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ESTIMATION OF EFFECTIVE DOSE CAUSED BY ^{40}K, ^{90}Sr AND ^{137}Cs IN DAILY FOOD

Donatas Butkus[1], **Inga Laučytė**[2], **Rima Ladygienė**[3]

[1, 2]*Dept of Environmental Protection, Vilnius Gediminas Technical University, Saulėtekio al 11, LT-10223 Vilnius, Lithuania. E-mail: butkus@ap.vtu.lt*

[3]*Radiation Protection Centre, Kalvarijų g. 153, LT-08221 Vilnius, Lithuania. E-mail: r.ladygiene@rsc.lt*

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Abstract. This paper presents ^{137}Cs, ^{90}Sr and ^{40}K activity concentrations in daily food and an annual effective dose caused by these radionuclides. Samples were taken during the period 28 October 2004–23 June 2005 once a month in a students' canteen of Vilnius Gediminas Technical University (VGTU). The weight of samples varied from 1,37 kg to 2,26 kg, and an average weight was 1,89 kg. The volume of liquids varied from 500 cm^3 to 1000 cm^3, and the average was 816 cm^3. The average of activity concentration of ^{90}Sr in daily food from the students' canteen was (0,03±0,01) Bq/kg, of ^{137}Cs – (0,02±0,01) Bq/kg and of ^{40}K – (34±3) Bq/kg. An annual effective dose caused by these radionuclides was estimated using measured activity concentrations in daily food and dose coefficients. An annual effective dose caused by ^{90}Sr was in the range of (1,9–14)·10^{-8} Sv, by ^{137}Cs – (0,47–6,2)·10^{-8} Sv and by ^{40}K – (6,8–21)·10^{-5} Sv.

Keywords: ionizing radiation, effective dose, radiological measurements, daily food.

1. Introduction

Due to atomic bomb testing in the period 1945–1963 and an accident at Chernobyl Nuclear Power Plant (NPP) in 1986 man-made radionuclides were spread worldwide. Man-made radionuclides are discharged to the environment during the normal operation of nuclear power installations, recycling of spent nuclear fuel and accidents at such installations.

An average activity concentration of ^{137}Cs before the accident at Chernobyl NPP in the soil of Lithuania was 10,0 Bq/kg, of ^{90}Sr – 5,8 Bq/kg, and the distribution of these radionuclides was not homogenous. After the accident at Chernobyl NPP approximately 43 % of ^{137}Cs was deposited in the territory of Lithuania and some of this amount passed into feed.

The results of measurements show that in the regions of Lithuania over which contaminated plume passed an average density of ^{137}Cs activity concentration was 1190 Bq/m^2. In other regions of Lithuania the density varied from very low up to 8430 Bq/m^2. Contamination with ^{90}Sr in the Lithuanian territory varied slightly after the accident at Chernobyl NPP [1].

The influence of radionuclides on the environment and its components is different. The influence of some of the radionuclides was estimated. However, it varied in time or depended on local conditions. Dose estimation of all possible sources is important for the population [2].

Radionuclides pass from the atmosphere to the ground surface with rain or dry deposition. They accumulate in plants through their roots and deposit from the air to the soil. Radionuclides come into the organism of animals from feed that was contaminated with these radionuclides. In a human organism radionuclides accumulate by a food chain [3–5].

The aim of this work was to measure the activity concentrations of man-made radionuclides ^{137}Cs, ^{90}Sr and a natural one ^{40}K in students' food, and to estimate an annual effective dose caused by these radionuclides.

2. Methods of sampling and measurements

2.1. Sampling and preparation for measurements

Samples were taken in VGTU students' canteen once a month (usually at the end of a month) during the period 28 October 2004–23 June 2005. Each sample was constituted of two parts: liquids and solids.

For breakfast, pancakes with curd, various salad and tea were usually selected, for lunch – various soup and meat dishes, for dinner – various dishes from potatoes, tea and so on, including bread, popular drinking products, such as Coca-Cola, Sprite and others.

Preparation of samples for measurement was performed in a way explained below.

1. The volume of liquids was measured using a 1 000 ml measuring flask, solids were weighed using electronic balances with resolution of 0,01 g.

2. Weighed solids were ground and weighed again. Such an operation indicates the lost weight of a sample during these procedures. After that solids were dried in a drying oven at 105 °C temperature, then ashed for 3 hours at 300 ºC temperature and for 15 hours at 400 ºC temperature [6].

3. After measuring the volume of liquids, a solution was placed into an evaporating bowl and dried to a dry mass. The dry residue was ashed using the same procedure as that for solids. Then liquid and solid ashes were mixed, and the activity concentration of radionuclides in the ashes was measured.

2.2. Radiochemical method for separation of ^{90}Sr

The method of determining ^{90}Sr by measuring ^{90}Y counts after extraction with 10 % di(2-ethyl-hexyl) phosphoric acid (HDEHP) in toluene and counting by a liquid scintillation spectrometer was used [6]. Ashes of samples were dissolved in 1 M hydrochloric acid, pH was used in the range of 1,0–1,2 for extracting ^{90}Y from a solution with HDEHP. After this yttrium was re-extracted using 3 M nitric acid, and precipitations of $Y(OH)_3$ were performed. Then the beta counts from dissolved precipitations were measured [6].

2.3. Counting of ^{90}Sr, ^{137}Cs and ^{40}K

Counting of ^{90}Y was carried out because ^{90}Y is a daughter of ^{90}Sr and is in equilibrium in a sample. The activity concentration of ^{90}Y in a sample was measured using a liquid scintillation counter Quantulus 1220–003. Counting was performed by counting the high-energy beta particles of ^{90}Y (2,27 MeV) by the Cherenkov method (typical background was 0,77 cpm, efficiency – 62 %). The chemical yield of ^{90}Y was determined according to stable yttrium carrier [6].

The activity concentration of ^{90}Sr in a sample in Bq was calculated according to equation [6]:

$$A = \frac{\left(N - N_f\right) \cdot A_k}{N_k - N_f}, \tag{1}$$

where
A – activity concentration of ^{90}Sr in sample, in becquerel; N – sample counting rate, in counts per minute; N_f – background counting rate, in counts per minute; N_k – counting rate of calibration source, in counts per minute; A_k – activity of calibration source, in becquerel.

The activity concentration of ^{90}Sr in a sample in Bq/kg was calculated according to equation [6]:

$$A_{^{90}Sr} = \frac{A}{Y \cdot m}, \tag{2}$$

where
$A_{^{90}Sr}$ – activity concentration of ^{90}Sr in sample, in becquerel per kg; A – concentration of ^{90}Sr in sample, in becquerel; Y – chemical yield of yttrium, in percent; m – weight or volume of sample, in kg or m^3.

Samples for gamma spectrometry were prepared according to the method described in [7] paper. An appropriate volume (50 ml) of a sample was put on a gamma spectrometer with a high-purity Ge detector. The time of counting was estimated according to the activity concentrations of radionuclides in a sample because the time has to be long enough to have an appropriate amount of pulses [7].

Generated spectrum was saved in the spectrometer memory and analyzed using Genie 2000 with mathematical calibration option [7].

2.4. Calculation of annual effective dose

An annual effective dose was calculated according to the following equation:

$$D_e = A \cdot 365 \cdot m \cdot K_d, \tag{3}$$

where
D_e – annual effective dose, in Sv; A – activity concentration of radionuclide in sample, in becquerel per kg; 365 – number of days; m – weight of daily food, in kg; K_d – dose coefficient, in Sv/Bq.

Dose coefficients were used: for ^{90}Sr – $2{,}8 \times 10^{-8}$ Sv/Bq, for ^{137}Cs – $1{,}3 \times 10^{-8}$ Sv/Bq and for ^{40}K – $6{,}2 \times 10^{-9}$ Sv/Bq [8].

3. Results and discussion

Average activity concentrations of man-made long-lived radionuclides ^{90}Sr and ^{137}Cs in daily food samples from VGTU students' canteen were: ^{90}Sr – (0,03±0,01) Bq/kg, ^{137}Cs – (0,02±0,01) Bq/kg. The highest values were measured: for ^{90}Sr – (0,09±0,03) Bq/kg, for ^{137}Cs – (0,08±0,01) Bq/kg (Fig 1). The highest concentration of ^{90}Sr and ^{137}Cs was found in a sample taken on 28 April 2005 that consisted of herring with carrot salad, salad of bread and beans, fish with mashed potatoes, beetroot soup and cabbage salad.

For comparison of food products that may lead to increase of activity concentration in a sample from 28 April 2005, average annual activity concentrations of ^{90}Sr and ^{137}Cs in different types of raw food products are shown in Table 1 [9]. The data in Table 1 show that the highest activity concentration for ^{90}Sr can be subject to vegetables, and for ^{137}Cs – subject to fish. It is believable that the highest activity concentration of ^{137}Cs in a sample from 28 April 2005 was subject to fish and herring in a sample. In the case of ^{90}Sr the highest activity concentration was subject to cabbage salad.

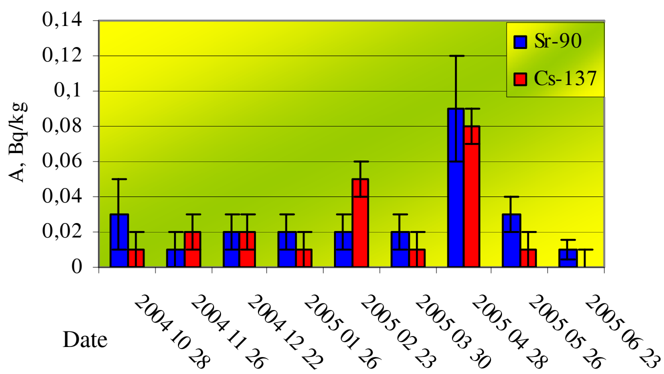

Fig 1. Activity concentration A of ^{90}Sr and ^{137}Cs (Bq/kg) in food samples from VGTU students' canteen on 28 October 2004 – 23 June 2005

The range of the activity concentration of natural ^{40}K measured in the samples of daily food was from (22±2) Bq/kg to (42±3) Bq/kg, and an average activity concentration was (34±3) Bq/kg (Fig 2).

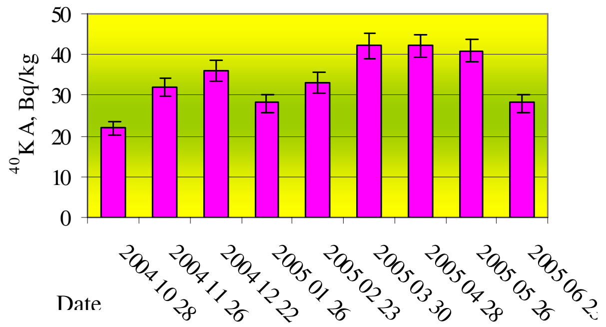

Fig 2. Activity concentration A of ^{40}K (Bq/kg) in daily food of VGTU students' canteen on 28 October 2004 – 23 June 2005

The activity concentrations of ^{40}K were much higher than those of man-made radionuclides.

Table 1. Average activity concentrations of ^{90}Sr and ^{137}Cs (Bq/kg) in different types of raw food products in 2004 [9]

Food product	Radionuclide	Activity concentration, Bq/kg
Milk	^{90}Sr ^{137}Cs	0,04±0,01 0,03±0,01
Meat	^{90}Sr ^{137}Cs	0,02±0,01 0,09±0,09
Cabbage	^{90}Sr ^{137}Cs	0,15±0,14 0,05±0,03
Potatoes	^{90}Sr ^{137}Cs	0,02±0,01 0,02±0,01
Fish	^{90}Sr ^{137}Cs	0,03±0,01 0,79±1,21
Grain	^{90}Sr ^{137}Cs	0,15±0,08 0,04±0,01

An annual effective dose calculated using the results of measurements and equation (3) are presented in Table 2.

An average annual effective dose caused by ^{90}Sr is $4{,}6 \cdot 10^{-8}$ Sv, by ^{137}Cs – $2{,}0 \cdot 10^{-8}$ Sv and by ^{40}K – $1{,}4 \cdot 10^{-4}$ Sv. The total annual effective dose is $1{,}4 \cdot 10^{-4}$ Sv (Fig 3).

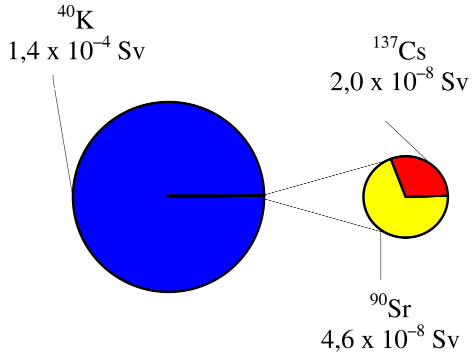

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Fig 3. Composition of effective dose

Fig 3 shows that effective dose is caused mainly by ^{40}K in food, the dose caused by man-made radionuclides is much lower. The range of an annual effective dose caused by ^{90}Sr varies from $(1{,}9\pm1{,}0) \cdot 10^{-8}$ Sv to $(1{,}4\pm0{,}3) \cdot 10^{-7}$ Sv.

An annual effective dose caused by ^{137}Cs varies from $(4{,}7\pm4{,}7) \cdot 10^{-9}$ Sv to $(6{,}2\pm0{,}5) \cdot 10^{-8}$ Sv.

An annual effective dose caused by ^{40}K varies from $(6{,}8\pm0{,}5) \cdot 10^{-5}$ Sv to $(2{,}1\pm0{,}) \cdot 10^{-4}$ Sv.

The data given in this paper are comparable with those obtained during measurements of radionuclides in a mixed diet from two canteens of hospitals in Vilnius [10]. Measurements of 28 samples during the period 2001–2002 were made at the Radiation Protection Centre. Change dynamics of the activity concentrations of ^{90}Sr and ^{137}Cs measured in the samples is shown in Fig 4. An average intake of ^{90}Sr was estimated (0,09±0,01) Bq/day, of ^{137}Cs – (0,12±0,01) Bq/day. Dose estimation was performed in the same way as described in this paper. An average annual effective dose caused by

Table 2. Activity concentration of radionuclides (Bq/kg) measured in samples of daily food from VGTU students' canteen and annual effective dose caused by ^{90}Sr, ^{137}Cs and ^{40}K (Sv) in daily food in 2004–2005

Date of sampling	Weight of sample, kg	Activity concentration of ^{90}Sr in sample, Bq	Annual effective dose due to ^{90}Sr, $\cdot10^{-8}$, Sv	Activity concentration of ^{137}Cs in sample, Bq	Annual effective dose due to ^{137}Cs, $\cdot10^{-8}$, Sv	Activity concentration of ^{40}K in sample, Bq	Annual effective dose due to ^{40}K, $\cdot10^{-5}$, Sv
2004 10 28	1,374	0,04±0,02	3,8±1,9	0,01±0,01	0,47±0,47	30±2	6,8±0,5
2004 11 26	1,643	0,02±0,01	1,9±1,0	0,03±0,01	1,4±0,5	53±2	12,0±0,5
2004 12 22	1,710	0,03±0,01	2,9±1,0	0,03±0,01	1,4±0,5	62±3	14±1
2005 01 26	2,194	0,04±0,01	3,8±1,0	0,02±0,01	0,95±0,47	61±2	14,0±0,5
2005 02 23	2,258	0,05±0,01	4,8±1,0	0,11±0,01	5,2±0,5	75±3	17±1
2005 03 30	2,169	0,04±0,01	3,8±1,0	0,02±0,01	0,95±0,47	91±3	21±1
2005 04 28	1,649	0,15±0,03	14±3	0,13±0,01	6,2±0,5	69±3	16±1
2005 05 26	1,655	0,05±0,01	4,8±1,0	0,02±0,01	0,95±0,47	68±3	15±1
2005 06 23	1,850	0,02±0,01	1,9±1,0	0,01±0,01	0,47±0,47	52±2	12,0±0,5

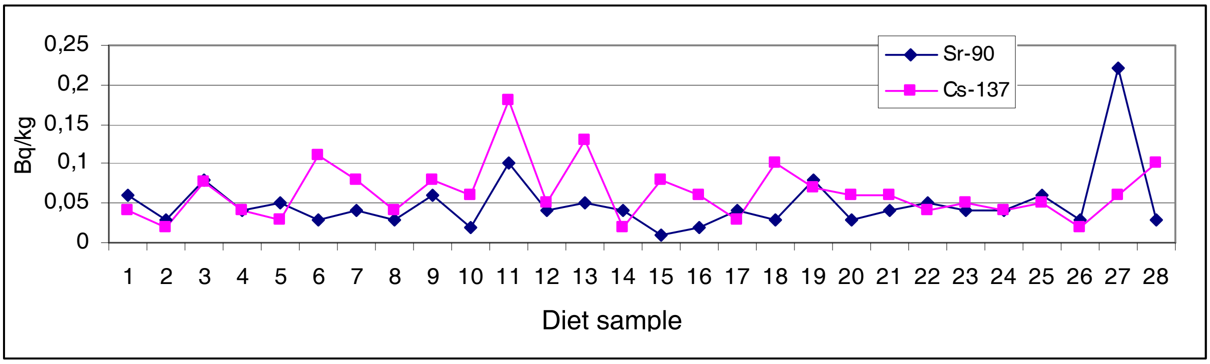

Fig 4. Activity concentration of ^{90}Sr and ^{137}Cs (Bq/kg) in mixed diet samples from canteens of two hospitals in October 2001–September 2002 [10]

Table 3. Average activity concentration of radionuclides (Bq/kg) measured in mixed diet samples from canteens of two hospitals and annual effective dose caused by ^{90}Sr, ^{137}Cs and ^{40}K (Sv) in mixed diet in 2001–2002 [10]

Radionuclide	Activity concentration, Bq/kg	Activity concentration, Bq / day	Dose coefficient, Sv/Bq [8]	Annual effective dose, Sv
^{90}Sr	0,05±0,01	0,09±0,01	2,8 x 10^{-9}	9,2 x 10^{-8}
^{137}Cs	0,06±0,02	0,12±0,01	1,3 x 10^{-8}	5,4 x 10^{-7}
^{40}K	45±4	51±7	6,2 x 10^{-9}	1,15 x 10^{-4}

^{90}Sr and ^{137}Cs in a mixed diet was 6,4 · 10^{-7} Sv, the total dose caused by ^{90}Sr, ^{137}Cs and ^{40}K – 1,15 · 10^{-4} Sv (Table 3).

Analyses of mixed diet samples from Helsinki during 2001 showed that the intake for ^{90}Sr was 0,12–0,13 Bq/day, for ^{137}Cs – 0,20–0,81 Bq/day in solids, and 0,34–0,36 Bq/day in liquids. An annual effective dose caused by ^{90}Sr and ^{137}Cs in a mixed diet for the population of Helsinki is less than 0,01 Sv [11]. The dose for the population of Helsinki is higher to compare with that for Lithuanians because the environment of the Nordic countries was more contaminated during atomic bomb testing and after the accident at Chernobyl NPP.

4. Conclusions

1. Average activity concentrations for ^{90}Sr and ^{137}Cs in daily food samples from VGTU students' canteen measured during the period 28 October 2004 – 23 June 2005 was: for ^{90}Sr – (0,03±0,01) Bq/kg, for ^{137}Cs – (0,02±0,01) Bq/kg.

2. An average annual effective dose caused by ^{90}Sr was (4,6±1,3) · 10^{-8} Sv, by ^{137}Cs – (2,0±0,5)·10^{-8} Sv and by ^{40}K – (1,4±0,8) · 10^{-4} Sv. The total annual effective dose caused by all the three radionuclides was (1,4±0,8) · 10^{-4} Sv.

3. The estimated doses were low and their variation was subject to the components of food.

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^{137}Cs, ^{90}Sr IR ^{40}K SPINDULIUOTĖS SUKELTOS EFEKTINĖS DOZĖS ŽMOGAUS PAROS RACIONE ĮVERTINIMAS

D. Butkus, I. Laučytė, R. Ladygienė

S a n t r a u k a

Straipsnyje pateikiami išmatuoti ^{137}Cs, ^{90}Sr, ^{40}K savitieji aktyvumai žmogaus paros racione ir jonizuojančiosios spinduliuotės sukeltos metinės efektinės dozės. Bandiniai eksperimentui buvo imami nuo 2004-10-28 iki 2005-06-23 kartą per mėnesį iš VGTU studentų valgyklos. Mėginių masė įvairavo nuo 1,37 kg iki 2,26 kg ir vidutiniškai buvo 1,89 kg. Skysčių tūris įvairavo nuo 500 iki 1000 cm^3 ir vidutiniškai buvo 816 cm^3. VGTU studentų valgyklos paros raciono bandiniuose nustatytos šios vidutinės savitųjų aktyvumų vertės: ^{90}Sr – 0,03±0,01 Bq/kg, ^{137}Cs – 0,02±0,01 Bq/kg, ^{40}K – 34±3 Bq/kg. Pagal nustatytus savituosius aktyvumus paros racione ir taikant dozės koeficientus buvo apskaičiuota, kad ^{90}Sr, esančio maiste, jonizuojančiosios spinduliuotės sukelta efektinė dozė kinta nuo $(1,9±1,0) \cdot 10^{-8}$ Sv iki $(14±3) \cdot 10^{-8}$ Sv, ^{137}Cs – nuo $(0,47±0,47) \cdot 10^{-8}$ Sv iki $(6,2±0,5) \cdot 10^{-8}$ Sv, ^{40}K – nuo $(6,8±0,5)\cdot10^{-5}$ Sv iki $(21±1)\cdot10^{-5}$ Sv.

Prasminiai žodžiai: jonizuojančioji spinduliuotė, efektinė dozė, paros racionas.

ОЦЕНКА ЭФФЕКТИВНОЙ ДОЗЫ, СОЗДАННОЙ ИЗЛУЧЕНИЕМ ^{137}CS, ^{90}SR, ^{40}K, В СУТОЧНОМ РАЦИОНЕ ЧЕЛОВЕКА

Д. Буткус, И. Лаучите, Р. Ладигене

Р е з ю м е

Анализируются измеренные концентрации активности радиоизотопов ^{137}Cs, ^{90}Sr, ^{40}K в суточном рационе человека и годовая эффективная доза. Образцы для эксперимента забирались в студенческой столовой ВТУ им. Гедиминаса один раз в месяц с 28-10-2004 по 23-06-2005. Масса образцов составляла от 1,37 кг до 2,26 кг, в среднем – 1,89 кг. Объем жидкости колебался от 500 см^3 до 1000 см^3, в среднем составлял 816 см^3. В образцах рациона были измерены концентрации активности ^{90}Sr – 0,03 ± 0,01 Бк/кг, ^{137}Cs – 0,02 ± 0,01 Бк/кг и ^{40}K – 34 ± 3 Бк/кг. По установленным концентрациям активности с использованием коэффициентов дозы было определено, что эффективная доза ^{90}Sr меняется от $(1,9 \pm 1,0) \cdot 10^{-8}$ Св до $(14 \pm 3) \cdot 10^{-8}$ Св, ^{137}Cs – от $(0,47±0,47) \cdot 10^{-8}$ Св до $(6,2±0,5) \cdot 10^{-8}$ Св и ^{40}K – от $(6,8±0,5)\cdot10^{-5}$ Св до $(21±1)\cdot10^{-5}$ Св.

Ключевые слова: ионизационное излучение, эффективная доза, суточный рацион.

Donatas BUTKUS. Dr Habil, Prof, Dept of Environmental Protection, Vilnius Gediminas Technical University (VGTU).

Doctor Habil of Science (environmental engineering), VGTU, 1999. Membership: a member of International Academy of Ecology and Life Protection. Publications: author of more than 180 research papers, co-author of monograph „Geophysical problems of atmospheric krypton-85“ (in Russian and English). Research interests: accumulation of radioactive noble gases, their interaction with environmental bodies, self-cleaning of the atmosphere, influence of ionizing radiation of radioactive noble gases on geophysical processes; consequences of Chernobyl accident in Lithuania.

Rima LADYGIENĖ. Head of Subdivision of Radiological Investigations, Radiation Protection Centre; doctoral student, Dept of Environmental Protection, Vilnius Gediminas Technical University (VGTU).

First degree in Chemistry, Vilnius State V. Kapsukas University (VU), 1984. Publications: author (with co-authors) of more than 10 research papers. Research interests: environmental radioactivity, measurements of activity concentrations of radionuclides in food, dose assessment for public, radiation protection.

Inga LAUČYTĖ. Master student, Dept of Environmental Protection, Vilnius Gediminas Technical University (VGTU).

Bachelor of Science (environmental engineering), Klaipėda University, 2004. Research interests: environmental radioactivity.