Journal of Environmental Radioactivity xxx (2016) 1–10

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

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

Heterogeneity of ^{90}Sr radioactive contamination at the head part of the East Ural radioactive trace (EURT)

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ARTICLE INFO

Article history:
Received 19 July 2016
Received in revised form
11 November 2016
Accepted 17 November 2016
Available online xxx

Keywords:
Kyshtym accident
East ural radioactive trace (EURT)
^{90}Sr
Concentration ratio
Rodents
Microtus oeconomus

ABSTRACT

1: We measured ^{90}Sr concentrations and beta particle flux density (BPFD) in 44 soil samples collected from four soil profiles across a central transect on the head of the East Ural Radioactive Trace (EURT). The relationship between BPFD and ^{90}Sr concentration of each soil sample can be characterised by a linear regression model; ^{90}Sr concentration in the upper 12 cm soil layer can thus be assessed by measuring BPFD in the soil surface.
2: The BPFD on the soil surface was measured at 969 points at seven sites with linear dimensions ranging from 140 × 20 m to 140 × 320 m. The correspondence of ^{90}Sr concentration in the 12 cm soil layer with its BPFD value was calculated for each of these seven sites. Eighty (80) % of ^{90}Sr concentration measurements in the 12 cm soil layer in each model site differed by a factor of 2.0–5. The variability of ^{90}Sr concentration increased significantly in the 12 cm upper soil layer over territories with visual features of landscape disturbance (pits, trenches). The ratio of maximum to minimum concentration of ^{90}Sr varied from 6.1 to 6.6 in the 12 cm soil layer over territories without visual features of anthropogenic soil disturbance.
3: The ^{90}Sr concentration was measured in the skeletons of 34 juvenile *Microtus oeconomus* individuals weighing less than 12.5 g and trapped at the four model sites in July. The assessment of ^{90}Sr concentration in the 12 cm soil layer was conducted for each point where an animal was trapped. The relationship between ^{90}Sr concentration in soil and in the skeleton was characterised by a linear regression model with a determination coefficient of 0.51.
4: The concentration ratio for ^{90}Sr from soil to skeleton ($CR_{skeleton-soil}$) was 2.0 ± 0.1 for *M. oeconomus* over the territory of the EURT, which is consistent with the minimum value of the same $CR_{skeleton-soil}$ for *M. oeconomus* from the Chernobyl area (Chesser et al., 2000).

1. Introduction

In the autumn of 1957, a tank containing radioactive wastes from radiochemical processes exploded at the «Mayak» plutonium production plant (Kyshtym accident). About 74 PBq of radioactive substances were released into the environment, 10% of which was dispersed by the wind in a north-eastern direction, resulting in radioactive contamination of an area of about 23,000 km^2 (the East Ural Radioactive Trace, EURT). Ninety-five % of the activity in the released radioactive substances comprised of radionuclides with half-lives of less than one year. The predominant long-lived radionuclides was ^{90}Sr. The portion of $^{90}Sr + {}^{90}Y$ released in the accident was 5% (UNSCEAR, 1996). The head part of the EURT and nearby territories were additionally contaminated due to wind-borne transfer of radionuclides from the bottom sediments of lake Karachay in 1967 (UNSCEAR, 1996; Atlas of the East Ural, 2013).

In 2013, the amount of ^{90}Sr over an area of 465 km^2 located near the hypocentre of the accident was approx. 328 TBq; 95% of this was concentrated in the territory at the head of the EURT

Abbreviations: BPFD, beta particles flux density.

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http://dx.doi.org/10.1016/j.jenvrad.2016.11.019
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(Molchanova et al., 2014a). The high level of radioactive contamination associated with the territory of the EURT rendered this as a potentially-useful experimental area where a wide range of radioecological studies could be conducted, in particular, analysis involving ^{90}Sr accumulation patterns by living organisms (Iljenko and Krapivko, 1989; Pozolotina et al., 2012; Karimullina et al., 2013; Molchanova et al., 2014b; Starichenko et al., 2014).

Iljenko and Krapivko showed that the difference in ^{90}Sr concentration in the skeleton of animals of the same species, taken from the same area (approx. 1 ha) may differ by a factor of four orders of magnitude in the territory of the EURT (Iljenko and Krapivko, 1989). Some researchers reported on the significant variability of ^{90}Sr accumulation by mammals caught at a small distance from each other at the EURT territory (Starichenko and Liubashevskii, 1998; Starichenko, 2011; Starichenko et al., 2014) and in the Chernobyl area (Chesser et al., 2000; Beresford et al., 2008; Gaschak et al., 2011). The heterogeneity of ^{90}Sr accumulation in rodents depends on the following factors (Iljenko and Krapivko, 1989; Wood et al., 2013): physico-chemical influences on uptake, such as pH, cation exchange capacity, concentrations of chemical analogues and temperature, heterogeneity of contaminant distribution, effect of seasonal changes in both the endocrine cycle and diet, organism age, animal species and migration of some animals through areas with various degrees of radioactive contamination.

Most mammals are capable of substantially changing their position within a given territory. However, the heterogeneity of radioactive contamination is not taken into account in assessing ^{90}Sr accumulation by such animals. Some species of rodents, such as *Ellobius talpinus* Pallas 1770, have a settled life pattern, and the communities of relatives (families) of *E. talpinus* live in soil at some distance from each other (Gromov, 2008). Starichenko (2011) conducted a study of eight families from the EURT territory living in close proximity to each other and showed that 83% of the heterogeneity in ^{90}Sr accumulation by the animals is caused by an interfamily factor, while 17% are a result of intrafamily effects. One of the reasons of such variability could be the heterogeneity in ^{90}Sr contamination of the soil at the sites of the *E. talpinus* family habitats. Thus, it is important to study settled animals as model species for ^{90}Sr accumulation.

The currently available information on the heterogeneity of soil contamination with ^{90}Sr is not sufficient to assess the variability of accumulation by rodents over the territory at the head part of the EURT. The coefficient of variation of radioactive contamination density of three to five soil samples from an area of 100–400 m^2 is 36% at the central axis and 68% at the peripheral territories of the EURT (Molchanova et al., 2014a). A part of the EURT territory has been reclaimed; the most contaminated upper soil layer has been buried to a depth of 0.5–1 m. There are areas on the territory of the EURT where the contamination density differs between zones by a factor of 6 (Bakurov, 2008; Pozolotina et al., 2012; Molchanova et al., 2013). Up to now, detailed studies of the heterogeneity of radioactive soil contamination over small areas corresponding to areas of the rodents' home range (approx. 360–5000 m^2) with homogeneous relief and soil type have not been conducted.

This lack of data on the heterogeneity of contamination of the EURT territory is probably related with the high complexity of ^{90}Sr concentration measurements in soil. As ^{90}Sr and its daughter radionuclide ^{90}Y represent the highest input into the total beta activity of the soil at the head of the EURT, ^{90}Sr concentration in a soil sample may be assessed on the basis of BPFD of the soil sample.

The major part of ^{90}Sr is accumulated in the upper 10–15 cm soil layer of undisturbed black soils and soils of upland meadows at the territories of the EURT (Molchanova et al., 2014b). This soil layer has been used by Beresford et al. (2008) to assess ^{90}Sr transfer coefficients from soil to rodents. Thus, in the present study, we focussed on the radioactive contamination of the upper 12 cm soil layer.

The objectives of the study were:

1. To assess the relationship between ^{90}Sr concentration and BPFD in the upper 12 cm soil layer;
2. To assess the spatial distribution of BPFD on the soil surface and ^{90}Sr concentration in the soil at the sites with linear dimensions varying from 140 × 20 m to 140 × 320 m at the territory of the EURT;
3. To analyse the relationship between ^{90}Sr accumulation in young *Microtus oeconomus* (Pallas, 1776) individuals and heterogeneity of contamination over the area where the animal was trapped. For this study, it was assumed that all the tested animals have settled life patterns.

The map of radioactive contamination of the EURT shows large territories falling within a similar contamination range (Atlas of the East Ural ..., 2013). Such territories are several times larger than the rodents' home range (Gromov, 2008). Thus, the contamination level of home range and, as a result, the accumulation of ^{90}Sr by rodents may vary by a factor of several times.

2. Materials and methods

2.1. Description of the studied area

The study was conducted over the territory of the head part of the EURT at a distance of 20 km from the hypocentre of the explosion in 1957. Fig. 1 shows the location of the studied sites (*1*–*7*). Geographical coordinates of the studied area are latitude 55°49′N, longitude 60°52–54′E. The area was a rural area before the explosion of 1957; after this, the village was destroyed, people were resettled and a reserve was established on the territory at the head of the EURT. Since then, the territory has no infrastructure. Soil at the studied area is represented by black soil and humus, with various degrees of transformation due to anthropogenic activities.

The most contaminated sites (*1* and *2*) were located at the flat shore of lake Uruskul at a distance of 100–400 m from the water level. Site *1* was located on the meadow with the following visual traces of human activity: a pit and earthwork of 20 m^2 as well as a drain at the northern border of the area. The herbaceous community was mainly comprised of *Cirsium setosum* (Willd.) Bess. and *Bromopsis inermis* (Leyss.) Holub.

Sites *3*–*6* were located at a distance of 500 m to the western direction from the lake at the location of a former village, which had been resettled after the Kyshtym accident. The distance between the sites was 100–300 m. The buildings had been destroyed by a digger and buried in trenches (Bakurov, 2008). The herbaceous community of the studied area was dominated by ruderal weeds, mainly by the species *Bromopsis inermis, Urtica dioica* L. *Cirsium setosum* and *Poa* sp. Site *7* was located at a forb-grass upland meadow.

The most accurate information about the radioactive contamination of the studied area, including forecasts until 2047, can be obtained from the Atlas of the East Ural and Karachay radioactive trace (Atlas of the East Ural …, 2013). According to the Atlas, the studied sites are located over territories where ^{90}Sr radioactive contamination densities vary from 3.3 to 22 MBq m^{-2} (Fig. 1).

Over a number of years, rodents have been trapped in particular areas, with the location of the traps remaining the same (Starichenko et al., 2014; Orekhova and Modorov, 2016; Modorov, 2016). The chosen trapping method is described in detail in