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Accumulation particularities of ^{90}Sr and ^{137}Cs radionuclides in different fish groups

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Radionuclide accumulation in settled and migratory fish caught in Lithuanian lakes and rivers was analysed.

Migratory fish were found to accumulate radionuclides in muscles (53–63%) and bones (33–42%), mainly from food. ^{90}Sr levels were highest in salmon trout bone tissue (34% of the total contamination with ^{137}Cs and ^{90}Sr), whereas its activity concentrations in migratory fish muscles were not high and carried within 0.09 to 1%.

The highest ^{137}Cs levels were accumulated in the muscles and bones of perch caught in lakes Dusia and Lūkstas. The consequences of the Chernobyl accident seem to be most pronounced in West and South Lithuanian, whereas the whole territory of this country is contaminated with the ^{90}Sr isotope because its rather high levels were found in the bone tissue of predatory (4–41%) and peaceable (45–75%) fish.

The obtained data served as a basis for calculating the bioaccumulation factor values for different fish types depending on age. The accumulation intensity of ^{137}Cs and ^{90}Sr in migratory fish (salmon trout) respectively decreases and increases, whereas with age settled fish (roach) accumulate more ^{137}Cs in the muscles.

Key words: bioaccumulation, migratory and settled fish, radionuclides, pollution

INTRODUCTION

Radionuclides in food and drinking water are one of the sources of exposure for public. The fish are a potentially important link in the transfer of radionuclides from contaminated ecosystems to people. For this reason, the monitoring of the community and populations of fish is most important for the estimation of the stability of hydrosystems and for ensuring the safety of food.

The whole nature is constantly affected by radionuclides of cosmic origin and those from the earth crust. However, only with the use of radioactivity for medical and industrial purposes and nuclear bomb tests, radiation protection measures started to be implemented. After releasing man-made radionuclides to the environment man realized that they may cause cancer, genetic disturbances and other diseases. Since the last century man gives attention to protection against ionizing radiation. Creation of the protective system, not only of man but also of the environment, requires a lot of different tasks to be implemented, based on the knowledge of the dispersion of radionuclides in the environmental ecosystems (Nedveckaitė, 2004; Morkūnas, 2004).

The results of research show that the activity concentration of the long-lived radionuclides ^{137}Cs and ^{90}Sr in foodstuffs during the last 40 years in Lithuania decreased because of radionuclide decay and migration to deeper soil layers (Ladygienė et al., 2001). The highest activity concentration of these radionuclides, in comparison with other foodstuffs, was measured in fish (Butkus et al., 2006). Typically, activity concentration of ^{137}Cs and ^{90}Sr in fish from the Baltic Sea and Lithuanian lakes does not exceed 100 Bq/kg fresh weight, but radioactivity may cause a genetic breach in the human body.

Radiological investigations of fish in the world have been performed for the last several decades. At first, attention was focused on sea fish and on the dispersion of radionuclides in the sea environment, while less studies were oriented to lake fish and the lake environment (HELCOM, 1995; Hewett et al., 1976). The reason was the radioactive waste dumping in the ocean environment. Starting from the 1980 investigations of dispersion of radionuclides in the vicinity of radioactive waste repositories were performed with regard to the peculiarities of dispersion of groundwater (Marčiulionenė et al., 2001; Masiliūnas et al., 1998; Mažeika et al., 2003).

Fish is in contact with water environment during all the period of their life, and this environment affects the population of fish, its reproduction, prolificacy, migration, distribution in the water systems, etc. (Dušauskienė-Duž et al., 2002; Virbickas et al., 1994; Радиоэкология..., 1977). Fish feeding on water vegetation or smaller fish are more exposed to the radioactively contaminated environment, and their ontogenesis is linked with bottom sediments (Dušauskienė-Duž et al., 2002). It is a proven fact that more complicated organisms are more sensitive to radiation. Fish is one of the animals most sensitive to ionizing radiation. The lethal dose for fish is 8 to 70 Gy (Nedveckaitė, 2004). Lake and sea fish mostly accumulate ^{134}Cs and ^{137}Cs, ^{65}Zn, ^{90}Sr and ^{89}Sr and less ^{141}Ce and ^{144}Ce, ^{51}Kr, ^{103}Ru and ^{106}Ru, ^{95}Zr + ^{95}Nb, ^{54}Mn, ^{59}Fe, ^{60}Co, ^{140}Ba + ^{140}La radionuclides (Ильенко, 1974).

After the Chernobyl NPP accident in 1986, a lot of results of research indicated a negative influence of ionizing radiation on water organisms (Brittain et al., 1991; Dušauskienė-Duž et al., 2002; Marčiulionienė, 2005). The first radiological investigations of fish started in Lithuania in 1995 at the Vilnius University Institute of Ecology and at the Laboratory of Environmental Ministry and are continued till now. A lot of research were performed also by other institutions of the country. Since 1965, the radiological monitoring of food is being performed. The Radiation Protection Centre and the National Veterinary Laboratory are performing radiological investigations of fish. Results of investigations show that a dose caused by ^{137}Cs in fish is higher than in the other food products, and the dose in 2000 was 0.16 ± 0.09 µSv (Ladygienė et al., 2001). This indicates that the radiological investigation of fish must be performed periodically in order to estimate the dose to people consuming fish products.

The aim of the work was to identify the coefficients of accumulation of different radionuclides in different body parts of fish (with both the migratory and settled styles of living) and to identify the distribution of radionuclides in the body of fish according to age and the food consumed.

METHODS

Measurements of activity concentrations of ^{137}Cs and ^{90}Sr were performed in fish sampled in rivers and lakes of Lithuania (Fig. 1). Location of the lakes and rivers where sampling was performed was selected according to the monitoring carried out in the last years and according to environment contamination identified by radiological measurements after the Chernobyl NPP accident. Radiological measurements were performed in samples of different ecological groups of fish: fish with the migratory style of living – salmon trout (*Salmo trutta trutta* L.) sampled in the rivers Jūra, Žeimena and Vilnelė, and silver smelt (*Osmerus eperlanus* L.) sampled in the Nemunas delta. Fish with the settled style of living was divided into two trophy groups: benthofagous fish – roach (*Rutilus rutilus* L.) and ichthyofagous – perch (*Perca fluviatilis* L.).

Fish with the settled style of living were also divided into two age groups: young fish – group 1 (3–8-year-old roach and 5–8-year-old perch) and old fish – group 2 (9–12-year-old roach and 6–12-year-old perch). This distribution was made to evaluate the dependence of radionuclide accumulation on the age of fish. Fish with the settled style of living were investigated from lakes of different eutrophy levels (Dusia, Plateliai, Lūkstas and Drūkšiai). For the analysis, two types of samples – muscles and bones were prepared. The weight of a sample was for muscles 1.0–1.5 kg, and bones (including the head) were taken from the same fish that had been used for a muscle sample.

Sampling and investigations were performed during two years – in 2004 and 2005. Sampling was performed in summer and autumn (August–November), once per month, and additionally in February for the sampling of smelt during the migration period of this kind of fish.

Fish was sampled in rivers using the electric fishery method (Junge, 1965) and in the Nemunas delta using selective gill nets (Thoresson, 1993).

The ichthyologic analysis of fish sampled during expeditions was performed at the Laboratory of Ecology and Physiology of Hydrobionts, Institute of Ecology of Vilnius University, using universal well known methods of Pravdin and Thoresson (Thoresson, 1996; Правдин, 1966). For the preparation of samples and radiological measurements, standard radiological procedures were used (LAND 36-2001; LAND 64-2005) at the Radiation Protection Centre.

For the preparation of samples, muscles and bones (including heads of fish) were taken separately. Samples were dried at 105 °C for 8 h and ashed for 3 h at 300 °C and for 15 h at 400 °C. The activity concentration of ^{137}Cs and ^{40}K was measured in the ash of a sample using a high purity germanium detector gamma spectrometer with the mathematical calibration software ISOCS/ labSOCS. ^{90}Sr counting was performed after radiochemical separation of ^{90}Y (which is a daughter of ^{90}Sr and is in equilibrium) from the ash of a sample. For separation, a 10% HDEHP (di(2)-ethyl-hexyl) phosphoric acid solution in toluene was used. Counting was performed with a Quantulus liquid scintillation counter.

Radionuclide accumulation in fish is indicated by the bioaccumulation factor. The transfer of radionuclides from water using various trophic levels of aquatic organisms to food species consumed by humans is indicated by the bioaccumulation factor *BF* (Nedveckaitė, 2004) calculated using the equation

$$BF_i = C_{m,p} \cdot 1000 / C_{w,t}, \quad (1)$$

where BF_i is the ratio of the activity concentration of radionuclide *i* in aquatic food *p* to its dissolved concentration in water (Bq · kg^{-1} / Bq · L^{-1});

$C_{m,p}$ is the activity concentration of radionuclide *i* in aquatic food *p* (Bq kg^{-1});

$C_{w,t}$ is the activity concentration of dissolved radionuclide *i* in water (Bq m^{-3});

1000 is the conversion factor from m^3 to L.

The calculation of the coefficient of correction P_{BFF_i} for the factor of bioaccumulation *BF* was performed using the equation

$$P_{BF_i} = \frac{|BF_i - BF_{av.}|}{BF_{av.}}, \quad (2)$$

where P_{BF_i} is the coefficient of correction for bioaccumulation factor *BF* for radionuclide *i* for the appropriate age of fish (Bq · kg^{-1} / Bq · L^{-1});

Fig. 1. Location of rivers (a) where fish sampling was performed: *1* – Jūra, *2* – Žeimena, *3* – Vilnelė, *4* – Nemunas delta, and lakes (b): *5* – Plateliai, *6* – Lūkstas, *7* – Dusia, *8* – Drūkšiai

BF_i is the ratio of the activity concentration of radionuclide *i* at the appropriate age of fish and the activity concentration of dissolved radionuclide *i* in water (Bq · kg^{-1} / Bq · L^{-1});

$BF_{av.}$ is the average of the bioaccumulation factor for radionuclide *i* evaluated for the muscles and bones of fish (Bq · kg^{-1} / Bq · L^{-1}).

The uncertainty ΔBF of the bioaccumulation factor *BF* was calculated using the equation (Martinėnas, 2004)

$$\Delta BF = \pm \sqrt{\left(\frac{\partial BF}{\partial C_{m,p}}\right)^2 \Delta C_{m,p}^{\ 2} + \left(\frac{\partial BF}{\partial C_{w,t}}\right)^2 \Delta C_{w,t}^{\ 2}} \ , \quad (3)$$

where ΔBF is the maximum uncertainty of the calculated bioaccumulation factor *BF*;

∂BF is the calculated value of bioaccumulation factor *BF*;

$\partial C_{m,p}$ is the activity concentration of radionuclide *i* in aquatic food *p*;

$\partial C_{w,t}$ is the activity concentration of dissolved radionuclide *i* in water;

$\Delta C_{m,p}$ is the direct uncertainty of activity concentration *i* in aquatic food *p*;

$\Delta C_{w,t}$ is the direct uncertainty of activity concentration of dissolved radionuclide *i* in water.

RESULTS AND ANALYSIS

Estimation using ichthyologic morphology analysis showed that the age of predatory fish sampled during this investigation differed significantly from the age of peaceful fish. For fish with migratory style of living and sampled in rivers, the age ranged from 2 to 6 years, for salmon trout from 4 to 6 years, for silver smelt – 2 and 3 years. For fish with the settled style of living, the age varied from 3 to 12 years, for roach from 3 to 12 years and for perch from 4 to 12 years.

Results of radiological investigation has shown that the activity concentration of ^{37}Cs and ^{90}Sr in the muscles of fish is determined by the general consistent pattern of radionuclide accumulation due to absorption and metabolic processes (Table 1). ^{90}Sr belongs to the group of "osteotropic" radionuclides which accumulate in the bones as calcium, and ^{137}Cs is a typical "diffusion" radionuclide which accumulates in the soft muscles as potassium. ^{137}Cs accumulates in different parts of the body of fish and is evenly distributed (Dušauskienė-Duž et al., 2002; Kesminas, 1997).

Table 1. **Average activity concentrations of ^{137}Cs and ^{90}Sr in the muscles and bones of silver smelt and salmon trout, Bq kg^{-1} of net weight, 2004–2005**

Fish	Tissue	Number of fish in a sample	^{90}Sr	^{137}Cs
Smelt	Muscles	24	0.08 ± 0.03	7.8 ± 0.7
	Bones		0.6 ± 0.2	6.1 ± 0.4
Salmon trout	Muscles	4	0.03 ± 0.02	16.6 ± 4.3
	Bones		1.1 ± 0.3	8.7 ± 0.9

Results of the investigation show that ^{137}Cs accumulates in the muscles of migratory fish mainly due to food contamination (Fig. 2). The highest levels of ^{90}Sr accumulation in this study were estimated in the bone tissue of salmon trout and reached 34% of the total activity concentration of ^{137}Cs and ^{90}Sr, whereas the activity concentration of ^{90}Sr in the muscles of migratory fish were negligible and made 0.09% to 1% of the total activity concentration of ^{137}Cs and ^{90}Sr. It is partly due to the exuviae of fish, which stops the penetration of radionuclides into fish muscles.

Investigations of accumulation for ^{137}Cs in the muscles of river fish showed that the activity concentrations of this radionuclide in the fish with a settled style of living ranged from 14.9 ± 1.0 Bq kg^{-1} to 18.2 ± 12.6 Bq kg^{-1}. The highest activity concentration of ^{137}Cs was measured in the muscles of a salmon trout female sampled in the river Žeimena (Fig. 2). The ability to accumulate ^{137}Cs in the bones increases with the age of fish. Because the activity concentration of ^{137}Cs in the water of the Baltic Sea is lower than in the water of lakes or rivers, the fish that is going for spawning a long way accumulates more ^{137}Cs in the muscles. ^{137}Cs activity concentrations measured in the bone tissue samples of silver smelt and salmon trout are more than twice less than in the muscles (7.0 ± 0.5 Bq kg^{-1} to10.2 ± 0.9 Bq kg^{-1}).

The accumulation of ^{90}Sr in the muscles and bones of migratory fish is low and in muscles ranges within 0.01–0.08 Bq kg^{-1} and in bones within 0.38–2.04 Bq kg^{-1}. The highest activity concentration of ^{90}Sr was measured in the muscles of silver smelt (0.08 ± 0.03 Bq kg^{-1}). Also, the highest activity concentration of ^{90}Sr was found in the bones of salmon trout from the river Jūra (Fig. 2). A conclusion was made that the age of salmon trout influences the accumulation of ^{137}Cs in the bone tissue.

Results of radiological measurements have shown that the contamination of migratory fish with ^{137}Cs and ^{90}Sr is small and does not exceed the permitted levels approved for ^{137}Cs in Lithuania. It should be mentioned also that the activity concentration in the fish measured by other researchers (Marčiulionienė et al., 1997; Dušauskienė-Duž, 1997; Dušauskienė-Duž et. al., 2002; Marčiulionenė, 1998) is smaller than the measured in this study. Therefore, measurements of activity concentrations of man-made radionuclides in migratory fish should be carried out in future.

For some of radionuclides, accumulation in fish with a settled style of living was in general the same as in migratory fish (Figs. 3 and 4).

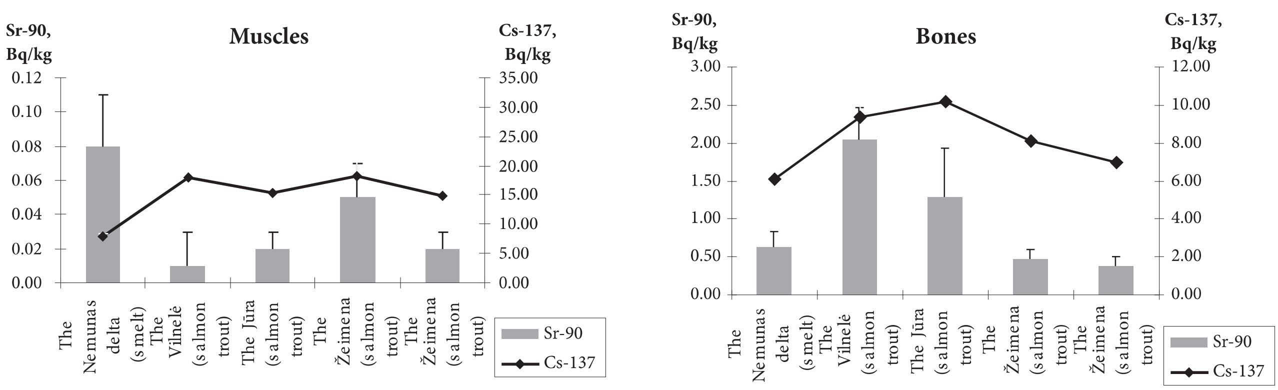

Fig. 2. Activity concentration of ^{137}Cs and ^{90}Sr in muscles and bones of silver smelt and salmon trout, Bq kg^{-1} of net weight, 2004–2005

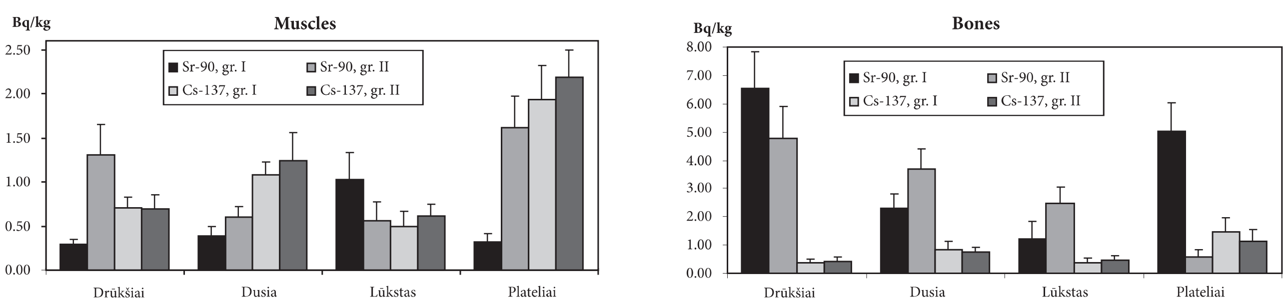

Fig. 3. Activity concentration of ^{137}Cs and ^{90}Sr in muscles and bones of roach, Bq kg^{-1} of net weight, 2004–2005

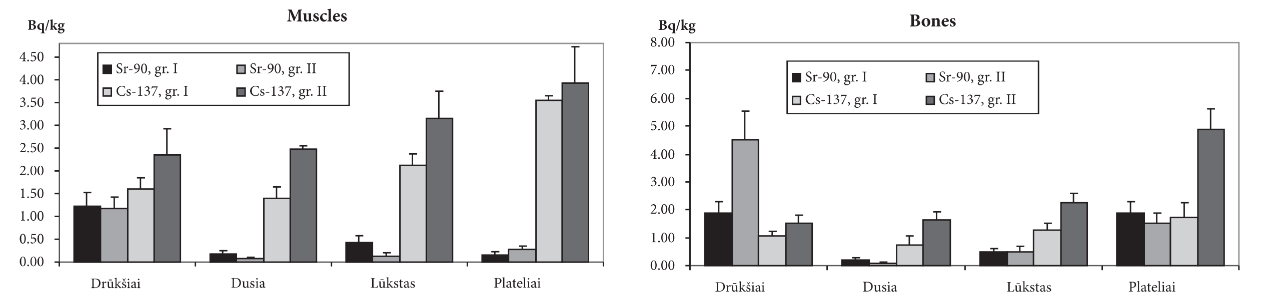

Fig. 4. Activity concentration of ^{137}Cs and ^{90}Sr in muscles and bones of perch, Bq kg^{-1} of net weight, 2004–2005

Data on the accumulation of water-soluble ^{137}Cs in the muscles of samples of fish from lakes Drūkšiai, Lūkstas, Plateliai and Dusia show that activity concentration of this radionuclide in the predatory fish (perch) ranged within 1.9–5.9 Bq kg^{-1} and was higher than in samples of peaceful fish (roach) in which it reached 0.6–1.2 Bq kg^{-1}. In the samples of muscles of roach, the activity concentration of ^{137}Cs was measured in the range from 0.4 Bq kg^{-1} to 1.3 Bq kg^{-1} and in the muscles of perch from 1.2 to 3.3 Bq kg^{-1}. According to these results, the highest activity concentration of ^{137}Cs is accumulated in the muscles and bones of perch sampled in the lakes Dusia and Lūkstas. It indicates that the contamination of the environment after the Chernobyl accident was higher in the west and southwest of the country where these lakes are located. At the same time, all territory of Lithuania is contaminated by ^{90}Sr at similar activity concentrations, and almost the same activity concentration value of this radionuclide was measured in the bone tissue of predatory (4–41% of the total activity of ^{137}Cs and ^{90}Sr) and peaceful (45–75% of the total activity of ^{137}Cs and ^{90}Sr) fish. The highest activity concentrations of ^{137}Cs were measured in roach samples from Lake Plateliai: in muscles they ranged within 0.50–2.19 Bq kg^{-1} and in bone samples within 0.36–1.46 Bq kg^{-1}.

Radiological measurements showed higher activity concentrations of ^{137}Cs (and accumulation as well) in the muscles of predatory fish – 3.9 ± 0.8 Bq kg^{-1} *versus* 2.2 ± 0.3 Bq kg^{-1} in peaceful fish (Figs. 3 and 4). The dependence of accumulation of ^{137}Cs activity concentration in predatory fish indicates that the main factor of contamination is sea food, and predatory fish consume more contaminated food – smaller fish (Fig. 4). This means that this radionuclide accumulates more in fish of a higher trophic level. For fish of a higher trophic level, the role of food chain increases during the biological migration of ^{137}Cs as was estimated by D. Marčiulionienė, R. Dušauskienė-Duž and others.

Age dependence of the levels of accumulation of ^{137}Cs and ^{90}Sr in the muscles of fish in some lakes is evident. Radiological data show that these radionuclides are at higher activity concentrations in fish from Lake Drūkšiai. The average activity concentration of ^{90}Sr in the bones of fish from this lake was 6.54 ± 1.30 Bq kg^{-1}, and in the muscles it ranged from 0.29 ± 0.06 to 1.6 ± 0.4 Bq kg^{-1}. This area (Lake Drūkšiai) was contaminated after the accident at the Chernobyl NPP. Some radionuclides are emmited from the Ignalina NPP to the lake, and this could be the reason for more contaminated fish as well.

The activity concentration of ^{90}Sr in the bones of predatory fish is 3.7 times higher than in their muscles (Fig. 4). The highest activity concentration of ^{90}Sr in the bone samples was measured in perch from Lake Drūkšiai (4.50 ± 1.04 Bq kg^{-1}). Accumulation of ^{90}Sr in the muscles of roach varied within 0.5 to 1.0 Bq kg^{-1}. For perch, activity concentration was mainly the same in all samples from three lakes (0.1 ÷ 0.3 Bq kg^{-1}), but the activity concentration of ^{90}Sr in the samples of predatory fish from Lake Drūkšiai was 1.2 Bq kg^{-1} (Fig. 4), and in bone samples of predatory fish it was half as low as in peaceful fish (3.2 and 5.7 Bq kg^{-1}, respectively).

Our results indicate low activity concentrations of ^{90}Sr; however, it should be mentioned that fish is a typical food product, and some people like to cook fish for soup. In this case, ^{90}Sr may be dissolved in soup and consumed (Illus et al., 1998; Grimas et al., 1996).

According to some investigators (Dušauskienė-Duž et al., 2002; Радиоэкология..., 1977), ^{90}Sr accumulates in the tissues of fish due to adsorption in fish skin and body tissues. Taking into account the fact that in water basins, which are not stable as regards temperature, the content of suspended particles is increasing and the absorption processes are increasing as well, most of ^{90}Sr is deposited in the form of insoluble carbonates on the exuviae and skin, and at the same time the activity of ^{90}Sr in the body muscles fluctuates in a wide range. ^{90}Sr activity concentration in the muscles of perch was lower (0.08–1.23 Bq kg^{-1}) than in bones (0.08–4.50 Bq kg^{-1}).

The values of the bioaccumulation factor (*BF*) of ^{137}Cs were calculated using equation 1. For salmon trout, this value ranged from 2790 ± 85 to 3408 ± 110, mean 3109 ± 110. The average level for silver smelt was 1461 ± 59, i. e. two times less than for salmon trout. Data in Table 2 indicate that for

Table 2. **Bioaccumulation factor for silver smelt and salmon trout (calculations were made for the activity concentration of ^{137}Cs in water 5.34 ± 1.18 Bq m^{-3} and of ^{90}Sr 11.0 ± 0.88 Bq m^{-3} (Aplinkos..., 2005)**

Fish	Activity concentration in the muscles, Bq kg^{-1}	Bioaccumulation factor
	^{137}Cs	
Smelt	7.8 ± 0.7	1461 ± 59
Salmon trout	17.9 ± 1.9	3352 ± 160
	15.4 ± 1.5	2884 ± 130
	18.2 ± 1.3	3408 ± 110
	14.9 ± 1.0	2790 ± 85
	Average	3109 ± 110
	^{90}Sr	
Smelt	0.63 ± 0.21	57 ± 24
Salmon trout	2.04 ± 0.43	185 ± 49
	1.29 ± 0.64	117±73
	0.47 ± 0.12	43 ± 14
	0.38 ± 0.12	35 ± 14
	Average	95 ± 35

Table 3. **Bioaccumulation factor for settled fish (calculations were made for the activity concentration of ^{137}Cs in water of Lake Drūkšiai 1.28 ± 0.44 Bq m^{-3} and in other lakes 1.12 ± 0.40 Bq m^{-3}) (Aplinkos..., 2005)**

Fish	Age group of fish	Lake	Activity concentration of ^{137}Cs in the muscles, Bq kg^{-1}	Bioaccumulation factor
Roach	Young	Drūkšiai	0.71 ± 0.12	554 ± 27
	Old		0.70 ± 0.15	547 ± 34
	Young	Dusia	1.08 ± 0.14	964 ± 35
	Old		1.24 ± 0.32	1107 ± 80
	Young	Lūkstas	0.50 ± 0.17	446 ± 43
	Old		0.62 ± 0.13	552 ± 33
	Young	Plateliai	1.94 ± 0.38	1732 ± 95
	Old		2.2 ± 0.3	1955 ± 75
			Average	982 ± 53
Perch	Young	Drūkšiai	1.60 ± 0.26	1250 ± 59
	Old		2.36 ± 0.56	1844 ± 130
	Young	Dusia	1.39 ± 0.10	1241 ± 25
	Old		2.47 ± 0.08	2205 ± 20
	Young	Lūkstas	2.12 ± 0.41	1893 ± 100
	Old		3.16 ± 0.59	2821 ± 150
	Young	Plateliai	3.56 ± 0.44	3179 ± 110
	Old		3.92 ± 0.80	3500 ± 200
			Average	2242 ± 100

Table 4. **Bioaccumulation factor for settled fish (calculations were made for the activity concentration of ^{90}Sr in water of Lake Drūkšiai 12.0 ± 1.1 Bq m^{-3}, in Lake Dusia 9.0 ± 0.84 Bq m^{-3}, in other lakes 7.0 ± 0.8 Bq m^{-3}) (Aplinkos..., 2005)**

Fish	Age group of fish	Lake	Activity concentration of ^{90}Sr in the muscles, Bq kg^{-1}	Bioaccumulation factor
Roach	Young	Drūkšiai	6.54 ± 1.30	545 ± 120
	Old		4.77 ± 1.13	398 ± 100
	Young	Dusia	2.32 ± 0.48	258 ± 57
	Old		3.67 ± 0.71	408 ± 85
	Young	Lūkstas	1.20 ± 0.65	171 ± 81
	Old		2.49 ± 0.58	356 ± 73
	Young	Plateliai	5.01 ± 1.02	716 ± 130
	Old		0.58 ± 0.25	83 ± 31
			Average	367 ± 89
Perch	Young	Drūkšiai	1.90 ± 0.41	158 ± 37
	Old		4.50 ± 1.04	375 ± 4
	Young	Dusia	0.22 ± 0.05	24 ± 5
	Old		0.08 ± 0.03	9 ± 4
	Young	Lūkstas	0.49 ± 0.12	70 ± 15
	Old		0.51 ± 0.20	73 ± 25
	Young	Plateliai	1.88 ± 0.41	269 ± 51
	Old		1.52 ± 0.38	217 ± 48
			Average	149 ± 24

^{90}Sr in salmon trout the average *BF* is 95 ± 35, its values ranging from 35 ± 14 to 185 ± 49. For silver smelt, the average *BF* value was 57 ± 24, i. e. approximately twice less than for salmon trout.

Data in Table 3 indicate that the calculated *BF* values for ^{137}Cs in the muscles of roach were more than twice as low as in the muscles of perch (446 ± 43 to 1955 ± 75 versus 1241 ± 25 to 3500 ± 200, respectively), the average values being 982 ± 53 for roach and 2242 ± 100 for perch.

The *BF* value for ^{137}Cs in the muscles of silver smelt was 1461 ± 59, i. e. more than twice as low as the average value estimated for salmon trout (Table 2).

A conclusion has been made that the increase of *BF* for ^{137}Cs in muscles of settled fish depends on the age of fish. The *BF* value in muscles of roach was 77% and of perch 35%. The *BF* dependence on the age of fish was not estimated for ^{90}Sr.

The average value of *BF* for ^{90}Sr calculated for perch was 149 ± 24, range: 9 ± 4 to 375 ± 4. The difference in values was 98%. The appropriate range of *BF* value for roach is within 88% and increases from 83 ± 31 to 716 ± 130 (Table 4). The difference of the average *BF* values for roach and perch is 59%. Estimation of *BF* for ^{137}Cs and ^{90}Sr showed that not in all cases the *BF* increased with the age of fish. The tendency of increase was determined for settled fish and of decrease for migratory fish. Therefore, *BF* uncertainty was calculated using equation 2 for migratory (salmon trout) and settled (roach) fish (Figs. 5 and 6). The decreasing tendency of *BF* for ^{137}Cs (Fig. 5, a) with the age for salmon trout indicates that in the first year of living

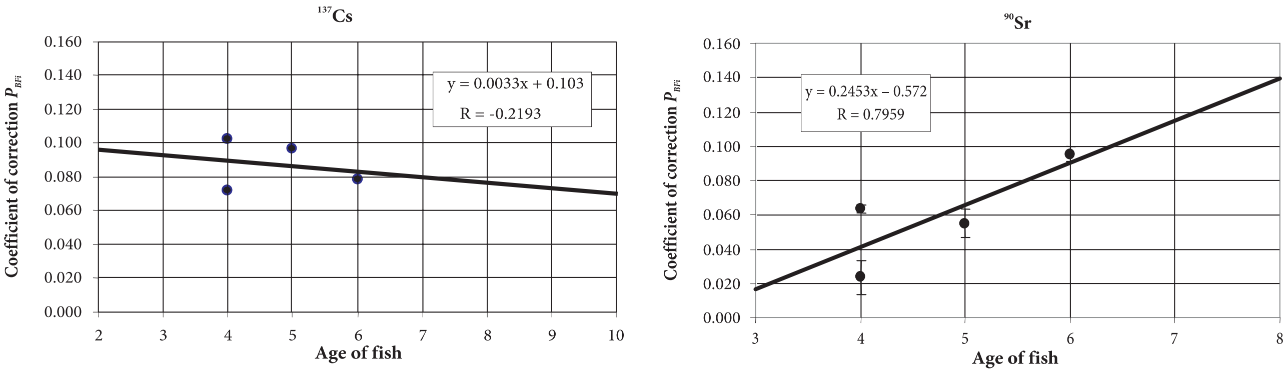

Fig. 5. Coefficient of correction P_{BF_i} for the bioaccumulation factor of migratory fish (salmon trout): for ^{137}Cs (a) and ^{90}Sr (b)

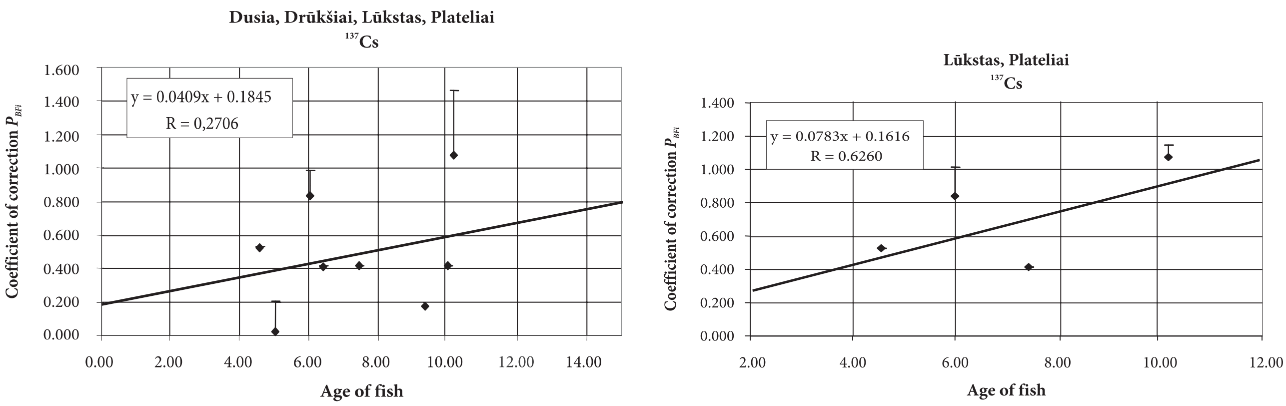

Fig. 6. Coefficient of correction P_{BF_i} for the bioaccumulation factor of settled fish (roach): for ^{137}Cs (a) and ^{90}Sr (b) according to lakes of sampling

in lakes and rivers, settled fish accumulates more ^{137}Cs . This fact can be explained by a higher accumulation of ^{137}Cs in the bottom sediments of saline waters. The standard deviation for *BF* for ^{137}Cs is 27%.

With age, ^{90}Sr accumulation in salmon trout muscles increases (Fig. 5, b). This indicates that the main route of fish contamination by radionuclides is food. The standard deviation of *BF* for ^{90}Sr is 27%.

The value of *BF* for ^{137}Cs in the muscles of settled fish (roach) increased (Fig. 6, a). The style of living and food favour ^{137}Cs accumulation in the muscles of that kind of fish. A great influence on temperature fluctuations in the cooling pool of the Ignalina NPP – Lake Drūkšiai – is exerted by the power plant. Therefore, ^{137}Cs migration and other related processes in water are very specific (Figs. 3 and 4). In the lakes where anthropogenic processes are not intensive, ^{137}Cs accumulation is higher (Fig. 6, b). A very fast accumulation of ^{137}Cs in the muscles of roach during the growth of fish was found in Lake Dusia (Table 3). This fact indicates that in lakes and rivers of the southern part of the country, contamination after the Chernobyl accident in 1986 was dominant (Butkus, 2006). The standard BF deviation of ^{137}Cs for muscles of roach in lakes Dusia and Drūkšiai is 24% and in lakes Plateliai and Lūkstas 16%.

CONCLUSIONS

1. Migratory fish accumulate more ^{137}Cs in muscles (53–63% of total ^{137}Cs) than in bones (33–42% of total ^{137}Cs). The main route for the contamination of fish with this radionuclide is the ingested food.

2. The highest levels of ^{90}Sr accumulation were estimated for the bones of salmon trout (approximately 34% of the total amount of ^{137}Cs and ^{90}Sr). At the same time, ^{90}Sr activity concentrations in the muscles of migratory fish were low (approximately 0.09 to 1% of the total amount of ^{137}Cs and ^{90}Sr in this kind of fish).

3. Accumulation of ^{137}Cs in the roach does not depend on the age of the fish, whereas in the case of perch ^{137}Cs accumulation increases with age.

4. The highest value of the bioaccumulation factor for ^{137}Cs was determined in migratory fish (3109 ± 110). It is explained by the fact that fish migrate to the sea, and food for this kind of fish is the main source of contamination.

5. ^{90}Sr accumulation in migratory fish bones depends on the age of fish. This dependence was estimated for salmon trout sampled in Lithuanian rivers.

6. Radioecological monitoring of lakes and rivers should be continued, especially of Lake Drūkšiai during the decommissioning of the Ignalina NPP where this lake is used for cooling, and release to the lake is possible, considering that this territory was contaminated after the Chernobyl accident also.

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RADIONUKLIDŲ ^{90}Sr IR ^{137}Cs KAUPIMOSI YPATUMAI ĮVAIRIOSE ŽUVŲ GRUPĖSE

S a n t r a u k a

Analizuojama sėsliųjų ir praeivių žuvų, sugautų Lietuvos ežeruose bei upėse, užtarša radionuklidais.

^{137}Cs radionuklidus praeivės žuvys kaupia raumenyse (53–63%) ir kauluose (33–42%). Tyrimo duomenys rodo, kad šis radionuklidas į praeivių žuvų audinius patenka daugiausia su maistu. ^{90}Sr didžiausi akumuliacijos lygiai tyrimų metu buvo nustatyti šlakio kauliniame audinyje ir sudarė 34% nuo bendros šios rūšies užtaršos ^{137}Cs ir ^{90}Sr radionuklidais. Tuo tarpu ^{90}Sr savitieji aktyvumai, nustatyti praeivių žuvų raumenyse, yra nedideli ir kinta nuo 0,09 iki 1%.

Remiantis gautais duomenimis, daugiausia ^{137}Cs yra sukaupta ešerių, sugautų Dusios bei Lūksto ežeruose, raumenyse bei kauluose. Galima teigti, kad Černobylio AE avarijos pasekmės yra juntamiausios Vakarų ir Pietų Lietuvoje. Tuo tarpu ^{90}Sr izotopo užtaršos regionu yra visa Lietuvos teritorija, kadangi nemaža jo nustatyta plėšriųjų (4– 41%), ypač taikiųjų žuvų kauliniame audinyje (45–75%).

Pagal gautus rezultatus apskaičiuotos bioakumuliacijos faktoriaus vertės skirtingoms žuvų rūšims bei nustatytos jų priklausomybės nuo žuvies amžiaus. ^{137}Cs ir ^{90}Sr radionuklidų kaupimo praeivėse žuvyse (šlakiuose) intensyvumai atitinkamai mažėja ir didėja. Tuo tarpu didėjant sėsliųjų žuvų (kuojų) amžiui, intensyvėja ^{137}Cs radionuklidų akumuliacija šių žuvų raumenyse.

Raktažodžiai: *bioakumuliacija***,** praeivės žuvys, radionuklidai, sėsliosios žuvys, užtarša