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Assessment of radiation exposure of murine rodents at the EURT territories

Research Article

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Abstract: The study provides data on contemporary levels of radiation exposure of organs and tissues of murine rodents (several species of mice and voles) inhabiting the East-Ural Radioactive Trace. The estimation procedure involves the most advanced approach based on application of appropriate voxel phantom and biokinetic model. Input data for dose assessment are the results of measurements of skeletal ^{90}Sr activity concentration. Maximal internal dose to skeleton, accumulated during 45 days, is 303 mGy. Median internal dose rates on the last day before trapping were 0.83, 0.092 and 0.023 mGy/day for animals trapped at the sites with initial (1957) ^{90}Sr surface contamination >37 MBq/m^2, 18.5-37 MBq/m^2 and 0.074-18.5 MBq/m^2 respectively. Taking to account internal and external exposures, upper boundary of the ICRP Derived Consideration Reference Level (DCRL) is exceeded on the territory with maximal level of the initial ^{90}Sr surface contamination. On the territory with 18.5-37 MBq/m^2, whole body mean dose rates to murine rodents exceed the lower boundary of DCRL. On the areas with lower level of surface contamination, even the 90-th percentile of dose rate is below the DCRL.

Keywords: *EURT • Murine rodent • Radiation doses • Sr-90 • Environment contamination*

1. Introduction

East-Ural Radioactive Trace is the territory contaminated by radioactive elements after the accident at the Mayak nuclear plant in 1957. Overheating and consequent explosion of the tank with wastes of weapon grade plutonium production resulted in large amount of short- and long-lived radionuclides to be released into the atmosphere [1].

Initial level of surface contamination by ^{90}Sr in the head part of EURT exceeded 37 MBq/m^2. Population of the most contaminated territories was evacuated in a few months after the accident. Biota of these areas received very high doses of exposure. According to [2], small mammals inhabiting the epicenter and the head part of EURT were exposed to the lethal doses of radiation during the early months after the accident; degradation of phytocenoses was observed during the first two years [3].

After the short lived radionuclides completely decayed, radioactivity of the soil is mostly caused by the long lived ^{90}Sr and to less extent by ^{137}Cs. ^{90}Sr is of particular interest for radiobiology and radiation immunology, as it accumulates in skeleton and affects bone surface, haematopoiesis and, consequently, the immune system.

Until the end of 1980-s, results of studies on EURT biota were classified. Nevertheless, the investigations of the radioactive contamination and health effects of biota and population were carried out and their results were published later (*e.g.* [2]). Studies performed during the last 20 years in the EURT were devoted to the transfer of radionuclides to plants and animals and the effects of ionizing radiation exposure of EURT biota. Estimates of

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doses and effects of irradiation on plants are presented in [3,4]. Among other animals, the murine rodents are the most studied [5-16].

Studies of mole vole (*Ellobius talpinus*), a subterranean rodent with a lower rate of migration, provided important results. These animals have demonstrated the activation of immune system, completeness of immune response to infection. Effects such as increase in the frequency of aberrant cells, pathological changes and suppression of both immune and hematopoietic systems were not seen [10,12,17,18]. Lyubashevskiy *et al.* [18] have concluded that EURT mole vole have developed perfect adaptation to the surrounding radiation.

The mice and voles inhabiting the same territories and spending considerable time aboveground successfully occupy the unfavourable contaminated environment yet maintain a population density comparable to those in the control group. At the same time, about 70% of animals had changes in blood count, structure and function of the cells and chromosomes (increased frequency of chromosomal aberrations and micronuclei), symptoms of immunosuppression and other non-lethal pathologies [12,18,19]. That's why their adaptation can not be considered as perfect. Results mentioned above and other findings become valuable when compared with adequately estimated doses of radiation exposure. In order to further our understanding in the radioecological studies of EURT small mammals, precise estimations of doses to organs and tissues caused by ^{90}Sr accumulated in the skeleton are necessary.

Earlier assessments of exposure of small mammals accumulated ^{90}Sr are presented in [5,20-22]. Typically, dose calculations were based on estimates of the fraction of radiation energy that is absorbed in the skeleton and soft tissues of the animal (absorbed fraction, AF). To date, the most accurate estimates of absorbed fractions can be obtained using voxel phantoms and simulation of radiation transport with specialized computer codes. *E.g.* for humans, the calculations of dose coefficients relating the intake of radionuclides and the equivalent dose in organs are made using the human voxel models. Recently, a number of animal voxel phantoms, particularly mice voxel phantoms, were developed [23-27].

For the purposes of internal dose assessment it is important to take into consideration the dynamics of radionuclide accumulation in the each organ using biokinetic models. It should be noted that there are a lot of studies of strontium retention in the organism of murine rodents, but usually these studies are limited to the analysis of strontium accumulation in the skeleton.

The purpose of the present study is to calculate and analyse the internal doses to EURT murine rodents using newer dosimetric and biokinetic models and the data on the skeletal ^{90}Sr activity for animals inhabiting territories of EURT with different levels of surface contamination.

2. Materials and Methods

Internal doses to organ and tissues were estimated for several species of mice and voles trapped at the EURT territories by the staff of the Institute of Plants and Animals Ecology (IPAE) in 1992-2010. ^{90}Sr activity in the long bones was measured using conventional method of ashed bone radiometry [7,19]. Starichenko *et al.* [19] published a review of the data on skeletal ^{90}Sr activity in mice and voles inhabiting territories of EURT with different levels of surface contamination. A total of 1042 animals were used for the study. Of the animals studied, 12 were trapped at the area with initial ^{90}Sr surface contamination of more than 37 MBq/m^2, 561 – at the areas with initial ^{90}Sr surface contamination of 18.5-37 MBq/m^2 and 469 – 0.074-18.5 MBq/m^2. Using developed nondestructive methods [28] ^{90}Sr activity was measured in the skulls of 38 animals stored in environmental samples depository of the IPAE. The animals were trapped in 2005 at territories with the maximal level of ^{90}Sr surface contamination (>37 MBq/m^2) [29]. In the present study the data on ^{90}Sr activity was measured using two methods with the assumption that average ^{90}Sr activity in skeleton is equal to that in long bones and is 1.8 times higher than in skull.

To estimate the internal dose to organs and tissues, the coefficients linking the skeleton ^{90}Sr activity and absorbed doses were used [29]. These coefficients were calculated using published values of absorbed fractions of beta-radiation energy for different combinations of source and target organs [23] and spectra of ^{90}Sr and ^{90}Y radiation [30]. The distribution of ^{90}Sr in organs and tissues was estimated using existing biokinetic models for mouse-like rodent that was adjusted and verified with published experimental data on strontium retention in the bodies of laboratory and wild mice [31]. External dose was estimated using RESRAD Biota tool [32].

3. Results

Combined data on murine rodent skeletal ^{90}Sr activity are presented in Figure 1. The figure shows cumulative distribution functions of skeletal ^{90}Sr activity in animals trapped at the territories with different ^{90}Sr surface contamination.

The results of estimates of doses to organs and tissues of murine rodents inhabiting the most

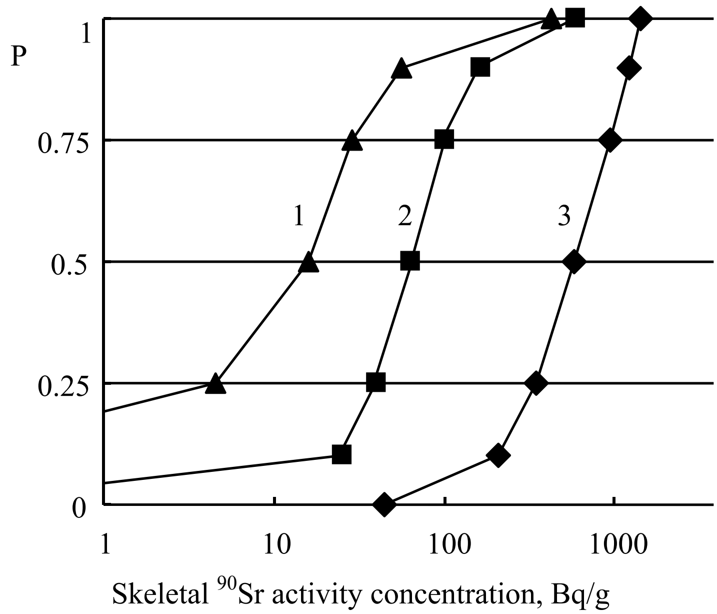

Figure 1. Cumulative distribution of skeletal ^{90}Sr activity of animals trapped at the territories of EURT with different ^{90}Sr surface contamination: 1 – 0.074-18.5 MBq/m^2 (n=561); 2 – 18.5-37 MBq/m^2 (n=469); 3 – >37 MBq/m^2 (n=50) [19,29].

contaminated part of the EURT are presented in Figure 2. The figure shows the median value (bars) and 90-th percentile of internal dose (whiskers). Maximal and mean internal doses to skeleton are 303 and 134 mGy respectively. The most exposed organs among the soft tissues are the lungs, where the internal dose amounts to 46% of that to skeleton. Doses to other organs and tissues are in the range of 5-30 mGy. In territories with lower surface contamination, the radiation doses decrease proportionally to the average skeletal ^{90}Sr activity concentration: by 89% at the area with 18.5-37 MBq/m^2 and by the 97% at the area with 0.074-18.5 MBq/m^2.

Figure 3 shows the whole-body dose rates estimated on the last day before trapping for murine rodents from different sites. Median internal dose rates on the last day before trapping were 0.83; 0.092 and 0.023 mGy/day for the animals trapped at the sites with initial ^{90}Sr surface contamination >37 MBq/m^2; 18.5-37 MBq/m^2 and 0.074-18.5 MBq/m^2 respectively. External dose rate at the most contaminated area is about 0.43 mGy/day.

4. Discussion

The presented study provides data on contemporary levels of radiation exposure to organs and tissues of EURT murine rodents. The estimation procedure involves the most advanced approach based on the use of appropriate voxel phantom and biokinetic models. Input data for dose assessment were the results of direct measurements of the skeletal ^{90}Sr activity concentration that allows avoiding the use of radionuclide transfer coefficients.

Contemporary doses of radiation exposure of murine rodents inhabiting certain areas remain rather high. Mean skeletal doses accumulated during 45 days (the period from the weaning to the trapping in August, assuming that the animal was born in June and the period of lactation lasted for 3 weeks) exceed 100 mGy. Maximal skeletal dose exceed 200 mGy. Annual dose for animals escaping the trapping would be much higher. Such doses of exposure to bones and bone marrow may account for the adverse effects to the haematopoiesis and immune system that were observed in animals exposed to radiation. The pathogenesis of such disorders may be associated with hereditary damage or tissue reactions to irradiation. Evidence suggesting hereditary effects caused by the exposure to more than 100 generations of animals is supported by genomic instability found in offspring [6,8] and morphological changes of the mandible of the pygmy wood mouse (*sylvaemus uralensis* Pall.) [14]. At the same time, biochemical changes [15] and morphological variation of the skull of mole vole are associated with the level of ^{90}Sr accumulation in the skeleton [33]. Results of the study of allozyme variability in the population of EURT rodents [16] provide new data for the discussion about the mechanism of the effects of radiation.

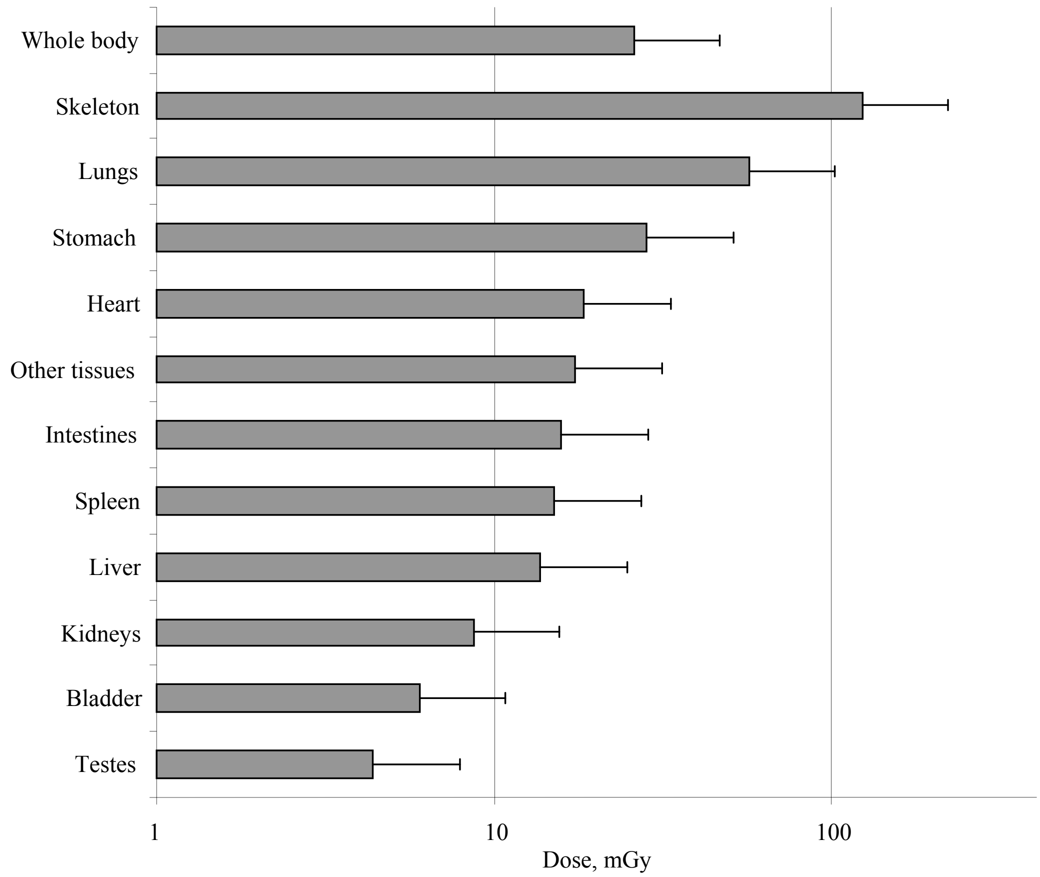

Figure 2. Internal doses to organs and tissues and whole-body dose to murine rodents from the most contaminated part of EURT (^{90}Sr surface contamination >37 MBq/m²), accumulated during 45 days. Bars – median value, whiskers – 90-th percentile, n=50.

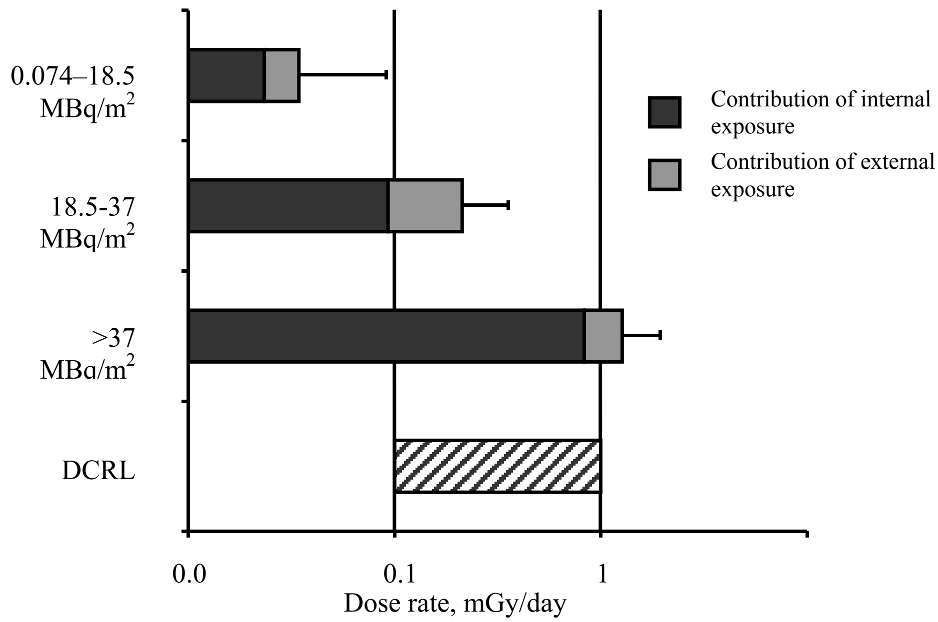

Figure 3. Whole-body dose rates on the last day before trapping for murine rodents from different sites compared to DCRL. Bars – median value, whiskers – 90-th percentile.

It should be noted that similar doses (about 100 mGy) were accumulated in the skeleton of human population of EURT that lived in 1957-1962 in contaminated settlements [34]. Generally, observed health effects, particularly the increase of risk of immune related diseases [35], are comparable with the biological effects in murine rodents.

Contemporary levels of exposure of murine rodents is significant in the most contaminated part of the EURT only. In territories with initial ^{90}Sr surface contamination less than 18.5 MBq/m^2 contemporary radiation doses to skeleton are 30-40 times lower. In territories situated as far as 10 km from the EURT epicentre, the murine rodents do not experience significant radiation exposure taking into account the ICRP criteria and approaches to radiation protection of biota. While analyzing the radiation exposure of the animals, it should be taken into account that the doses are affected by a migration, which is discussed *e.g.* in [19]. Different levels of contamination would causes uneven daily ^{90}Sr intake that would change the pattern of dose cumulating. Measured skeletal Sr activity concentration that determines the dose rate on the last day before trapping may be used as a marker of migration. According to [19] in the most contaminated area, 10% of mice and voles are migrants.

In publication 108 [36] for the purposes of the radiation safety of biota, the ICRP introduces the concept of Reference Animals and Plants. Based on the data from biological effects of radiation for each reference organism, the Derived Consideration Reference Levels (DCRL) have been defined. For existing or planned exposure situation doses to reference organisms are to be compared with relevant DCRLs. For the purposes of the environment protection, ICRP recommends the representative organism, which is the actual object of protection under consideration. Murine rodents may be chosen as the representative organisms for the EURT. The closest reference organism to these animals is the reference rat, for which the DCRL is 0.1-1 mGy/day. As shown in Figure 3, upper boundary of the DCRL is exceeded in the territory with maximal level of the initial ^{90}Sr surface contamination. In territory with 18.5-37 MBq/m^2, mean doses to murine rodents exceed the lower boundary of DCRL. While in the areas with lower level of surface contamination even 90-th percentile does not reach the DCRL.

The analysis of contemporary doses demonstrates that in accordance with ICRP recommendations the optimisation of biota radiological protection is required on the EURT territories with initial ^{90}Sr surface contamination greater than 18.5 MBq/m^2. Radiation protection of EURT biota should be aimed to reduce exposures to levels that are within the relevant DCRL bands. Appropriate approaches to radiation protection of biota under existing exposure situation should be developed.

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