

RADIOLOGICAL INVESTIGATION OF RED FOX (*VULPES VULPES*) IN LITHUANIA

Raimondas Leopoldas Idzelis¹, Slavomir Bolut², Violeta Čepanko³, Dainius Paliulis⁴

Dept of Environmental Protection, Vilnius Gediminas Technical University,

Saulėtekio al. 11, LT-10223 Vilnius, Lithuania

E-mails: ¹raimondas.idzelis@vgtu.lt; ²slavomir.bolut@gmail.com;

³violeta.cepanko@vgtu.lt (corresponding author); ⁴dainius.paliulis@vgtu.lt

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Abstract. The paper presents ⁴⁰K and ¹³⁷Cs activity concentrations in muscle, bones and liver of red fox (*Vulpes vulpes*) from eastern and northern Lithuania. The short description of the applied radiochemical method is given. Activity concentrations of ⁴⁰K in muscle ranges between 46.06 ± 0.43 and 110.92 ± 4.5 Bq kg⁻¹ (fw = fresh weight). Average content of radioactive Cs in muscle is on the level of 5.78 ± 0.29 Bq kg⁻¹. No clear relationship observed among the radionuclide concentrations in liver. The analyzed test-samples do not show elevated contamination levels when compared with results of bones of small animals (rodents or insectivorous mammals) determined previously, so no accumulation of bone seeking isotopes on higher step of the trophic chain concluded.

Keywords: red fox, radioecology, radionuclide, trophic chain.

1. Introduction

Human activity is closely related with an increasing environmental impact. During the recent years, pollution of the environment has been growing into an extremely relevant issue which changes its significance level from local into regional and progressively gains its global character. There exists a wide range of sources of toxic chemical elements and other pollutants released into the environment. The mankind, continuously using earth resources and encouraging development of civilization, not always ensures environmental protection from different chemical or biological pollution. Some contaminants threaten human health directly while others get into trophic chains and bodies of animals and then become dangerous to our health.

The impact of ionizing radiation became obvious after X-ray, radioactivity, and radioactive materials had been discovered. Radiation protection is a very complex area. Validation of sites for new activities encounters many problems as it is not always easy to estimate quantitatively the benefits and damages of practical action. Application of optimization principle in practice is really complicated – sometimes it is unclear what norms of radiation protection should be applied in one case or another. It is hard to evaluate doses received from different radiation sources and provide for most effective protection measures, and finally, make people believe that invisible and intangible radiation should be beware of, and to prove the others that we cannot do without the ionizing radiation (Butkus 1994).

All the living nature is under the continuous influence of the ionizing radiation emitted by radionuclides of cos-

mic origin and those contained in the Earth's crust. However, only after beginning of its application in medicine, industry and for military purposes, where people faced against larger amounts of artificial ionizing radiation and learned it may cause cancer, genetic damage, and other diseases, limitation of exposure to radiation initiated.

It is necessary to mention the increasing focus on the environmental radiation protection. Development of the system for protection against the impact of ionizing radiation not only for people but living nature as well will encounter many complex problems, solving of which requires not only the endeavor of most of the countries but also the experience accumulated during the researches of the radionuclide dispersion in different ecosystems (Beresford *et al.* 2005).

People follow one principle in radiation protection. It is assumed that sufficient protection of people also safeguards all the living nature. In order to insure themselves, people have established another principle. Protection of living organisms from ionizing radiation must be effective enough to prevent the whole species from extinction due to radiation (Butkus 1994).

Just at the end of the past decade, we could hear some alarming questions on whether people were right in ensuring the living nature protection of such a level that was needed to protect themselves only. There were other issues as well. For example, some organisms are much more sensitive to ionizing radiation than people are and doses tolerable by the latter might be vital to the others. After it is decided that environmental radiation protection is of the same importance as it is for people, a necessity will arise to find ways of evaluating an impact of radionuclide emitted ionizing radiation to terrestrial ecosystems (Mietelski *et al.* 2008).

forest tracts are dominated by areas of birches, black alders, ashes, and oaks all blended with firs.

During the hunting season, five foxes hunted for radiological analysis. One of the foxes hunted in *Linksmučiai* forest, *Pakruojis* district (winter 2007/2008) and the rest four hunted in *Garbenas* forest, *Ukmergė* district (winter 2008/2009).

The analysis performed using following parts of a fox's body: muscle, bones, and liver (Fig. 2).

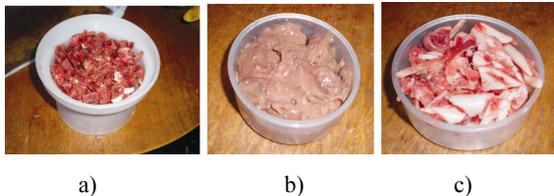


Fig. 2. Samples of fox organs and tissues ready for analysis: a – muscle, b – liver, c – bones

Test-samples of fox organs and tissues chopped up prior burning. Then test-samples mineralized using *SNOL-1,6,2,5.1/9-15* moisture oven until a white ash was obtained. Prepared test-samples put into *Marinelli* vessels for further analysis.

Sampling of plants and mouse-like rodents performed during summer season in *Garbenas* forest (*Ukmergė* district) and its surroundings. 4 bank (common red-backed) voles (*Clethrionomys glareolus*) and 9 striped field mice (*Apodemus agrarius*) captured.

Traps for capturing the rodents positioned in a line (10 pcs., every 15 m). One of the trap-lines set in the forest and the other – in the field two kilometers away. An oil fried bread used as bait. Traps kept in place for 48 hours and checked once a day.

Method of geochemical profiling and survey according to the envelope principle applied for plant sampling. The distance between sampling spots was around 25 meters.

Prior the radiological analysis, plant test-samples dried until a dry mass at 105 °C and then chopped. Radionuclide activity in the test-samples prepared as described above measured using a gamma spectrometer (Radioactive... 2005).

Rodent test-sample preparation for radiological analysis was analogical to fox samples. The prepared test-samples put into measurement vessels and analyzed using a gamma spectrometer.

Measurement of radioactive ^{137}Cs and ^{40}K in fox, rodent, and plant test-samples performed using a gamma spectrometer for spectral analysis with a semiconductor detector. Specific activity of ^{137}Cs and ^{40}K radionuclides first determined in burned test-samples of foxes and rodents and then calculated back to the fresh weight using ascertained coefficients of ash content. Meanwhile, specific activity in plants determined in respect to their dry weight and later converted to the net weight (plant concentration ratio averaged 0.10 ± 0.03).

Radionuclide specific activity, determined in rodent and fox (tissues and organs) ashes converted into net weight (LAND 2001, LAND 2005). Specific activity in

plants calculated in respect of test-sample dry weight. Average concentration ratio of plant net weight and dry weight was 1:10.

Evaluation of specific activity in tissues of plants, rodents, and foxes performed using RESRAD-BIOTA code. The model applied for evaluation of fox trophic chain component contamination with ^{137}Cs technogenic radionuclide. This code is not available for modeling intake rates of natural radionuclides in components of terrestrial and aquatic ecosystems.

The following key parameters used as an input for the code:

1. Specific activity of ^{137}Cs in soil: 7, 70, and 200 Bq/kg (Butkus *et al.* 2002);
2. Volumetric activity of ^{137}Cs in water: 2 Bq/m³ (Kiponas 2002).

Model estimations considered nutrition peculiarities of rodents and predatory mammals, their body weight and a lifespan. Evaluation of plant pollution performed using radioactive contamination transfer parameters that are standard and set in the model of RESRAD-BIOTA code automatically.

Assessment of errors. Errors are influenced by multiple causes: sample unrepresentativeness and test-sample inhomogeneity; sample or test-sample cross-contamination; overlapping of gamma peaks of various radionuclides; inaccuracies in weighing and measurement of volume; measurement of reference source activity; random nature of nuclear transformations (statistical error). In order to avoid cross-contamination of test-samples of different nature and activity, separate sampling and measurement equipment is recommended. System error contains two components: one of them depends on the error (up to 5%) of assessment of the spectrometric system effectiveness, and the other (up to 5%) – on test-sample's inhomogeneity and also on the preset measurement configuration (Bubinas *et al.* 1986).

3. Results and discussion

Data of radiological analysis shows (Fig. 3) that content of ^{137}Cs and ^{40}K radionuclides in fox tissues is conditioned by a common consistent pattern of radionuclide accumulation in an animal body due to the absorption and metabolic processes. It is known that ^{137}Cs belongs to the "diffusion-type" of radionuclides as it accumulates in all kinds of soft tissues, which contain much of potassium and this results in even distribution of ^{137}Cs in bodies of animals (Čepanko *et al.* 2007).

Figs 3 to 9 show specific activities of artificial ^{137}Cs determined in fox muscle, bones, and liver. The analysis results show that the highest accumulation levels of ^{137}Cs as well as of ^{40}K isotope are in muscle (3.18–8.23 Bq kg⁻¹). Meanwhile, activity concentrations of ^{40}K are lower and range from 2.64 to 5.21 Bq kg⁻¹. The highest specific activities of ^{40}K determined in fox muscle and liver (Figs 4 to 6).

^{137}Cs radionuclide accumulation in fox muscle (4.95–10.72%) as per Fig. 3 shows that this radionuclide mostly gets into animal tissues with food. The largest content of ^{137}Cs has accumulated in fox liver, i.e. 10.72% of the total content of ^{137}Cs and ^{40}K radionuclides.

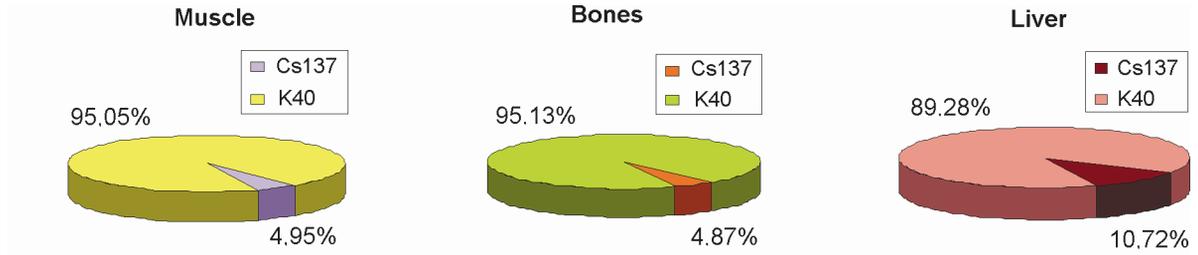


Fig. 3. Average percentage levels of ¹³⁷Cs and ⁴⁰K radionuclide accumulation in fox muscle, bones, and liver

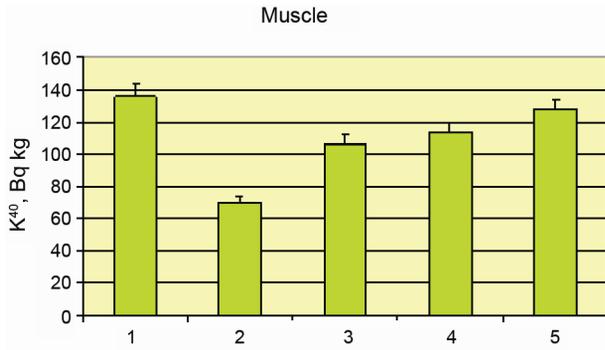


Fig. 4. Specific activities of ⁴⁰K in fox muscle: 1 – Linksmučiai forest; 2, 3, 4, 5 – Garbenas forest

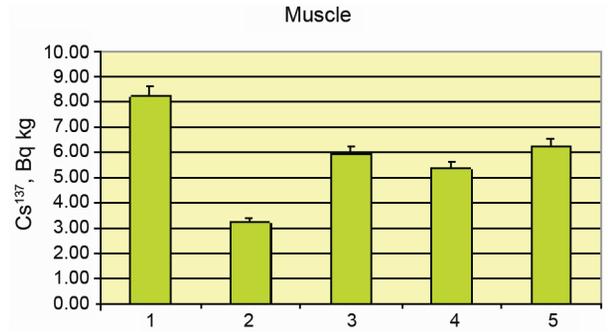


Fig. 7. Specific activities of ¹³⁷Cs in fox muscle: 1 – Linksmučiai forest; 2, 3, 4, 5 – Garbenas forest



Fig. 5. Specific activities of ⁴⁰K in fox bone tissues: 1 – Linksmučiai forest; 2, 3, 4, 5 – Garbenas forest



Fig. 8. Specific activities of ¹³⁷Cs in fox bone tissues: 1 – Linksmučiai forest; 2, 3, 4, 5 – Garbenas forest

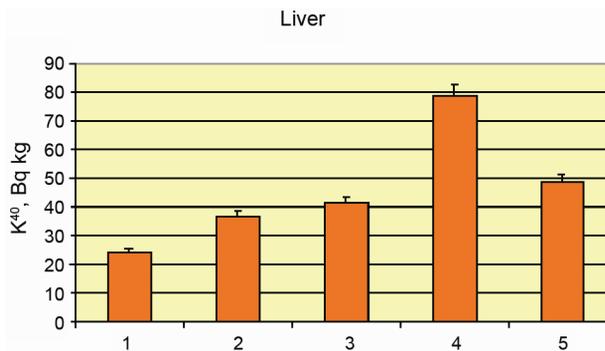


Fig. 6. Specific activities of ⁴⁰K in fox liver: 1 – Linksmučiai forest; 2, 3, 4, 5 – Garbenas forest

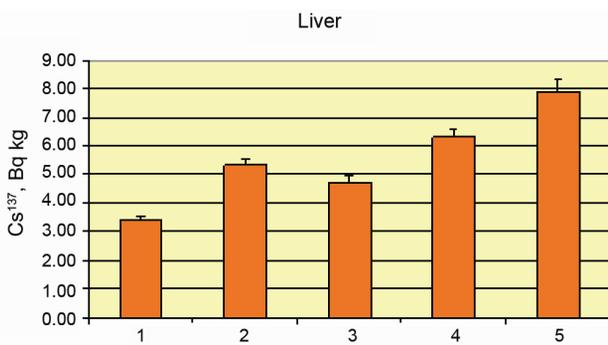


Fig. 9. Specific activities of ¹³⁷Cs in fox liver: 1 – Linksmučiai forest; 2, 3, 4, 5 – Garbenas forest

The highest levels of ^{40}K accumulation determined during the analysis were in fox bone tissues and muscle and amounted respectively to 95.13% and 95.05% of the total contamination of this type with ^{137}Cs and ^{40}K radionuclides. Meanwhile, specific activities of ^{40}K determined in fox liver were slightly lower than in other tissues and amounted to 89.28%.

Like in every human body, fox tissues normally contain radioactive elements, such as potassium, carbon, tritium, radium, plumbum, polonium, and other elements. Tissues contained radioactive potassium, which is usually found in muscle, nervous tissues, and liver. Potassium exists on the Earth from the very start and gets into human and animal bodies not from the nuclear plants as many people might think.

It is determined that radionuclide specific activity in plants and animal bodies depends on the radionuclide, physical and biological properties of its compounds, and also on biological and ecological features of plant and animal species, and environmental pollution (Bluzma 1990; Strand 1997; Lubyte *et al.* 2007).

Tissues of foxes contained ^{40}K , which is not subject to regulation. Average values of fox muscle, bone, and liver analysis presented in Fig. 4 to 6. The analysis results of specific activity of the ^{40}K show that this radionuclide was mostly accumulated in fox muscle. Comparing with the results of radiological analysis of other wild animals (Idzulis *et al.* 2007), levels of ^{40}K specific activity in muscle were quite similar. However, content of this radionuclide accumulated in liver of predators is much higher than in

wild hoofed animal offal put together. This phenomenon can be explained knowing the fact that ^{40}K gets into predators' organs with their food (blood of peaceful animals) and increases the activity concentration. This may also be related with an increased pollution of biosphere components, such as water or soil. The volumetric activity of ^{40}K in the *Baltic Sea* water alone ranges from 500 to 6,000 Bq/m^3 (Nedveckaitė 2004). Moreover, high scale accumulation of ^{40}K might have been influenced by the build-up of this radionuclide in plant and mouse-like rodent mass, knowing the fact that these components comprise major part of a fox's food ration.

Literature data shows (Baltrūnaitė 2006) that ^{40}K is a corresponding element to ^{137}Cs . With respect to this statement, it can be assumed that ^{40}K accumulation levels can be used for estimating ^{137}Cs activity concentrations in animal tissues and organs.

Fig. 10 shows dependencies of ^{40}K and ^{137}Cs distribution in different fox tissues. Correlation coefficients $r^2 = 0.8703$ (muscle), $r^2 = 0.6564$ (bones), and $r^2 = 0.3721$ (liver) that were determined during the research show that accumulation of ^{137}Cs in bones and muscle is directly proportional to the cumulation level of ^{40}K isotope (strong correlation), though in liver, this relation is imperceptible.

It is known that K^+ is the primary exchange ion in respect of Cs^+ ; therefore, their transfer coefficients are usually compared. The research determined positive correlation relation between ^{40}K natural isotopes and ^{137}Cs artificial isotopes.

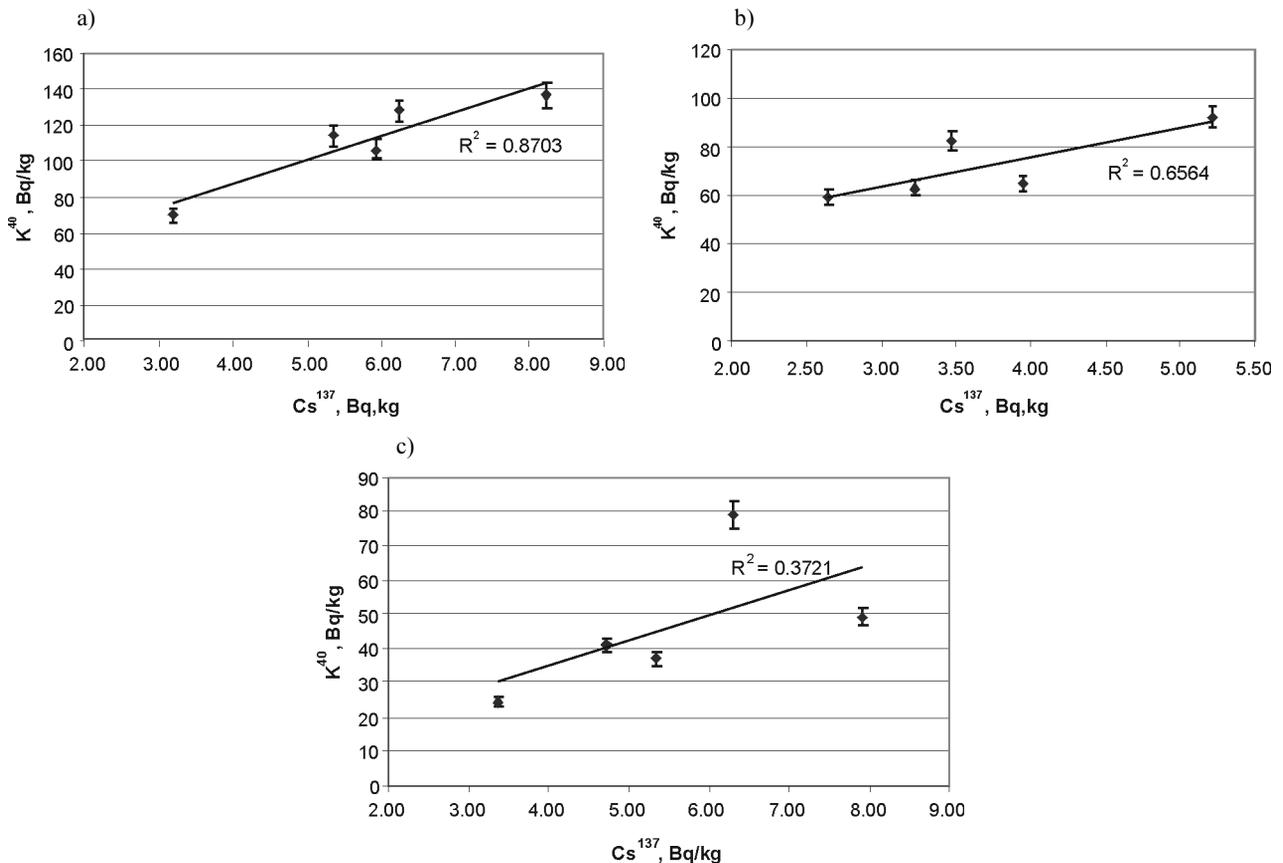


Fig. 10. Correlation of ^{137}Cs and ^{40}K activity concentrations in fox muscle (a), bones (b), and liver (c)

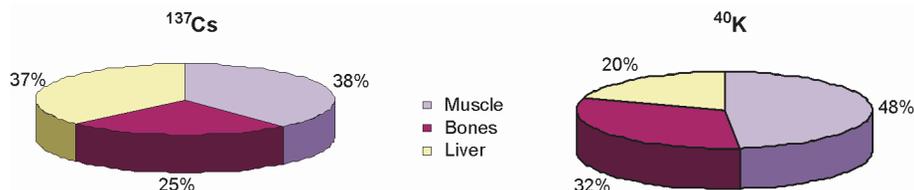


Fig. 11. Specific activities of ¹³⁷Cs and ⁴⁰K in different tissues and organs of the red fox (*Vulpes vulpes*)

Correlation analysis shows that ¹³⁷Cs specific activities can be predicted based on ⁴⁰K activities. Comparing ¹³⁷Cs and ⁴⁰K specific activities in a body of red fox (*Vulpes vulpes*) we see that dissimilarities in different tissues and organs are insignificant and range from 7 to 17%. The greatest difference determined in fox liver with ¹³⁷Cs content 1.85 times higher than ⁴⁰K (Fig. 11).

Foxes hunted in the eastern and northern parts of Lithuania; therefore, their migration area might have been close to the Ignalina Nuclear Power Plant. ¹³⁷Cs activity content accumulated in different tissues and organs of red fox (*Vulpes vulpes*) may be compared using values of radionuclide specific activities determined by Marčiulionienė, Petkevičiūtė (1997) in plants and soil of terrestrial ecosystem in the region of the Ignalina NPP. Mean ¹³⁷Cs activities in a lichen (60.5 Bq/kg) and fox muscle and liver differ by 11 times, and in bones – more than 16 times. Meanwhile, ¹³⁷Cs activity concentration accumulated in terraneous part of the grassland plants (6.6 Bq/kg) differed insignificantly and stayed below the value of 2 times. Mean specific activity of ¹³⁷Cs in fox muscle and liver was 5.78 Bq/kg and 5.53 respectively and came to 17% of the content accumulated in the soil of the Ignalina NPP region (34 Bq/kg); content in bones – around 11%.

As determined during the investigation, ¹³⁷Cs specific activity in fox muscle differs more than 5 times comparing with meat samples of hunted hoofed beasts (Idzelis et al. 2007). This shows that herbivorous animals accumulate higher content of this radionuclide. According to some authors (Mietelski et al. 2008; Il'enko 1974), content of ¹³⁷Cs accumulated in muscle mass of wild beasts may reach up to 100 Bq/kg. The same authors state that ¹³⁷Cs specific activity in red fox bones (ashes) ranges from 1.5 to 41.1 Bq/kg. Mean specific activity of this radionuclide in 64 test-samples of fox bone ashes was 7.48 Bq/kg; this is 250 times more than it was determined during our analysis of 15 test-samples of 5 foxes (up to 0.03 Bq/kg). In this case, it is possible to raise a hypothesis confirmed by the researches of other scientists (Butkus et al. 2005; Marčiulionienė et al. 1997; Nedveckaitė et al. 2004; Ladygienė et al. 2005; Dušauskienė-Duž et al. 1997; Idzelis et al. 2007; Čepanko et al. 2007) and to maintain that background radiation in contaminated areas after the Chernobyl NPP accident is 100 and more times higher than it is in areas close to currently operating nuclear power plants.

Fig. 12 shows results obtained by modeling with RESRAD-BIOTA code. The model used to determine ¹³⁷Cs specific activities in components of the trophic chain of foxes (predatory mammals) at a different level of

soil contamination, i.e. at 7, 70, and 200 Bq/kg. Specific activities in the same components were determined during the research and are presented below.

¹³⁷Cs transfer among components of a fox trophic chain evaluated using the accumulation coefficient which was calculated for the following systems: soil-plants, plants-rodents, and rodents-predators (Fig. 12). Values of transfer and accumulation coefficients obtained during the research compared with data from (Радиоэкология... 1977; Resrad biota...2004; EPIC... 2003) literature sources (Fig. 13).

Figs 14 and 15 show that values of transfer coefficients presented in literature published before the Chernobyl NPP accident (Радиоэкология... 1977) differed from coefficients determined in 2003 (EPIC... 2003). The significant difference of results determined for predators can be explained by estimation of radionuclides ingested with soil. Today it is already known what part of food

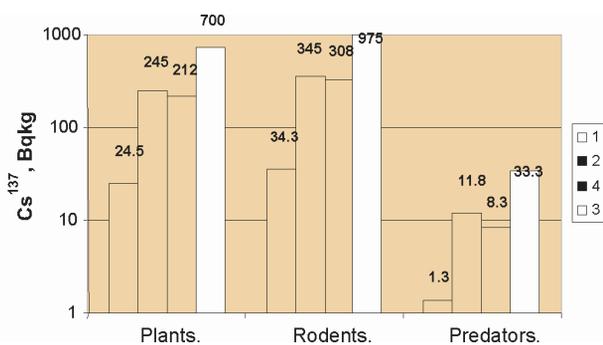


Fig. 12. Modeled (1, 2, 4) and determined (3) ¹³⁷Cs specific activities in components of a fox trophic chain: 1 – soil specific activity is 7 Bq/kg; 2 – soil specific activity is 70 Bq/kg; 3 – soil specific activity is 73 Bq/kg; 4 – soil specific activity is 200 Bq/kg

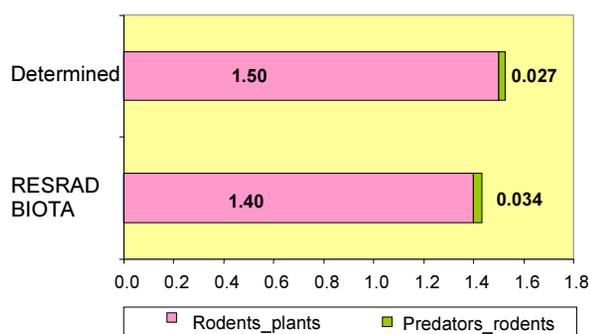


Fig. 13. Determined and used for modeling ¹³⁷Cs accumulation coefficients in components of fox trophic chain

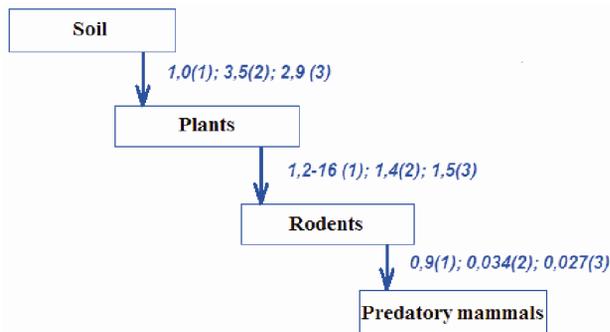
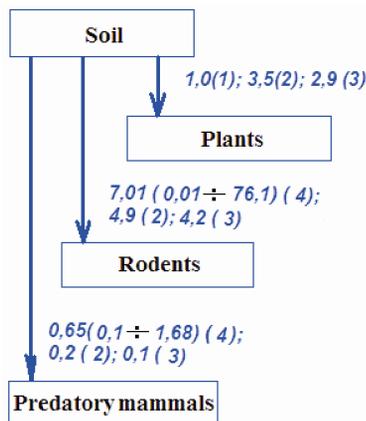


Fig. 14. Values of ^{137}Cs transfer coefficients in fox trophic chain: 1 – Радиоэкология... 1977; 2 – Resrad biota 2004; 3 – research determined; 4 – EPIC... 2003



Note:

Fig. 15. Values of ^{137}Cs accumulation coefficients in fox trophic chain: 1 – Радиоэкология... 1977; 2 – Resrad biota 2004; 3 – research determined; 4 – EPIC... 2003

ration of foxes or other predatory animals is comprised of soil. For instance, literature source (Lowe 1991) states that foxes assimilate 6% of soil with their food and this content has a significant influence for evaluation of contamination with ingested radionuclides. A considerable contribution into the determination of ^{137}Cs transfer coefficients was made by the researches and published papers of Beresford (2005).

Transfer coefficients, which calculated for the systems plants-rodents and rodents-predators, determined for evaluation of ^{40}K migration in a fox trophic chain. Values of the transfer coefficients from plants to rodents were 0.13 and from rodents to predators – 0.34. Potassium is essential for normal functioning of most of the body systems. Therefore, it is not subject to regulation, and transfer coefficients determined are recommendatory.

4. Conclusions

1. The highest specific activities of ^{40}K determined were in fox bone tissues and muscle and amounted respectively to 95.13% and 95.05% from the total contamination of this type with ^{137}Cs and ^{40}K . Meanwhile, specific activities of ^{40}K determined in fox liver were lower than in other tissues and amounted to 89.28%.

2. The analysis results show that the highest accumulation levels of ^{137}Cs radionuclide as well as of ^{40}K isotope are in muscle (3.18–8.23 Bq kg⁻¹).

3. Correlation coefficients $r^2 = 0.8703$ (muscle), $r^2 = 0.6564$ (bones), and $r^2 = 0.3721$ (liver) that were determined during the research show that accumulation of ^{137}Cs radionuclide in bones and muscle is directly proportional to the cumulation level of ^{40}K isotope (strong correlation), though in liver, this relation is imperceptible.

4. Correlation analysis shows that ^{137}Cs specific activities determined in red fox muscle can be predicted based on ^{40}K activities.

5. The results of modeling ^{137}Cs specific activities in a fox body and components of its trophic chain using Resrad-biota code had the insignificant differences from the experimental data; the differences came to 42%, 12%, and 16% in test samples of foxes, rodents, and plants respectively.

6. The following values of ^{137}Cs transfer coefficients in components of a fox body and its trophic chain were determined during the research: plants – 2.9, rodents – 1.5, and predators – 0.027. Meanwhile, values of accumulation coefficients were 2.9, 4.2, and 0.1 respectively.

7. The research determined that values of the transfer coefficients from plants to rodents were 0.13 and from rodents to predators – 0.34.

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RUDŲJŲ LAPIŲ (*VULPES VULPES*) RADIOLOGINIAI TYRIMAI LIETUVOJE

R. L. Idzelis, S. Bolut, V. Čepanko, D. Paliulis

Santrauka

Įvertintos ^{40}K ir ^{137}Cs aktyvumo koncentracijos, nustatytos rudųjų lapių (*Vulpes vulpes*) iš Rytų ir Šiaurės Lietuvos raumenyse, kauluose ir kepenyse. ^{40}K koncentracijos raumenyse svyravo nuo $46,06 \pm 0,43$ iki $110,92 \pm 4,5$ Bq·kg⁻¹ (FW = gyvojo svorio). ^{137}Cs savitojo aktyvumo vidutinis lygis raumenyse siekė $5,78 \pm 0,29$ Bq kg⁻¹ (FW). Akivaizdžios priklausomybės tarp ^{40}K ir ^{137}Cs radionuklidų koncentracijų kepenyse nepastebėta. Mėginių analizės rezultatus palyginus su kitų autorių gautais mažų gyvūnų (graužikų ir vabzdžiaėdžių žinduolių) kaulų užtaršos duomenimis, užtaršos lygiai nebuvo dideli, todėl šioje tyrimų stadijoje išvadas apie radionuklidų izotopų kaupimosi dėsninumus viršutinėje mitybos grandinės pakopoje sunku daryti. Remiantis tyrimo duomenimis, galima teigti, kad ^{137}Cs savitieji aktyvumai, nustatyti rudųjų lapių raumenyse, gali būti prognozuojami pagal ^{40}K aktyvumus.

Reikšminiai žodžiai: rudosios lapės, radioekologija, radionuklidai, mitybos grandinė.

РАДИОЛОГИЧЕСКОЕ ИССЛЕДОВАНИЕ РЫЖЕЙ ЛИСЫ (*VULPES Vulpes*) В ЛИТВЕ

Р. Л. Идзялис, С. Болут, В. Чепанко, Д. Палюлис

Резюме

Оценена активность и концентрация ^{40}K и ^{137}Cs в мышцах, костях и печени рыжей лисы (*Vulpes vulpes*) в восточной и северной частях Литвы. Представлено краткое описание применяемого радиохимического метода. Установлено, что концентрации ^{40}K в мышцах колеблются от $46,06 \pm 0,43$ до $110,92 \pm 4,5$ Бк кг^{-1} (FW = живого веса). Средние результаты ^{137}Cs для мышц находятся на уровне $5,78 \pm 0,29$ (FW). Отсутствие четкой взаимосвязи между концентрациями радионуклидов наблюдалось в печени. Результаты исследования не выявили повышенного уровня загрязнения по сравнению с результатами анализа костей мелких животных (грызунов и насекомоядных млекопитающих), проведенного другими авторами, поэтому сделать заключение о накоплении изотопов костной массой на высшей ступени пищевой цепи не представляется возможным.

Ключевые слова: рыжая лиса, радиоэкология, радионуклиды, пищевая цепь.

Raimondas Leopoldas IDZELIS. Dr, Assoc. Prof., Dept of Environmental Protection, Vilnius Gediminas Technical University (VGTU).

Doctor of Natural Sciences, 1993. Publications: author of more than 70 research papers, 1 study guide, co-author of 3 monographs. Research interests: landscape management, ecology, environmental protection, animal guide urbanization.

Slavomir BOLUT. Master student, Dept of Environmental Protection, Vilnius Gediminas Technical University (VGTU). Bachelor of Science (environmental engineering), VGTU. Research interests: environmental protection, protection from radiation.

Violeta ČEPANKO. Dr, Associate Professor at the Department of Environmental Protection, Vilnius Gediminas Technical University. She gained her Environmental Engineering and Landscape Management PhD in 2010 from Vilnius Gediminas Technical University. Publications: author/co-author of 14 scientific papers, 1 collective monograph and 1 invention. Research interests: waste disposal and management, organic waste composting, combustion, air and waste treatment technology.

Dainius PALIULIS. Dr, Assoc. Prof., Dept of Environmental Protection, Vilnius Gediminas Technical University (VGTU).

Doctor of Technological Sciences, 2000. Publications: author (with co-authors) of more than 15 scientific publications, 1 study guide, co-author of 1 monograph and 2 patents. Research interests: environmental chemistry, air pollution, environmental protection.