds, bats and ground-dwelling small mammals were sampled from a site within the CEZ and analysed for ^{137}Cs, Pu isotopes and ^{90}Sr. To our knowledge, this is the first study purposefully designed to test the hypothesis that radioecological modelling parameters derived from the sampling and analysis of unprotected species (i.e. ground-dwelling small mammals) result in a conservative dose assessment for protected species inhabiting the same site. The paper also makes an important contribution to the available database of Pu isotope data for terrestrial wildlife, few studies having been published previously (e.g. Johansen et al., 2014, 2015).

2. Materials and methods

2.1. Study sites

In Beresford et al. (2008c) we report a study to determine the exposure of small mammal species at three forest sites within the CEZ conducted during the summer of 2005. The sites were initially selected to have a range in radionuclide activity concentrations; animal samples from each site were collected within a 100 × 100 m area. In the present study, samples have been collected from one of these sites (termed the '*Medium* site' in Beresford et al., 2008c).

The *Medium* site was approximately 8 km to the west of the Chernobyl power plant complex. The woodland at the *Medium* site consisted mainly of *Pinus sylvestris* (Scots pine) and *Quercus robur* (Oak), with some *Sorbus aucuparia* (Rowan) and *Tilia platyphyllos* (Large leaved lime). The sparse understorey vegetation included *Pteridium aquilinum* (Bracken). The site had soddy pseudopodzolic sandy and boggy soils on modern alluvial deposits.

Beresford et al. (2008c) describes the collection and analyses of soils (n = 23) from the *Medium* site; soils were collected from an area extended to 50 m beyond the animal sampling area to encompass the likely home ranges of the animal species being trapped (i.e. soils were collected from an area of 200 m × 200 m or 40000 m^2). Soil activity concentrations were reported in Beresford et al. (2008c) as: 43.3 ± 25.7, 0.83 ± 1.49, 18.6 ± 14.9 kBq kg^{-1} dry mass for ^{137}Cs, ^{238,239,240}Pu and ^{90}Sr respectively. Whilst variable, there was no spatial pattern in soil activity concentrations across the sampling site.

2.2. Biota samples

2.2.1. Bird samples

A range of passerine species were collected by mist net at the *Medium* site during June 2005, euthanised and retained frozen. Species, sample numbers and information on feeding and home range are presented in Table 1.

2.2.2. Bat samples

Three species of bats were collected from the site during the period May–June 2008 using mist nets (Table 1). After being euthanised the samples were stored frozen whilst awaiting analyses.

2.2.3. Ground-dwelling small mammals

In Beresford et al., 2008c, live-monitoring (see approach of Bondarkov et al. (2011) outlined below) results for ^{90}Sr and ^{137}Cs in *Apodemus flavicollis*, *Myodes glareolus* and *Microtus* spp. are

Table 1
Species samples at the study site in the Chernobyl Exclusion Zone.

Species	n	Approximate home range (m^2)	Diet
Birds			
Erithacus rubecula	7	6000 m^2	Ground & flying invertebrates, some fruit
Ficedula albicollis	1	6000 m^2	Flying & ground invertebrates
Ficedula hypoleuca	3	<3000 m^2	Flying & ground invertebrates, some fruit
Fringilla coelebs	4	7000 m^2	Seeds, insects (especially caterpillars)
Parus major	2	<20000 m^2	Insects (especially caterpillars)
Sylvia atricapilla	2	11000 m^2	Flying & ground invertebrates
Turdus merula	2	Minimum 2000 m^2	Ground invertebrates, some fruit
Bats			
Nyctalus leisleri	4	Travel up to 13 km from roosts to foraging sites	Flying insects
Pipistrellus pipistrellus	3	May travel up to 5.1 km from roosts	Flying insects
Plecotus auritus	3	Forage close to the roost (usually within 1.5 km)	Flying insects
Ground-dwelling small mammals			
Myodes glareolus	14	400 – 700 m^2	Plants (including seeds & fruit), some ground invertebrates
Sorex araneus	4	370 – 630 m^2	Ground invertebrates, carrion
Sylvaemus flavicollis	4	5000 m^2	Plants (including seeds & fruit), fungi, ground insects

Data sources: Arnold (2004); Holden and Cleeves (2014); Lindblom (2008); Voyinstvenskyy (1960); http://www.jstor.org/stable/1934734?seq=6#page_scan_tab_contents; http://www.snh.gov.uk/docs/C208532.pdf; http://en.wikipedia.org/wiki/Common_shrew; http://www.mammal.org.uk/species-factsheets/Yellow-necked%20mouse

Table 2
Activity concentrations (kBq kg^{-1} fresh mass) in specific bird, bat and ground-dwelling small mammals sampled at a site within the Chernobyl Exclusion Zone. Geometric mean values are presented with the geometric standard deviation given in brackets.

Species	n	^{137}Cs	^{238,239,240}Pu	^{90}Sr
Birds				
Erithacus rubecula	7	3.1E + 3 (3.6)	1.6E-1 (3.4)	2.3E + 3 (3.9)
Ficedula albicollis	1	1.2E + 4	5.8E-2	3.4E + 3
Ficedula hypoleuca	3	1.8E + 3 (2.2)	6.1E-2 (1.4)	1.7E + 3 (2.1)
Fringilla coelebs	4	1.8E + 3 (1.5)	6.4E-2 (2.2)	7.0E + 3 (1.9)
Parus major	2	4.2E + 3 (1.3)	4.4E-2 (2.1)	2.8E + 3 (1.1)
Sylvia atricapilla	2	1.6E + 3 (1.1)	8.2E-2 (2.7)	5.1E + 3 (3.5)
Turdus merula	2	3.8E + 3 (1.1)	6.2E-2 (1.4)	2.9E + 3 (1.0)
Bats				
Nyctalus leisleri	4	1.1E + 3 (1.1)	4.8E-2 (1.8)	3.9E + 3 (2.4)
Pipistrellus pipistrellus	3	2.4E + 2 (1.4)	9.8E-2 (1.3)	1.2E + 4 (2.5)
Plecotus auritus	3	2.6E + 3 (2.9)	7.6E-2 (2.4)	1.2E + 4 (2.1)
Ground-dwelling small mammals				
Myodes glareolus	14	3.4E + 4 (2.4)	2.1E-1 (1.7)	3.7E + 4 (2.0)
Sorex araneus	4	2.4E + 4 (1.4)	3.4 (3.3)	1.6E + 4 (2.3)
Sylvaemus flavicollis	4	8.3E + 4 (3.2)	1.5E-1 (1.1)	5.8E + 4 (2.3)

reported. Some carcasses of *A. flavicollis*, *M. glareolus* and also *Sorex araneus* (Table 1), collected in Sherman humane traps (baited with cereals) during this study, were retained and stored frozen. Some of these have been analysed for the purposes of the present paper.

2.3. Analyses

Prior to analysis, samples were defrosted and prepared as follows: bird carcasses were plucked and had the gastrointestinal tract (GIT) removed; bat samples had the GIT removed; and ground-dwelling small mammals had the pelt and GIT removed. All prepared samples were then weighed and washed before analyses.

The wholebody ^{137}Cs and ^{90}Sr concentrations were determined using the method described by Bondarkov et al. (2011). Prior to counting, the carcasses were placed in a small, disposable, cardboard box (70 × 40 × 40 mm), the upper side of which was made from <0.1 mm thick polyethylene. The box was then placed inside a lead shielded counting container. The detectors comprised a hyper-pure germanium detector and thin-film (1 mm) NaI scintillation detector to measure ^{137}Cs and ^{90}Sr, respectively. The ^{137}Cs spectra were analysed using the Canberra Genie-2000 software package. The activity concentration of ^{90}Sr was determined from that of its daughter nuclide, ^{90}Y. The method has previously been calibrated against phantoms containing ^{137}Cs and ^{90}Sr; the methodology has been validated against traditional radiochemical extraction and analysis methodologies. Counting times varied from 150 to 1200 s depending upon the radioactivity in the animal. Counting errors were typically <3% for ^{90}Sr and <7% for ^{137}Cs.

To determine Pu isotopes, samples were initially dissolved in 65% HNO_3 and ^{242}Pu was added as a yield tracer. Following anion exchange separation (Bio Rad AG 1 × 8, 100–200 mesh) and co-precipitation, the samples were counted using a planar ion implanted silicon detector. Counting errors were typically <20% for the Pu isotopes.

3. Results

Radionuclide activity concentrations summarised by species are presented in Table 2. Given the limited sample numbers of some species we have not attempted any statistical comparison at the species level, focussing instead on group-level comparisons ('bird', 'bat' and 'ground dwelling small mammal') (Table 3). Recognising that radionuclide activity concentration data for wildlife generally follow a lognormal distribution (Wood et al., 2013), the data were log-transformed prior to analysis. The ground-dwelling small mammals had significantly higher activity concentrations of all three radionuclides compared to the other two groups (Generalised Linear Model; $p < 0.05$). Differences between birds and bats were not consistent between radioisotopes, with ^{137}Cs activity concentrations being higher in birds and ^{90}Sr concentrations higher in bats. The ^{137}Cs:^{90}Sr activity concentration ratio in bats was significantly lower than that for both the other groups by a factor of *c.* 6.

The transfer of radionuclides to wildlife is most commonly described by the whole-organism concentration ratio ($CR_{wo\text{-}soil}$) (IAEA, 2014; Beresford et al., 2008a), where for terrestrial animals:

$$CR_{wo-soil} = \frac{whole - organism\ activity\ concentration\,(Bq\ kg^{-1}\ fresh\ mass)}{soil\ activity\ concentration\ (Bq\ kg^{-1}\ dry\ mass)}$$

As only a total ^{238,239,240}Pu activity concentration in soil was available, we calculated Pu $CR_{wo\text{-}soil}$ values by combining the ^{238}Pu and ^{239,240}Pu values for each animal. Concentration ratios are presented by species in Table 4 and by group in Table 5. Significant differences in $CR_{wo\text{-}soil}$ between the groups (Table 5) were the same as for activity concentrations (Table 3). For all groups the highest $CR_{wo\text{-}soil}$ values were for ^{90}Sr which were approximately double those determined for ^{137}Cs ($p < 0.001$; paired t-test); the Pu $CR_{wo\text{-}soil}$ values were two to three orders of magnitude lower than the ^{137}Cs $CR_{wo\text{-}soil}$ values ($p < 0.001$; paired t-test).

Table 3
Activity concentrations (kBq kg^{-1} fresh mass) in birds, bats and ground-dwelling small mammals sampled at a site within the Chernobyl Exclusion Zone. Geometric mean values are presented with the geometric standard deviation given in brackets. For each radioisotope, significant differences between geometric means are indicated by letters; geometric means with different letters are significantly different.

Group	n	^{137}Cs	^{238,239,240}Pu	^{90}Sr
Bat	10	9.1E + 2 (3.0)^{a}	6.8E-2 (1.9)^{a}	7.6E + 3 (2.6)^{b}
Bird	21	2.7E + 3 (2.5)^{b}	8.4E-2 (2.5)^{a}	3.1E + 3 (2.7)^{a}
Ground-dwelling small mammals	22	3.8E + 4 (2.5)^{c}	3.3E-1 (3.8)^{b}	3.5E + 4 (2.3)^{c}

Table 4
Concentration Ratios ($CR_{wo\text{-}soil}$) for bird, bat and ground-dwelling small mammals sampled at a site within the Chernobyl Exclusion Zone. Geometric mean values are presented with the geometric standard deviation given in brackets.

Species	n	^{137}Cs	^{238,239,240}Pu	^{90}Sr
Birds				
Erithacus rubecula	7	7.2E-2 (3.6)	1.9E-4 (3.4)	1.2E-1 (3.9)
Ficedula albicollis	1	2.7E-1	7.0E-5	1.9E-1
Ficedula hypoleuca	3	4.0E-2 (2.2)	7.3E-5 (1.4)	9.1E-2 (2.1)
Fringilla coelebs	4	4.2E-2 (1.5)	7.8E-5 (2.2)	3.8E-1 (1.9)
Parus major	2	9.6E-2 (1.3)	5.4E-5 (2.1)	1.5E-1 (1.1)
Sylvia atricapilla	2	3.7E-2 (1.1)	9.9E-5 (2.7)	2.7E-1 (3.5)
Turdus merula	2	8.8E-2 (1.1)	7.5E-5 (1.4)	1.6E-1 (1.0)
Bats				
Nyctalus leisleri	4	2.6E-2 (1.1)	5.8E-5 (2.2)	2.1E-1 (2.4)
Pipistrellus pipistrellus	3	5.6E-3 (1.4)	1.2E-4 (1.3)	6.5E-1 (2.5)
Plecotus auritus	3	6.0E-2 (2.9)	9.2E-5 (2.4)	6.3E-1 (2.1)
Ground-dwelling small mammals				
Myodes glareolus	14	7.8E-1 (2.4)	2.5E-4 (1.7)	2.1 (2.0)
Sorex araneus	4	5.6E-1 (1.4)	4.1E-3 (3.3)	8.8E-1 (2.3)
Sylvaemus flavicollis	4	1.9 (3.2)	1.8E-4 (2.2)	3.1 (2.3)

4. Discussion

It is likely that diet contributes to the higher activity concentrations, for all radioisotopes, observed in the ground-dwelling small mammals compared to the birds and bats (Table 2). The diet of all of these ground-dwelling small mammals includes ground living invertebrates. Previous studies have suggested that flying insects (which comprise the diet of study bat species and are an important component of the diet of most of the bird species sampled) generally have lower radionuclide activity concentrations than ground-dwelling invertebrate species collected from the same site (Wood et al., 2009; Barnett et al., 2014). Ground-dwelling invertebrates may contain soil in their digestive tract or be externally contaminated by soil. There is also more potential for the ground-dwelling small mammals to inadvertently ingest contaminated soil.

The $CR_{wo\text{-}soil}$ for Pu to shrews is 1–2 orders of magnitude higher than those for the other species studied in this paper (Table 4). A similar observation has been made for a number of toxic metals that have been shown to accumulate to higher levels in shrews than in other small mammals (Shore and Rattner, 2001; Tomášková et al., 2005). The high metabolic rate and diet of shrews have been suggested to be the reason for this (Hegstrom and West, 1989; Świergosz-Kowalewska et al., 2005).

Although protected bat species are often the target of assessment (Copplestone et al., 2003), there are very few available data on the transfer of radionuclides to this group of mammals. The only other data that we are aware of are those reported by Gaschak et al. (2010) for bats sampled during 2007–2009 from different areas of the CEZ. Gashchak et al. present transfer of ^{137}Cs and ^{90}Sr relative to the deposition in soil rather than as $CR_{wo\text{-}soil}$ values. For comparison with our data, Table 6 presents $CR_{wo\text{-}soil}$ values calculated from the data of Gaschak et al. (2010); these data were extracted from the database described by Copplestone et al., 2013. The $CR_{wo\text{-}soil}$ values presented in the present paper are within the range of those calculated from the Gashchak et al. paper. The only potential exception is that the *Pipistrellus pipistrellus* $CR_{wo\text{-}soil}$ value for Cs is lower than the range of values presented in the larger dataset of Gashchak et al.. We should acknowledge that, whilst the size of our sampling area was appropriate for the home range of the birds and small ground dwelling mammals, the bat species generally forage over a larger area (Table 1).

Table 5
Concentration Ratios ($CR_{wo\text{-}soil}$) for birds, bats and ground-dwelling small mammals sampled at a site within the Chernobyl Exclusion Zone. Geometric mean values are presented with the geometric standard deviation given in brackets. For each radioisotope, significant differences between geometric means are indicated by letters; geometric means with different letters are significantly different.

Group	n	^{137}Cs	^{238,239,240}Pu	^{90}Sr
Bat	10	2.1E-2 (3.0)^{a}	8.3E-5 (1.9)^{a}	4.1E-1 (2.6)^{b}
Bird	21	6.3E-2 (2.5)^{b}	1.0E-4 (2.5)^{a}	1.7E-1 (2.7)^{a}
Ground-dwelling small mammals	22	8.7E-1 (2.5)^{c}	4.0E-4 (3.8)^{b}	1.9 (2.3)^{c}

Table 6
Concentration Ratios ($CR_{wo\text{-}soil}$) for bats within the Chernobyl Exclusion Zone, calculated from the data discussed in Gaschak et al. (2010) (data extracted from the database described by Copplestone et al., 2013). Geometric mean values are presented with the geometric standard deviation given in brackets.

Species	n	^{137}Cs	n	^{90}Sr
Eptesicus serotinus	17	2.6E-01 (4.3)	17	4.4E-01 (3.5)
Myotis dasycneme	–		1	1.3E-01
Myotis daubentonii	2	1.0E-02 (4.0)	6	1.7E-01 (1.5)
Nyctalus leisleri	5	5.6E-02 (1.6)	6	6.4E-01 (3.0)
Nyctalus noctula	20	9.5E-02 (2.7)	20	4.4E-01 (3.5)
Pipistrellus kuhlii	6	3.4E-01 (15.2)	8	1.7E-01 (3.6)
Pipistrellus nathusii	51	1.0E-01 (4.4)	64	2.6E-01 (3.4)
Pipistrellus pygmaeus	2	2.3E-01 (4.3)	4	6.8E-01 (8.3)

The lower ^{137}Cs:^{90}Sr ratio observed in bats compared to the other animal types implies a comparatively high transfer of Sr compared to Cs in bats. The diet of insectivorous bats is limited in calcium (Adams et al., 2003) a strong Sr analogue. It is therefore, likely that the dietary absorption of calcium, and consequently Sr, is higher in bats than in the other species. However, we acknowledge that the ^{137}Cs:^{90}Sr ratio is not consistent across the CEZ (Kashparov et al., 2003) and the greater home range of the bats compared to the other species may contribute to our observation.

Data from previous studies both within the Chernobyl Exclusion Zone and in other areas support our observation that the transfer of Sr is comparatively high compared to Cs (Barnett et al., 2014; Gashchak et al., 2003, 2008; 2009, 2010; Maklyuk et al., 2007; Sheppard, 1991 [1]; Sheppard et al., 2004 [1], 2008 [1]; 2010 [1] Sheppard and Evenden, 1990 [1]). Data presented by Beresford et al. (2008c) for small ground-dwelling mammals sampled from the Chernobyl Exclusion Zone in 2005 suggest that the extent of this difference between Sr and Cs transfer was highest at sites with a generally low level of contamination (<10 kBq kg^{-1} dry mass ^{137}Cs). At the most contaminated site, which was located on the western trace (*c*.100 kBq kg^{-1} dry mass ^{137}Cs), the results of Beresford et al. (2008c) suggest that the transfer of Cs was higher than that for Sr. Gaschak et al. (2010) suggested that for bats sampled throughout the CEZ there was a decreasing transfer of ^{90}Sr with increasing deposition. Similar observations have been reported for amphibians, small birds and ungulates (Gashchak et al., 2008, 2009; Gashschak, 2009; Gaichenko et al., 2001). This may be because Sr contamination is predominantly in particulate form at the highest contamination sites. Kashparov et al. (1999) showed that the dissolution rate of Sr from particles to the west of the reactor (where the most contaminated site in Beresford et al. was located) was lower than that from other areas.

The data presented in this paper provide an opportunity to test the hypothesis that sampling unprotected species (represented by two species of the ground-dwelling small mammals, *M. glareolus* and *Sylvaemus flavicollis*) and determining activity concentrations in these will allow a conservative estimate of activity

[1] Data from these papers as supplied to the Wildlife Transfer Database described by Copplestone et al., 2013.

concentrations in protected species to be obtained. Table 2 demonstrates that sampling *M. glareolus* and *S. flavicollis* would give higher activity concentration estimates for ^{137}Cs, ^{238,239,240}Pu and ^{90}Sr than those measured in bats directly. Therefore, using data for these two small ground-dwelling mammals to make an assessment of dose to bats would result in a conservative estimate. Given that many species of birds are also protected, Table 2 also lends confidence to the use of a similar approach to conservatively assessing doses to birds. However, in the case of *S. araneus*, a protected species of ground-dwelling small mammal in the United Kingdom (HMSO, 1981), sampling the *M. glareolus* and *S. flavicollis* would underestimate activity concentrations and, therefore, dose from Pu isotopes given the higher transfer of Pu to this species as discussed previously.

5. Conclusions

The data presented in this paper significantly improves the available information on small bird and bat species and also Pu isotope levels in wildlife from the CEZ. The data provide a valuable addition to available transfer databases and will also facilitate more accurate dose assessments for wildlife in the Chernobyl exclusion zone perhaps aiding the debate on reported effects from the area (e.g. Beresford and Copplestone, 2011; Garnier Laplace et al., 2013).

Bats had a high ^{90}Sr:^{137}Cs ratio compared to other species; a diet deficient in calcium may contribute to this observation.

The data support the hypothesis that sampling and analyses of small ground-dwelling mammals would provide a conservative estimate of exposure for birds and bats which are often protected and for which there are comparatively few data.

The $CR_{wo\text{-}soil}$ value for Pu transfer to shrews (a protected species in the United Kingdom) was 1–2 orders of magnitude higher than those for the other species. This should be taken into account when conducting assessments if using other small mammals as surrogates for shrews.

Acknowledgements

We would like to acknowledge the support of the following IRL staff in this work: Mikhail Bondarkov (Director of IRL), Valentin Martynenko, Vasily Maksimenko and Sergey Paskevich. The bat study and the analyses of samples for Pu-isotopes was funded under CEH National Capability funding. Manuscript preparation was facilitated by funding from the EU funded COMET project (S. Gaschak & N.A. Beresford; www.comet-radioecology.org) and the TREE project (M.D. Wood & N.A. Beresford; www.ceh.ac.uk/TREE) funded by the Natural Environment Research Council, the Environment Agency and Radioactive Waste Management Ltd.. We would also like to thank the University of Salford for funding this paper to be published as open access and Prof. Andy Miah (University of Salford) for producing the accompanying video abstract (http://bit.ly/1JesKPc).

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