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^{137}Cs IN THE ORGANISMS OF MOUSE-LIKE RODENTS INHABITED THE AREA OF NUCLEAR WEAPON TESTING

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The paper presents the results of researching ^{137}Cs radionuclide concentration in the organisms of mouse-like rodents (organisms of jerboa (*Allactaga major* Kerr and *Allactaga saltator* Eversmann) and marmots (*Citellus erythrogenus* Brandt)) living in the field of nuclear-weapon testing at the Semipalatinsk test site and the parameters of ^{137}Cs radionuclide transition to organisms of studied animals. It is revealed that relatively elevated magnitudes of ^{137}Cs activity concentration in organisms of jerboa and marmots are observed on the assumption of their residence in local contamination sites. With venturing from contamination sites at the distance exceeding the radius of animal activity, high values of radionuclides' activity concentration are not reported. Despite the fact that animals live in the environment which components display high activity concentration of radionuclides, the extremely high concentration of radionuclide in these animals' organisms has not identified.

The midpoint measures (AM±SD) of CR_{muscl} of ^{137}Cs radionuclide for the muscle tissue of *Allactaga saltator* Eversmann amounted $(2.1\pm1.3)\times10^{-3}$ (n-11), for muscle tissue of *Allactaga major* Kerr – $(4.7\pm2.7)\times10^{-3}$ (n-9), for the muscle tissue of *Citellus Erythrogenus* Brandt – $(7.0\pm5.6)\times10^{-3}$ (n-6).

Keywords: *radioecology, radionuclides, ^{137}Cs, mouse-like rodents, STS.*

INTRODUCTION

Currently, researchers are focusing on the risk assessment of numerous factors affecting biota. Notably, there have been developed multiple models for evaluation of radiation exposure of wild animals [1]. Typically, the models are based on data obtained in areas that have been exposed to radionuclide contamination as a result of radiation accidents. The measures of radionuclide transition parameters (concentration ratio values (CR)) into organisms of wild animals obtained for areas of nuclear-weapon testing on the territory of Semipalatinsk test site (STS) are outnumbered [2]. The STS territory differs both in the nature of radionuclide contamination and in its natural and climatic characteristics. Furthermore, there have been passed more than 60 years since separate tests on the STS were completed. Therefore, data acquisition about radionuclide transition parameters in this area is essential for understanding peculiarities of radionuclide mobility in food chains in the remote period after contamination of natural ecosystems.

Previously, various authors detected high values of radionuclides activity concentrations in organisms of animals which had close contact with radioactive grounds: soil fauna, fossorial mammals (mice, rats, etc.), amphibians (toads, frogs, etc.), reptiles (lizards, snakes) [1, 3–6]. Accordingly, mouse-like rodents were chosen as the object of research in this work. These are the red-cheeked marmot (*Citellus erythrogenus* Brandt) and two species of the jerboa family (*Dipodidae*) – the jumping jerboa (*Allactaga saltator* Eversmann) and the large jerboa (*Allactaga major* Kerr). Previously, researches of radioecological state of mouse-like rodents on the STS territory have not been carried out.

This article aims to estimate the radioecological state of mouse-like rodents and obtain certain parameters of the transition of radionuclides into organisms of gophers and jerboa for continued use in risk assessment for biota.

1. MATERIALS AND TECHNIQUES

1.1. Objects of research

The mouse – like rodents – red-cheeked gopher (*Citellus erythrogenus* Brandt) and two species of the jerboa family (*Dipodidae*): the jumping jerboa (*Allactaga saltator* Eversmann) and the large jerboa (*Allactaga major* Kerr) widespread on the STS territory, was chosen as an object of research.

The systematic position of the species is given in the table below (Table 1).

Table 1 Systematic position of research objects the Mammalia class – the Rodentia order

Family	Genus	Species
Squirrels (*Sciuridae*)	Marmots (*Spermophilus*)	Red-cheeked marmot (*Spermophilus erythrogenus*)
Jerboa (*Dipodidae*)	Allactaga	Large jerboa (*Allactaga major* Kerr)
Jerboa (*Dipodidae*)	Allactaga	Jumping jerboa (*Allactaga saltator* Ewersmann)

Aspects of the biology of these species have been studied extensively.

The red-cheeked marmot. This is a medium-sized mouse-like rodent. The body length is 23.5–28 cm. The weight of the animal in the investigated regions can reach 230–250 g. The red-cheeked marmot leads a settled way of life. It is a herbivorous species. Marmots feed on succulent vegetative parts and seeds of various steppe plants. The size of the feeding area of red-cheeked marmot on average is about 1800 m^2.

The large jerboa. The large jerboa is the biggest one among jerboa. It has a relatively short body (18.7–26 cm long). The body weight is more than 300 g. The large jerboa leads a settled way of life. However, it is characterized by local movements related to food conditions. The radius of daily activity can be 4–5 km. There is a prevalence of bulbs, green parts of plants, seeds and insects in the diet of large jerboa. Its diet may equally include the corpses of birds (larks).

The jumping jerboa. The jumping jerboa is a medium-sized rodent. The body length is 13–15 cm. The body weight can reach 150 g. The jumping jerboa also leads a settled way of life. Its behavior barely differs from the large jerboa. However, the radius of daily activity (2–3 km) and body sizes are smaller.

1.2. Sampling

The capture of the animals was held from 2006 to 2010, in summer. Adults were used for the study.

The jerboas were caught by slow sneaking up and then quick covering the animals with a net. The marmots were poured out of their holes with water. The average weight of caught marmots was 170±60 g (AM±SD, n-28). The average weight of the large jerboa was 300±50 g (AM±SD, n-19). The average weight of the jumping jerboa was 103±15 g (AM±SD, n-55).

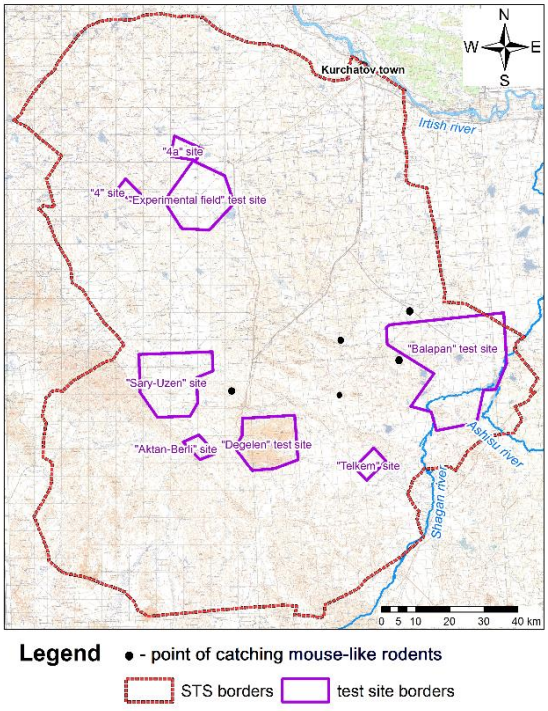
The catch of animals was carried out in the following areas:

– "background" parts of the STS beyond the testing grounds (Figure, a.);

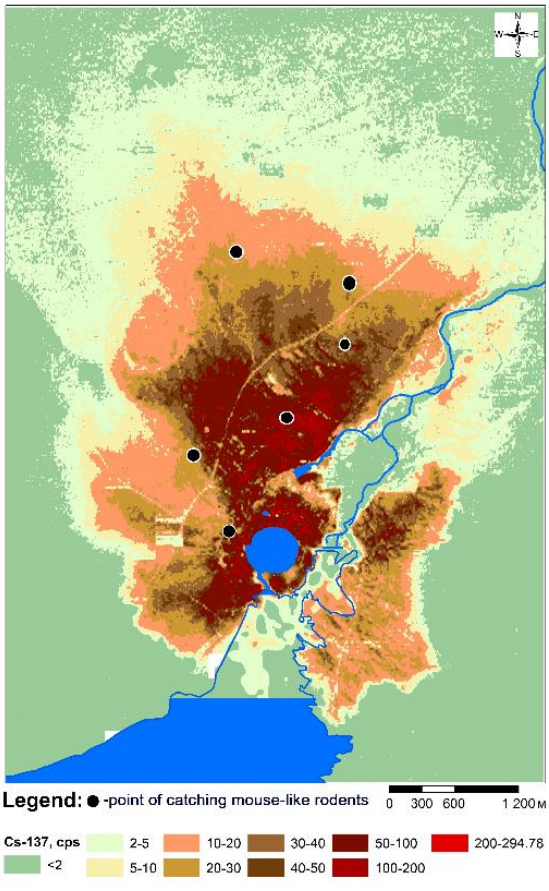
– the trace of an excavated nuclear explosion that runs in a northern direction from the "Atomic Lake". Jerboas were also caught within this trace. Marmots were caught in the area of the trail located 1000 m from the embankment of the "Atomic Lake" in the northwestern direction (Figure, b.) [7].

1.3. Assessment of radionuclide content in the soil of animal capture sites

For estimation of ^{137}Cs activity concentration in ground of caged animals' habitats on the track of excavating nuclear explosion the available data on radionuclides activity concentration in soil (0–5 cm layer) at points located around the sites of their capture was analysed. These points are accessible in the electronic database of the branch of the National Nuclear Center of the Republic of Kazakhstan, Institute of Radiation Safety and Ecology. As a result, it was found that the maximum magnitude of ^{137}Cs activity concentration in the ground of the mouse-like rodents' capturing area reaches 2.6×10^4 Bq·kg^{-1}. The distribution of values by frequency of occurrence does not follow the normal Gauss law. The coefficient of variation was 88 %, which indicates a spread in the general data set. The arithmetic average values of ^{137}Cs activity concentration (± standard error) in the soil on the trail of excavation explosion were $(6.6\pm1.1)\times10^3$ (n-29) Bq·kg^{-1}. In the "background" territories, the activity concentration does not exceed 15 Bq·kg^{-1}.



a)



b)

Figure. Territory for animals' capture: a) "background" parts of the STS beyond the testing grounds; b) trace of an excavated nuclear explosion – the "Atomic Lake"

1.4. Radionuclide analysis

After entrapment, the animals were delivered to the laboratory and euthanized. Determination of ^{137}Cs was pursued only in a well-homogenized wet mass of muscle tissue. Determination of radionuclides concentration in bone tissue, skin, hair, or internal organs was not carried out.

^{137}Cs activity concentration in the muscle tissue of mouse-like rodents was measured in accordance with standardized practices using calibrated equipment. Measurements of ^{137}Cs activity concentration were implemented using a Canberra GX-2020 gamma-spectrometer [8]. The statistical error of measurements (taking into account source error) did not exceed 10%.

2. RESULTS AND DISCUSSION

Results of ^{137}Cs activity concentration measurements in mouse – like rodents' muscle tissue are presented in Tables 1–3.

In the muscle tissue of the jumping jerboa (*Allactaga saltator Ewersm*), caught on the radioactive trail of excavated nuclear explosion, ^{137}Cs activity concentration evolves in the range of 5–30 Bq·kg^{-1}. Conversely, ^{137}Cs activity concentration in same tissue of the large jerboa (*Allactaga major Kerr*), caught at the same venue varies in the range of 6–59 Bq·kg^{-1}. At last, quantitative magnitudes of ^{137}Cs radionuclide activity concentration in the muscle tissue of both species of jerboas, caught in the "background" areas of STS, were not recognized. In the organisms of marmots caught on the trail of excavated nuclear explosion in the "Atomic Lake" region, ^{137}Cs activity concentration values varied within 1.5–92 Bq·kg^{-1}. There were no quantitative measures of ^{137}Cs radionuclide activity concentration in the muscular tissue of marmots, which were caught in the "background" areas of the STS, found. According to results, the levels of activity concentration of radionuclides in the animals' organisms depend on the levels of this activity concentration of radionuclides in the ground of their habitats.

For assessment of parameters of radionuclides transfer into mouse-like rodents' organisms there was used ratio values (CR) applied in the following works: [3, 9, 10].

In this paper, $CR_{muscl\text{-}soil}$ was defined as:

$$CR_{muscl\text{-}soil} = \frac{\textit{Activity concentration in biota (in the muscle tissue)(Bq·kg}^{-1}\textit{ FW)}}{\textit{Activity concentration in soil (Bq·kg}^{-1}\textit{ DW)}}$$

Table 4 shows the CR_{muscl} values for mouse-like rodents and the coefficients of variation of these values. Although, the average CR_{muscl} measures of ^{137}Cs radionuclide for all animals are within one order, there is a high variation of these values both within the samples of CR_{muscl} values for each animal species, and the entire sample for studied mouse-like rodents. The average values of CR_{muscl} of ^{137}Cs radionuclide for the muscle tissue of jumping jerboa were $(2.1\pm1.3)\times10^{-3}$ (n-11), for large jerboa – $(4.7\pm2.7)\times10^{-3}$ (n-9), and for red-cheeked marmot – $(7.0\pm5.6)\times10^{-3}$ (n-6).

Table 1. ^{137}Cs activity concentration of the muscle tissue of jumping jerboas (Bq·kg^{-1} FW)

"Background" parts of the STS (n-10)	Plume of excavation explosion (n-16)
< 0.6	19 ± 1
< 0.8	25 ± 1
< 1.3	8 ± 1
< 0.9	9 ± 2
< 2	1 ± 0.7
< 1	25 ± 1
< 0.6	14 ± 1
< 0.7	15 ± 2
< 0.4	6 ± 1
< 1.0	25 ± 1
	5 ± 1
	19 ± 1
	15 ± 2
	8 ± 1
	25 ± 2
	30 ± 2

Table 2. ^{137}Cs activity concentration of the muscle tissue of large jerboas (Bq·kg^{-1} FW)

"Background" parts of the STS (n-12)	Plume of excavation explosion (n-6)
< 0.5	59 ± 1
< 0.5	32 ± 1
< 0.5	14 ± 1
< 0.5	35 ± 1
< 0.5	19 ± 1
< 0.5	50 ± 1
< 0.5	
< 0.5	
< 1	
< 0.5	
< 0.5	
< 0.5	

Table 3. ^{137}Cs activity concentration of the muscle tissue of red-cheeked marmot (Bq·kg^{-1} FW)

"Background" parts of the STS (n-12)	Plume of excavation explosion (n-8)
< 0.5	63 ± 13
< 0.5	1.5 ± 0.3
< 0.5	20 ± 4
< 0.5	92 ± 18
< 0.5	79 ± 16
< 0.5	21 ± 4
< 0.5	
< 0.5	
< 1	
< 0.5	
< 0.5	
< 0.5	

Table 4. CR_{muscl} values for mouse-like rodents on the track of the excavation nuclear explosion

Area of capture	^{137}Cs (AM±SD)	N	CV%
Jumping jerboa	$(2.1\pm1.3)\times10^{-3}$	11	63
Large jerboa	$(4.7\pm2.7)\times10^{-3}$	9	57
Red-cheeked marmot	$(7.0\pm5.6)\times10^{-3}$	6	80
All mouse-like rodents	$(4.3\pm3.7)\times10^{-3}$	26	86

Thus, AM values of $CR_{muscl-soil}$ for all species of mouse-like rodents of interest were $n\times10^{-3}$. The paper [11] quotes $CR_{wo-soil}$ values (whole organism activity concentration, Bq·kg^{-1} fresh mass/soil activity concentration, Bq·kg^{-1} dry mass) of ^{137}Cs for the striped field mouse (*Apodemus agrarius*), bank vole (Myodes glareolous) and yellow-necked mouse (*Apodemus flavicollis*) inhabiting the Chernobyl exclusion zone. Unlike our results, AM values of $CR_{wo-soil}$ were 2 orders of magnitude higher being at the level of $n\times10^{-1}$. Lower CR values for mouse-like rodents within STS are attributable to less available species of ^{137}Cs (^{137}Cs was found in soil to be mainly in tightly bound form (up to 98 %)) at STS compared to the Chernobyl exclusion zone [12].

CONCLUSION

Research shows that the levels of radionuclides activity concentration of mouse-like rodents' organisms depend on the levels of this activity concentration of radionuclides in the ground of their habitats. Individuals live in areas with high values of radionuclides activity concentration in the soil, reaching 2.6×10^{4} Bq·kg^{-1}. Though, despite of previous fact, extremely high measures of activity concentration of these radionuclides in the animal organisms are not identified.

The average values (AM±SD) of CR_{muscl} of ^{137}Cs radionuclide for the muscle tissue of jumping jerboa were $(2.1\pm1.3)\times10^{-3}$ (n-11), for large jerboa – $(4.7\pm2.7)\times10^{-3}$ (n-9), and for red-cheeked marmot – $(7.0\pm5.6)\times10^{-3}$ (n-6).

Unfortunately, due to the lack of data on radionuclides concentration in organisms of rodents inhabited on the territory of the STS in the earlier date after radionuclide contamination, comparison of the obtained parameters of radionuclides' transition into organisms of mouse-like rodents in the long-term is not possible.

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ЯДРОЛЫҚ ҚАРУ СЫНАЛҒАН ЖЕРЛЕРДЕ МЕКЕНДЕЙТІН ТЫШҚАН ТӘРІЗДЕС КЕМІРГІШТЕРДІҢ АҒЗАСЫНДАҒЫ ^{137}Cs

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Жұмыста Семей сынақ полигонының ядролық қару сыналған жерлерде мекендейтін тышқан тәріздес кеміргіштердің ағзасындағы (жербоалардың (*Allactaga major* Kerr және *Allactaga saltator* Eversmann) және жер тиіндерінің (*Citellus erythrogenus* Brandt) денесінде) ^{137}Cs радионуклидінің құрамын зерттеу нәтижелері және ^{137}Cs радионуклидінің зерттелетін жануарлардың ағзасына өту параметрлері келтірілген. Қосаяқтың мен сарышұнақтардың ағзасындағы ^{137}Cs радионуклидінің меншікті белсенділігінің салыстырмалы түрде жоғарылауы олардың ластанудың жергілікті учаскелерінде тікелей мекендеген жағдайда байқалады. Ластану учаскелерінен жануарлар белсенділігінің радиусынан асатын қашықтыққа алыстаған кезде жануарлардағы радионуклидтердің меншікті белсенділігінің жоғары мәндері тіркелмейді. Жануарлар табиғи ортаның құрамдас бөліктерінде радионуклидтердің меншікті белсенділігі жоғары жерлерде мекендейтініне қарамастан, бұл жануарлардың ағзасында радионуклидтердің өте жоғары мөлшері байқалмайды.

Орташа мәні (AM±SD) CR_{muscl} ^{137}Cs радионуклидінің *Allactaga saltator* Eversmann бұлшықет тіндері үшін $(2.1\pm1.3)\times10^{-3}$ (n-11) құрады, *Allactaga major* Kerr бұлшықет тіндері үшін – $(4.7\pm2.7)\times10^{-3}$ (n-9), *Citellus Erythrogenus* Brandt бұлшықет тіндері үшін – $(7.0\pm5.6)\times10^{-3}$ (n-6).

Түйін сөздер: *радиоэкология, радионуклиды, ^{137}Cs, тышқан тәріздес кеміргіштер, ССП.*

^{137}Cs В ОРГАНИЗМЕ МЫШЕВИДНЫХ ГРЫЗУНОВ, ОБИТАЮЩИХ В МЕСТАХ ИСПЫТАНИЯ ЯДЕРНОГО ОРУЖИЯ

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В работе приводятся результаты исследования содержания радионуклида ^{137}Cs в организме мышевидных грызунов (тушканчиков *Allactaga major* Kerr, *Allactaga saltator* Eversmann и сусликов *Citellus erythrogenus* Brandt), обитающих в местах испытания ядерного оружия Семипалатинского испытательного полигона и параметры перехода радионуклида ^{137}Cs в организм исследуемых животных. Показано, что относительно повышенные значения удельных активностей радионуклида ^{137}Cs в организме тушканчиков и сусликов отмечаются при условии их непосредственного проживания на локальных участках загрязнения. При удалении от участков загрязнения на расстояние, превышающее радиус активности животных, высоких значений удельной активности радионуклидов в животных не фиксируется. Несмотря на то, что животные обитают на участках с высокой удельной активностью радионуклидов в компонентах природной среды, экстремально высокого содержания радионуклидов в организме этих животных не отмечается.

Средние значения (AM±SD) CR_{muscl} радионуклида ^{137}Cs для мышечной ткани тушканчиков прыгунов (*Allactaga saltator* Eversmann) составили $(2.1\pm1.3)\times10^{-3}$ (n-11), для мышечной ткани большого тушканчика (*Allactaga major* Kerr) – $(4.7\pm2.7)\times10^{-3}$ (n-9), для мышечной ткани суслика краснощекого (*Citellus erythrogenus* Brandt) – $(7.0\pm5.6)\times10^{-3}$ (n-6).

Ключевые слова: *радиоэкология, радионуклиды, ^{137}Cs, мышевидные грызуны, СИП.*