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Contemporary radiation doses to murine rodents inhabiting the most contaminated part of the EURT

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ABSTRACT

The contemporary radiation doses to the organs and tissues of murine rodents inhabiting the most contaminated part of the EURT were estimated. The bones of animals trapped in 2005 at territories with a surface ^{90}Sr contamination of 24–40 MBq/m^2 were used for dose reconstruction. The concentration of ^{90}Sr in the animals' skulls was measured using the nondestructive method of bone radiometry. The dose estimation procedure included application of the published values of absorbed fractions of beta-radiation energy for different combinations of source and target organs, accounting for the distribution of radionuclide by organs and tissues. Twelve conversion coefficients were obtained to link the skeleton ^{90}Sr concentration and doses to eleven organs and the whole body. The whole-body dose rate on the 45th day after the beginning of exposure normalised to whole-body activity is 0.015 (mGy day^{-1})/(Bq g^{-1}). The estimation yields the following values of doses for *Microtus agrestis*, *Sylvaemus uralensis* and *Clethrionomys rutilus*, respectively: maximum absorbed doses in the skeleton: 267, 121 and 160 mGy; mean whole body internal doses: 37, 14 and 23 mGy; mean internal dose rates on the last day before trapping: 1.2; 0.44 and 0.75 mGy/day. Approaches to the assessment of doses to foetuses and to offspring before weaning were also developed.

1. Introduction

Assessment of doses either to the entire organism or to organs and tissues is considered an important phase of radiobiological study. Obtaining quantitative estimates of radiation exposure allows the dose effect relationship to be contextualised for research. Radiation risk models are being developed to improve the radiological protection of humans and biota based on radiobiological experiments and observations with reliable dosimetric scaling.

In conventional radiation dosimetry, the radiation exposure is described by the absorbed dose, which is defined as the energy deposited in a medium by the ionising radiation per unit mass. Biological response to the radiation exposure is considered a function of the absorbed dose. The approach to dose assessment maintained by the ICRP for internal exposure in humans generally consists of the creation and application of biokinetic models of radioactive elements and dosimetric models of human organs and systems, such as the gastrointestinal and skeletal systems. To some extent, similar approaches can be applied to the exposure of animals and plants.

The East-Ural Radioactive Trace (EURT) is considered one of the most contaminated territories on Earth (Jones, 2008; Volobuyev et al., 2000) and draws significant research interest due to the high levels of environmental radiation exposure. Although many years have elapsed since the accident and radioactive contamination of 1957, the contemporary radiation situation remains elevated over the natural regional background and is mostly determined by long-lived ^{90}Sr that has been concentrated in the upper layers of soil.

Through a number of radiobiological and radioecological studies of the EURT, a substantial amount of observational data has been accumulated. The results of studies performed in early years after the accidents were published after 1989 (Alexakhin et al., 2004; Romanov, 1993), when information on the event was officially disclosed (Nikipelov et al., 1989). In later studies, the research topics were as follows: surface contamination (Kryshev et al., 1998; Molchanova et al., 2009; Pozolotina et al., 2008), characteristics of radiation exposure of plants (Karimullina et al., 2013; Pozolotina et al., 2010) and animals (Starichenko, 2011; Starichenko, 2000; Starichenko and Liubashevskii, 1998; Starichenko and Zhukovskii,

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2012), and effects of radiation exposure for biota (Bol'shakov et al., 2012; Gileva et al., 2000, 1996; Grigorkina and Olenev, 2009; Ialkovskaia et al., 2010; Liubashevskiĭ and Starichenko, 2010; Lyubashevsky et al., 1996, 1995; Orekhova and Rasina, 2012; Rasina et al., 2013; Vasil'eva et al., 2003; Vasil'ev et al., 2010). In particular, in the Institute of Plant and Animal Ecology (IPAE), a collection of bone specimens of murine rodents trapped in the EURT was established. Despite the numerous radioecological studies conducted, there are still a number of important unsolved problems, which require precise dose estimation. It is necessary to note that the problem of dose assessment due to ^{90}Sr internal exposure arises in radiobiological experiments as well. For example, in a recent ICRP publication (ICRP, 2012), relevant animal model data were considered in comparison with ^{90}Sr intake without estimation of either whole body or skeletal doses.

For purposes of dose estimation in radiobiological studies of EURT mammals, it is necessary to consider that strontium is a bone-seeking element. Retention of ^{90}Sr in bone tissues results in a strongly inhomogeneous distribution of the radionuclide through the organism. Recently, Malinovsky et al. (2013) suggested a model describing the biokinetics of strontium for murine rodents, which represented modification of the ICRP model for Reference Human with a reduced number of compartments. To estimate parameters of the biokinetic model (transfer rates), the published experimental data on strontium retention in the bodies of laboratory and wild mice were analysed. A suggested set of eleven transfer rates satisfactorily described both the laboratory experiments and the data on radio-strontium content available for wild animals. Application of the strontium biokinetic model allows estimation of the ^{90}Sr distribution by organs and tissues in the cases of both acute and chronic exposure with assessment of ^{90}Sr concentration in organs with the time since the beginning of exposure.

To estimate internal doses, two approaches are generally applied. In the first approach, the animal is represented using a simple geometry with a uniform distribution of the radionuclide by volume. The most elementary assessment of the internal dose due to β-radiation in this case is based on the assumption that the energy of the β-particles is entirely absorbed in the source object (Ryabokon et al., 2005). Taranenko et al. (2004) and Ulanovsky and Pröhl (2008) further developed this homogeneous simplification and calculated dose conversion coefficients for reference animals and plants based on an estimation of absorbed fractions. The conversion coefficients obtained by Ulanovsky and Pröhl (2008) are presented in ICRP Publication 108 (ICRP, 2008).

However, the homogeneous isotropic modelling of a mammal may result in significant bias of the radiation dose estimate in the case of internal exposure to radionuclides with inhomogeneous retention in organs and tissues. Designing inhomogeneous models is also important in radiobiological experiments when the dose absorbed in a specific organ is crucial. Considering an organism as an assembly of organs and tissues with known biokinetic characteristics is central in the procedure of internal dose assessment for humans. Consistent with this approach, digital 3D voxel-based models have been developed for various animals (Mohammadi and Kinase, 2011; Stabin et al., 2006).

In this paper, the voxel-based model approach is applied for the assessment of the contemporary radiation doses for murine rodents inhabiting the most contaminated part of the EURT.

2. Materials and methods

The absorbed doses were estimated for animals trapped in August of 2005 at EURT territories with surface ^{90}Sr contamination ranging from 24 to 40 MBq/m^2 (Molchanova et al., 2009; Pozolotina et al., 2008). The bones of 38 animals stored in the environmental samples depository of the IPAE, including 19 males and 19 females of three species (*Sylvaemus uralensis* – 14 animals, *Microtus agrestis* – 20 animals, *Clethrionomys rutilus* – 4 animals), were provided for measurements of ^{90}Sr activity. According to the accompanying records, the mean body mass of the trapped animals was 26 g (14.4–41.1 g).

The concentration of ^{90}Sr + ^{90}Y in bones was measured via non-destructive β-radiometry, as previously developed (Malinovsky et al., 2012). While the conversion coefficients from β-particles count rate to the ^{90}Sr concentration were obtained using the wet weight of bones, only the dry weight was known for skulls from the depository. To account for the bone drying, we applied a dry weight to fresh weight conversion factor of 2, which was experimentally observed. Also, based upon own data, skeleton ^{90}Sr concentration was accepted as 1.8 of that in skull.

For the estimations of energy absorbed in organs and tissues, values of absorbed fractions (AF) of β-radiation energy obtained by Stabin et al. (2006) using voxel-based mouse model were utilised. The model included the following organs and tissues: lungs, skeleton, heart, liver, kidneys, stomach, intestines, spleen, testes, bladder, and other tissues. The voxel dimensions were 0.2 × 0.2 × 0.2 mm. The AF values were presented for different combinations of source and target organs at discrete initial energies of electrons ranging from 0.1 to 4.0 MeV.

To estimate doses to animals inhabiting the EURT, we performed additional calculations as below. For each combination of source and target organs, the energy absorbed in the target organ per a decay of ^{90}Sr in source organ, AE, was calculated as a sum of the contributions from ^{90}Sr and ^{90}Y decays:

$$\mathrm{AE}_{i,j} = \frac{1}{\int_E \gamma_{\mathrm{Sr-90}}(\varepsilon)\mathrm{d}\varepsilon}\cdot\int_E \varepsilon\cdot\mathrm{AF}_{i,j}(\varepsilon)\cdot\gamma_{\mathrm{Sr-90}}(\varepsilon)\mathrm{d}\varepsilon + \frac{1}{\int_E \gamma_{\mathrm{Y-90}}(\varepsilon)\mathrm{d}\varepsilon}\cdot\int_E \varepsilon\cdot\mathrm{AF}_{i,j}(\varepsilon)\cdot\gamma_{\mathrm{Y-90}}(\varepsilon)\mathrm{d}\varepsilon, \quad (1)$$

where $\mathrm{AE}_{i,j}$ is the energy absorbed in the i-th target organ per the decay of ^{90}Sr and subsequent decay of ^{90}Y in j-th source organ, MeV; ε is the energy of β-radiation; $\gamma(\varepsilon)$ is the energy spectrum of ^{90}Sr and ^{90}Y (average energy is 0.196 MeV and 0.934 MeV, respectively); and $\mathrm{AF}_{i,j}(\varepsilon)$ is absorbed fraction of energy for a given combination of the i-th source and j-th target organ.

Table 1 shows the accepted masses of organs for murine rodent with total weight 27 g. For soft tissues, the organ masses were taken in accordance with the voxel-based mouse model presented by Stabin et al. (2006); skeleton mass was considered to be 10% of body mass. The AFs for cases when other tissues (including muscles)

Table 1
Organ masses of model mouse for radiation dose assessment (body weight 27 g).

Organ	Mass, g
Bladder	0.012[a]
Heart	0.143[a]
Intestine	0.952[a]
Kidneys	0.334[a]
Liver	0.780[a]
Lungs	0.125[a]
Skeleton	2.70[b]
Spleen	0.022[a]
Stomach	0.298[a]
Testes	0.141[a]
Other tissues (including muscles and fur)	21.49

[a] From Stabin et al. (2006).
[b] 10% of body weight.

are the source of radiation are not presented in the supplemental tables of Stabin et al. (2006). As seen in Table 1, other tissues constitute a significant part of the animal's body mass. To estimate the contribution of other tissues to the radiation dose, the value of energy absorbed in other tissues AE = 0.5 MeV was applied. It was also accepted that doses to other organs are equal to the dose of self-irradiation of other tissues.

Time dependencies of ^{90}Sr activity in each organ were estimated with a biokinetic model that consists of the following compartments: Blood, Gastrointestinal tract (GIT), Soft tissues, Skeleton, and Urinary bladder (Malinovsky et al., 2013). The compartment of the biokinetic model called "Soft tissues" was assumed to include the following organs: lungs, heart, liver, kidneys, spleen, testes, bladder, and other tissues. It was also assumed that activity in each organ is proportional to the ratio of the mass of that organ to the total mass of all organs included in the compartment "Soft tissues". Similarly, stomach and intestines were included in the compartment "GIT". The bladder belonged to "Soft tissues" because activity in the compartment "Urinary bladder" is associated more with the activity of ^{90}Sr in urine than in the organ walls.

The internal dose rate was calculated using the following equation:

$$\dot{D}_i\,(t) \;=\; 1.6\cdot 10^{-10}\left[\frac{\mathrm{J}}{\mathrm{MeV}}\cdot\frac{\mathrm{g}}{\mathrm{kg}}\right]\cdot 86400\left[\frac{\mathrm{s}}{\mathrm{day}}\right]\cdot\sum_j \frac{\mathrm{AE}_{i,j}}{m_i}\cdot A_j(t), \tag{2}$$

where $\dot{D}_i(t)$ – dose rate in B i-th organ due to ^{90}Sr incorporated in the organism, Gy/day; t – time after a beginning of ^{90}Sr intake, day; m_i – target organ mass, g; $A_j(t)$ – ^{90}Sr activity in the j-th source organ, Bq.

Internal dose to organs was calculated using the following formula:

$$D_i \;=\; \int_0^T \dot{D}_i\,(t)\mathrm{d}t, \tag{3}$$

where D_i is the dose to organ, Gy, received during a period of T days.

The whole-body internal dose was estimated as a ratio of the sum of the energy absorbed in each organ to the body mass.

In Equation (3), parameter T represents the time between the beginning of exposure and the trapping. It is assumed that ^{90}Sr intake begins at $t = 0$ and remains constant until time T. For subsequent calculations, T is accepted to be 45 days, corresponding to the minimum period of time from weaning (at the age of three weeks) to capture in August, with the animal at approximately 70 days of age. If the real age of the animal is greater, the obtained dose will be underestimated.

External doses were calculated with the computer software RESRAD Biota (ISCORS, 2004). The following parameters were set: ^{90}Sr concentration in soil amounts 264 kBq/kg (Molchanova et al., 2009), object dimensions 10 × 2 × 2 cm, mass 25 g. The ERICA Assessment Tool was not used because its dose conversion coefficients for situations of external exposure were estimated only for exposure to photons (Ulanovsky and Pröhl, 2008).

The doses during foetal life and lactation period were also estimated. This procedure was based on data from experiments carried out by Bertho et al. (2012) and Synhaeve et al. (2011), in which mice were contaminated through drinking water with a daily ^{90}Sr intake of 75–90 Bq. Parent contamination started two weeks before mating, females were treated during pregnancy and lactation, and offspring received contaminated water until they reached 20 weeks. Periodically, several animals were anesthetised and killed, and the activity of ^{90}Sr was measured in whole body and in bones. According to Synhaeve et al. (2011), the whole-body ^{90}Sr concentration of offspring at birth and at the time of weaning amounted to 20 and 40% of female parent whole-body ^{90}Sr concentrations, respectively. The data presented by Synhaeve et al. (2011) allow the estimation of doses to foetuses and young animals (before weaning) based on the ^{90}Sr concentration in the mother's skeleton. As a simplification, to assess the doses to foetuses and young animals, dose coefficients obtained for adults were applied. Periods of pregnancy and lactation were each assumed to be 21 days.

To account for the contribution of ^{90}Y ingestion, it was suggested that absorption of yttrium from the gastrointestinal tract is insignificant (e.g., for humans, the absorption fraction is $f1 = 0.0001$ (ICRP, 2006)). For organs and tissues other than the gastrointestinal system, the calculations were made under the assumption that the activities of ^{90}Sr and ^{90}Y are in equilibrium. Activity of ^{90}Sr in blood was distributed among organs in proportion to their weights.

3. Results

Measurements show that the skeleton ^{90}Sr concentration varies for animals of different species. A lower value of ^{90}Sr concentration is observed for the species *S. uralensis*: the mean is 300 ± 82 Bq/g (95% confidence interval), and the range is 44–562 Bq/g. The mean value of ^{90}Sr concentration for *M. agrestis* reaches 811 ± 133 Bq/g (range 116–1249 Bq/g). The third species (*C. rutilus)* is represented by only four animals, for which the mean value of skull ^{90}Sr concentration is 520 ± 273 Bq/g (354–751 Bq/g). Assuming that the strontium biokinetics are similar, solving the biokinetic model and considering those values of ^{90}Sr concentration returns a daily intake from 39 Bq for *S. uralensis* to 191 Bq for *M. agrestis*.

Considering the values of the AF presented by Stabin et al. (2006) for β-energy spectra of ^{90}Sr and ^{90}Y and using Equation (1), the energies absorbed in target organs per a decay of ^{90}Sr in source organs were estimated. The results of these calculations are presented in Table 2 for ten source and eleven target organs.

The data on absorbed energies were used to obtain conversion coefficients linking skeleton ^{90}Sr concentrations and the eleven organ doses (Table 3) as well as the whole-body dose received during $T = 45$ days by the adult animal. The conversion coefficient linking the skeleton ^{90}Sr concentration and the whole-body dose received during 45 days was $4.45\cdot 10^{-5}$ mGy/(Bq/kg). This value corresponds to a whole-body dose rate of $1.5\cdot 10^{-5}$ (mGy/day)/(Bq/kg of body weight) or $1.5\cdot 10^{-6}$ (mGy/day)/(Bq/kg of skeleton weight).

Fig. 1 presents the estimated doses to organs and tissues of murine rodents inhabiting the most contaminated part of the EURT. The mean and maximal internal doses to organs and tissues of murine rodents of three species are shown. The highest skeletal absorbed dose, of 267 mGy, was received by *M. agrestis*. Maximum values of skeletal doses for *S. uralensis* and *C. rutilus* are 121 and 160 mGy, respectively. Mean whole-body (Fig. 2) doses are 37, 14 and 23 mGy for *M. agrestis*, *S. uralensis*, and *C. rutilus*, respectively. Fig. 2 also shows the mean whole-body dose estimates for offspring accumulated over the periods of pregnancy and lactation, ranging from 1 to 7 mGy.

The mean whole-body internal dose rates on the last day before trapping for these species are 1.2; 0.44 and 0.75 mGy/day, respectively, while the external dose rate is approximately 0.4 mGy/day.

4. Discussion

The estimation presented here of the contemporary radiation doses to murine rodents inhabiting the EURT is based on conversion coefficients linking skeleton ^{90}Sr concentration and absorbed

Table 2
Energy absorbed in target organs per the decay of ^{90}Sr in source organ, MeV.

Source organ	Target organ										
	Other tissues	Skeleton	Lungs	Heart	Liver	Kidneys	Stomach	Intestine	Spleen	Testes	Bladder
Skeleton	4.5E-01	5.0E-01	1.0E-02	3.4E-03	1.2E-02	2.3E-03	6.9E-03	2.1E-03	3.0E-04	3.5E-04	6.8E-05
Lungs	4.8E-01	1.2E-01	3.1E-01	4.0E-02	1.0E-01	2.0E-04	1.8E-02	1.7E-04	4.2E-03	0.0E + 00	0.0E + 00
Heart	3.4E-01	0.0E + 00	3.6E-02	6.2E-01	4.6E-02	4.7E-06	1.3E-03	4.4E-05	6.5E-04	0.0E + 00	0.0E + 00
Liver	2.6E-01	2.4E-02	1.7E-02	8.4E-03	7.3E-01	9.4E-03	2.1E-02	2.8E-02	7.7E-03	1.4E-07	0.0E + 00
Kidneys	3.4E-01	1.0E-02	6.5E-05	0.0E + 00	2.2E-02	6.5E-01	1.1E-02	7.2E-02	1.6E-04	1.5E-06	0.0E + 00
Stomach	2.6E-01	3.4E-02	8.0E-03	6.6E-04	5.5E-02	9.1E-03	6.9E-01	2.8E-02	1.3E-02	5.5E-08	0.0E + 00
Intestine	2.6E-01	3.6E-03	2.8E-05	1.2E-06	2.3E-02	2.5E-02	9.1E-03	7.8E-01	1.7E-04	1.1E-03	8.5E-06
Spleen	2.3E-01	2.0E-02	2.5E-02	4.5E-03	2.7E-01	2.7E-03	1.7E-01	6.4E-03	4.0E-01	2.2E-07	0.0E + 00
Testes	4.8E-01	3.8E-03	0.0E + 00	0.0E + 00	8.9E-07	1.4E-05	4.6E-07	7.7E-03	0.0E + 00	5.7E-01	6.6E-03
Bladder	6.3E-01	8.9E-03	0.0E + 00	0.0E + 00	1.1E-06	3.1E-06	0.0E + 00	5.8E-04	0.0E + 00	8.0E-02	3.7E-01

doses that were calculated using published results of the modelling of β-radiation transfer through the organs and tissues of a mouse voxel phantom (Stabin et al., 2006). That approach to internal dose assessment for biota accounts for the inhomogeneous distribution of ingested strontium and allows specific organ dose estimates. The conversion coefficient values presented in Table 3 can be applied generally for the estimation of doses to murine rodents inhabiting the EURT in cases when the ^{90}Sr concentration in the skull or skeleton is available.

In previous studies, a simplified approach consisting of the presentation of mammals as homogeneous objects was generally applied for internal dose estimation for mammals. Ryabokon and Goncharova (2006) utilised a local absorption model to demonstrate low significance of dose due to ^{90}Sr in comparison with external exposure of murine rodents due to the Chernobyl accident. Chesser et al. (2000) and Gaschak et al. (2011) applied approximate estimations of the energy absorbed in the skeletal and muscle tissues of animals for assessment of the internal doses due to ^{90}Sr in murine rodents inhabiting the Chernobyl Exclusion Zone. In Chesser et al. (2000), the dose conversion coefficient was $3.5 \cdot 10^{-6}$ (mGy/day)/(Bq/kg of skeleton weight). The dose rates calculated using that coefficient were 1.5–25.4 mGy/day for skeletal ^{90}Sr concentrations of 112–7249 Bq/g (Chesser et al., 2001). According to Gaschak et al. (2011), the whole-body ^{90}Sr concentrations of 5.0–98.1 Bq/g resulted in internal dose rates of 0.05–0.95 mGy/day, corresponding to the coefficient $0.97 \cdot 10^{-5}$ (mGy/day)/(Bq/kg of body weight). Despite this rather simplified approach, the obtained coefficients are close to the values calculated in our study.

In their review, Alexakhin et al. (2004) presented an estimation of the doses of radiation exposure of EURT murine rodents in the acute period after the accident in 1957 and over the next two decades. The coefficient linking the skeletal radiation dose and the ^{90}Sr surface contamination was considered to be 0.7 (mGy year^{-1})/(kBq m^{-2}). Comparison of this value with the coefficient normalised to skeleton activity requires a concentration ratio (CR) that links surface contamination and skeletal ^{90}Sr activity. Estimates of this value are quite variable (Gaschak et al., 2011), and possible changes in the CR over time after the accident must also be considered.

The dose conversion coefficients proposed by the ICRP (2008) for reference animals and plants, including the reference rat modelled by ellipsoid with axis 20, 5 and 6 cm, were calculated under the assumption of uniform distribution of the radionuclide throughout the body (Taranenko et al., 2004; Ulanovsky and Pröhl, 2008). The estimated dose conversion coefficient for the reference rat in the case of internal exposure due to ^{90}Sr is $1.5 \cdot 10^{-5}$ (mGy/day)/(Bq/kg of body weight), which is equal to the value obtained in the present study for the mouse whole-body dose. Bertho et al. (2012) have also shown that whole-body doses estimated using the dose conversion coefficients provided by ICRP (ICRP, 2008) are close to those calculated by applying the AFs obtained by Stabin et al. (2006) with differences of less than 8%. Keum et al. (2010) proposed a set of seven Korean domestic reference organisms, including the reference rat represented by an ellipsoid with axes of 10, 3 and 2.5 cm and a mass of 39.4 g. The internal dose conversion coefficient calculated for this object, applying the uniform isotropic model, was $1.4 \cdot 10^{-5}$ (mGy/day)/(Bq/kg), which is close to the value obtained in the present study for murine rodent despite the difference in the size and the ^{90}Sr distribution through the volume.

Table 3
Conversion coefficients linking skeleton ^{90}Sr concentration and organs absorbed doses received during $T = 45$ days.

Organ	Coefficient, Gy/(Bq g^{-1})
Skeleton	2.14E-04
Lungs	9.88E-05
Heart	3.21E-05
Liver	2.39E-05
Kidneys	1.51E-05
Stomach	4.95E-05
Intestine	2.76E-05
Spleen	2.64E-05
Testes	7.61E-06
Bladder	1.04E-05
Other tissues	3.03E-05

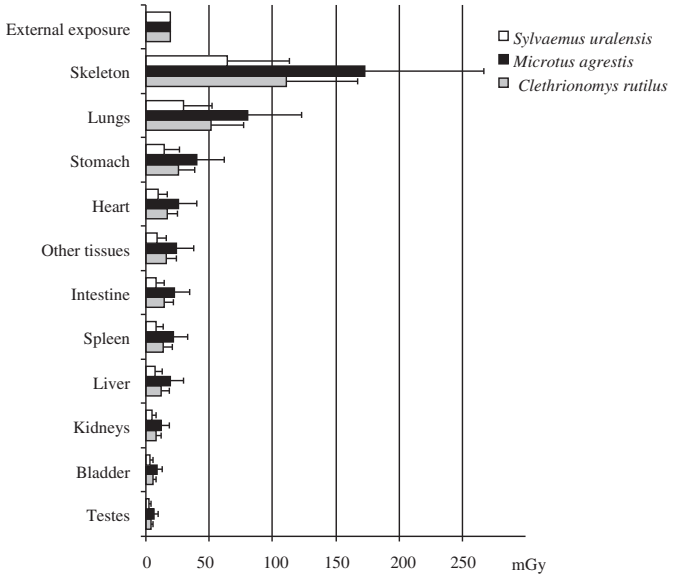

Fig. 1. Mean and maximal internal doses to organs and tissues of murine rodents from the EURT accumulated during 45 days, with external dose.

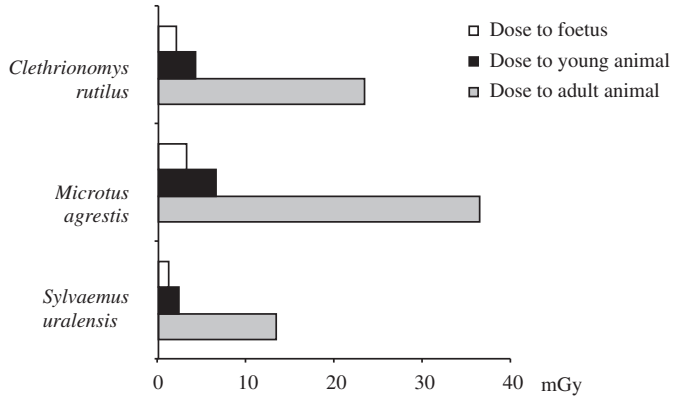

Fig. 2. Mean whole body doses to foetuses, to young animals during lactation, and to adult animals during 45 days.

Thus, it can be concluded that consideration of the distribution of ^{90}Sr through the organism as governed by biokinetics slightly improves the estimation of the whole-body dose for small mammals over that what can be modelled by an ellipsoid. At the same time, in the case of radiation exposure to an incorporated radionuclide, the doses to certain organs and tissues are also of interest. For rodents inhabiting territories contaminated with ^{90}Sr, it was shown that the organ absorbed doses vary by an order of magnitude. As expected, the highest dose estimate was obtained for the skeleton. According to calculations, the skeleton absorbed dose was approximately five times higher than the whole-body absorbed dose. Apparently, analysis of radiobiological effects of small mammals inhabiting ^{90}Sr contaminated areas should not be restricted to the consideration of only whole body exposure. This is particularly important in studying the effects of radiation exposure on organs closely related to the haematopoietic and immune systems.

Though the application of the conversion coefficients presented in Table 3 provides the possibility of assessment for eleven organs and tissues, the mouse model is still not sufficiently detailed. In particular, bone marrow could not be separated from bone tissue, while the technology of voxel phantom creation using computer tomography does not yet achieve the necessary resolution for modelling bone sections. Further, the animal's skin and fur, which may be significant as shielding from external radiation, are not distinguished. Moreover, in addition to the shielding effect, it is necessary to consider the possibility of contamination of the fur that contributes to external exposure.

In contrast to the radiobiological experiments, in the radioecological studies, substantial uncertainty in the assessment of radiation doses is associated with inaccuracy in determination of the age of wild animals. While the ^{90}Sr concentration in a skeleton at the moment of trapping can be measured, the absence of data on the age of the animal does not allow correct reconstruction of radionuclide accumulation dynamics. Therefore, a relatively valid estimate of the dose rate can be made only for the last day of the animal's life.

Thus, the approach developed here, on the one hand, provides the quantitative evaluation of the internal doses to organs and tissues of murine rodents inhabiting territory contaminated by ^{90}Sr. On the other hand performed estimations of whole-body dose confirmed applicability of dose coefficients estimated using homogeneous ellipsoid models of small mammals.

According to the results of calculations, the contemporary whole-body dose rate in the most-contaminated part of the EURT exceeds 1 mGy/day, and the dose to the bone accumulated during the summer season may exceed 100 mGy. In publication 108 ICRP for each reference organism suggested the Derived Consideration Reference Level (DCRL), which represent "band of dose rate within which there is likely to be some chance of deleterious effects of ionising radiation occurring to individuals of that type of reference animal or plant" (ICRP, 2008). For Reference Rat, suggested DCRL covers dose-rate range 0.1–1 mGy/day. According to performed dose assessment, the contemporary whole-body dose rate may exceed the upper boundary of the DCRL for some species in the most contaminated part of the EURT. Within the ICRP concept of radiological protection system, the optimisation of protection of EURT biota should be aimed to reduction of exposures to levels that are within or below the relevant DCRL.

According to the data presented by Alexakhin et al. (2004), the irradiation was lethal during the first year after the accident. In studies performed a few decades later, when the level of exposure became lower, a number of non-lethal effects were revealed. Such central biological effect as adaptation to radiation of murine rodents inhabiting the EURT was studied by Il'enko and Krapivko (1989), Il'enko et al. (1974), Lyubashevskiy et al. (1995). Liubashevskiĭ and Starichenko (2010) have described the phenomenon of radioadaptation of EURT mole vole (*Ellobius talpinus*), subterranean rodent, and suggested the idea that radioadaptation is primary biological process occurred in rodent populations at radioactively contaminated territories. In comparison with mole vole, adaptation of mice and voles is not complete due to higher migration. These animals demonstrate a number of effects, including alteration of haematopoiesis, increased frequency of aberrant cells, immune system suppression and non-lethal pathologies. The important task for future studies of the effects of radiation on EURT biota is the reconstruction of doses with application of the developed strontium biokinetic model and dosimetric approach.

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