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

G.P. Malinovsky [a,*], I.V. Yarmoshenko [a], M.V. Zhukovsky [a], V.I. Starichenko [b], M.V. Chibiryak [b]

[a] Institute of Industrial Ecology UB RAS, S. Kovalevskoy St., 20, Ekaterinburg 620219, Russia
[b] Institute of Plants and Animal Ecology UB RAS, Vos'mogo Marta St., 202, Ekaterinburg 620144, Russia

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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,

* Corresponding author. Tel.: +7 343 3623421; fax: +7 343 3743771.
E-mail address: georgy@ecko.uran.ru (G.P. Malinovsky).

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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.