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RADIOLOGICAL INVESTIGATION OF MEAT OF GAME AND DOSE ESTIMATION FOR HUNTERS AND MEMBERS OF THEIR FAMILIES

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Abstract. The paper describes dose estimation for hunters and members of their families due to radionuclides ^{90}Sr and ^{137}Cs in meat of game hunted in Lithuania during two hunting seasons: 2003–2004 and 2004–2005. Research in the Nordic countries showed higher activity concentrations of both radionuclides in meat of game and higher doses to public consuming this meat. The scope of this investigation is radiological measurements of meat samples of game and dose estimation for hunters and members of their families. Measurements show that activity concentrations of ^{90}Sr in samples of meat of game are less than for ^{137}Cs. An average activity concentration of ^{90}Sr in all the samples of meat of game analysed was 0,06±0,03 Bq/kg, for ^{137}Cs – 7,8±4,6 Bq/kg. The highest activity concentration of ^{137}Cs was measured in the sample of meat of moose from Matuiza forest near Varėna district, and it was 30,8±2,0 Bq/kg. It was estimated that an annual effective dose due to ^{90}Sr in meat of game was in the range from $5{,}6\cdot10^{-10}$ Sv to $3{,}6\cdot10^{-8}$ Sv, due to ^{137}Cs – in the range from $5{,}2\cdot10^{-8}$ Sv to $3{,}3\cdot10^{-6}$ Sv. The total dose due to ^{90}Sr in meat of all the different kinds of game was 0,06 μSv, for ^{37}Cs – 4,7 μSv. The results show that dose due to ^{137}Cs in meat of game may be much higher than the total dose due to ^{90}Sr and ^{137}Cs in the whole daily food (1,3 μSv). This dose value was estimated for the public of Lithuania in 2005 and based on the results of food radiological monitoring at Radiation Protection Centre. The main conclusion drawn during this study is that radiological monitoring of meat of game is needed, and dose estimation based on the results of measurements is necessary to protect the public of Lithuania from the harmful effects of ionizing radiation.

Keywords: ionizing radiation, dose, radiological measurements, game.

1. Introduction

Man-made radionuclides ^{90}Sr and ^{137}Cs appeared in the environment of Lithuania after nuclear bombs tests in the atmosphere in the northern part of the Earth and later – after the accident at Chernobyl Nuclear Power Plant (ChNPP) in 1986. After starting operation of Ignalina Nuclear Power Plant the releases of both radionuclides to the environment are continuous. ^{90}Sr and ^{137}Cs are the most dangerous from the view point of ecology because they are long-lived radionuclides and their behavior in the body of man is the same as for the stable calcium and potassium. The levels of contamination of the environment of Lithuania by ^{90}Sr and ^{137}Cs radionuclides were a point of investigations in different aspects. Some of them included measurements of arable land for the estimation of possible migration of both radionuclides from the soil to vegetation and food products. Average concentration of ^{137}Cs in the soil of Lithuania before the accident at ChNPP was 6,8±1,8 Bq/kg, after the accident – 6,7÷28,5 Bq/kg [1]. For uncultivated areas, the activity concentration of ^{137}Cs in the soil was much higher [2]. Sampling was performed at a depth of 5 cm dividing the territory of Lithuania to the sectors of 16 × 16 km in 1992, 4 years later after the accident at ChNPP. The highest activity concentration in the soil was measured in the southern and western parts of Lithuania and the Curonian Spit. At that time a most contaminated part of Lithuania was the Curonian Spit – in some places the highest activity concentration of ^{137}Cs was 20 kBq/m^2. It was estimated that the density of precipitations of ^{137}Cs in Lithuania was less than 18,5 kBq/m^2 [3]. The highest activity concentration of ^{137}Cs is located in two soil layers: at 0–4 cm depth and at a depth of 8–14 cm. The first maximum is due to contamination by nuclear bomb tests in the atmosphere in 1945–1960, the second one – due to contamination after the accident at ChNPP in 1986. According to investigation in the vicinity of a forest tree, it is estimated that the highest ^{137}Cs activity concentration is in a 0–5 cm layer, and it indicates a low migration in a sandy forest soil [4]. At that time ^{137}Cs is mostly located at a depth of 10–15 cm in the soil, and an average soil surface density of ^{137}Cs is 700–1200 Bq/m^2 [5]. The migration of ^{137}Cs in the soil is up to 25 cm in depth, and 40 % of ^{137}Cs is located in a 0–5 cm layer in sandy loam, and 59 % – in a clayey soil [6].

The forest environment still contains ^{90}Sr and ^{137}Cs in deep layers that are available for the uptake by vegetation. Wild food products, such as meat of game, are connected with the environment of forest components by a

food chain. Research works in the Nordic countries indicate much higher activity concentrations of ^{137}Cs in meat of game [7–10].

Hunting is a popular hobby in Lithuania, and it is typical of hunters to use meat of game for food as delicacies. The scope of this investigation is measurements of activity concentrations of ^{90}Sr and ^{137}Cs in meat of game and dose estimation for hunters and members of their families.

2. Investigation methods

2.1. Sampling

Sampling of meat of moose, wild boar, roe and dear was performed during two hunting seasons: 2003–2004 and 2004–2005. Random sampling was carried out in Varėna, Ukmergė, Ignalina, Druskininkai and Lazdijai districts. Game were hunted by the members of hunting groups in Matuiza, Garbenas forests, Baneliai, Ažvinčiai, Minčia countryside and an area near Kapčiamiestis. Samples were taken by hunters at hunting places and transported to a laboratory of Radiation Protection Centre for analysis. Before analysis the samples were stored in a freezer. An average weight of a sample was 0,77±0,16 kg, the sample weight varied from 0,26±0,09 kg up to 1,58±0,01 kg. Totally 17 samples were analysed for ^{90}Sr and ^{137}Cs.

2.2. Sample preparation

Sample preparation was performed taking away all the parts that cannot be used for consumption. After that meat samples were grounded and dried at 105 °C temperature to dry weight. Later the ashing procedure of 3 hours at 300 °C temperature and of 15 hours at 400 °C temperature [11] was performed to reduce all organic materials from the sample. For the analysis, at first the ash was used for gamma counting, later radiochemical separation of ^{90}Sr from sample ash was performed.

2.3. Measurement of activity concentration of ^{137}Cs

Counting of prepared sample ash by gamma spectrometry was performed for the estimation of concentrations of ^{137}Cs [12]. An appropriate fixed volume (50 ml) with sample ash was counted by a gamma spectrometer with a high-purity germanium detector. Time of counting was estimated according to activity concentrations of radionuclides in a sample to have an appropriate amount of pulses generated in the gamma spike. Generated spectrum was analysed using Genie 2000 with mathematical calibration option ISOCS/labSOCS.

2.4. Measurement of activity concentration of ^{90}Sr

Activity concentration of ^{90}Sr was measured by counting in a liquid scintillation counter Quantulus. A radiochemical procedure for separation was performed [11]. According to the procedure, extraction of yttrium (a daughter in equilibrium with strontium) was performed using HDEHP. Later an yttrium nitrate solution was counted in a plastic 20 ml volume scintillation counting vial for 100 min each sample. Chemical yield was determined by titration of added to the initial sample stable yttrium.

2.5. Estimation of average annual consumption of meat of game for a person

An average annual consumption for a person was calculated using statistical data of an average number of hunters in the country during 5 years and an average number of game hunted per year during the last 6 years (for wild boars – the last 3 years).

Statistical data available from the Lithuanian Hunters' Association show that an average number of hunters in the country during the period 1999–2003 was 26 740, but only 45 % of them participate actively. For this reason a real average annual number of hunters is approximately 12 thousand. An assumption was made that the number of adult persons consuming meat of game in a hunter's family is 2. An average annual number of persons using meat of game for food is approximately 24 thousand.

An average annual number of game hunted in the country during hunting seasons in 2000–2006 (6 seasons of hunting, for wild boars – 3 seasons) was estimated using data from statistical publications [13–16] (Table 1). For one season, hunting of moose and red dears was not permitted.

An average weight of a wild animal was estimated to take the weight of an adult buck, an adult doe and a young animal, to summarize these weights and to take one third of weight of the total sum. An average weight for game was calculated as follows: for moose – 230 kg, for wild boar – 70 kg, for roe – 50 kg and for red deer – 144 kg. The yield of an edible part of meat was calculated as the third part of an average animal weight.

All these data were used for estimation of an average annual consumption. The following values of an average annual consumption of meat of game for a person (hunters and the members of their families) were used for dose estimation: 1 kg of moose, 13 kg of wild boar, 9 kg of roe and 2 kg red dear.

Table 1. Number of game hunted in Lithuania in 2000–2006, in units [13–16]

Kind of animal	2000–2001	2001–2002	2002–2003	2003–2004	2004–2005	2005–2006	average
Moose	550	500	480	no hunting	91	122	349
Red deer	1850	1300	800	no hunting	601	766	1063
Roe	10750	11600	12300	12750	14988	15181	12928
Wild boar	–	–	–	10919	13022	16554	13498

2.6. Estimation of annual effective dose due to ^{90}Sr and ^{137}Cs in meat of game

For the estimation of an annual effective dose due to ^{90}Sr and ^{137}Cs in meat of game, results from the measurements of activity concentrations of ^{90}Sr and ^{137}Cs, an average annual consumption of meat of game per person, dose coefficients for ^{90}Sr (2,8 10^{-8} Sv/Bq) and for ^{137}Cs (1,3·10^{-8} Sv/Bq) [17] were used. Dose estimation was made without taking into account the effects of food processing.

3. Results and discussion

Results of measurements of activity concentrations of ^{90}Sr and ^{137}Cs in the samples of meat of game show that the activity concentrations of ^{90}Sr are less than for ^{137}Cs. Average activity concentrations of ^{90}Sr and ^{137}Cs are shown in Fig 1 with an interval of confidence 2δ. All the results are for fresh weight. The highest activity concentration for ^{90}Sr was measured in a sample of meat of roe from an area close to Druskininkai (the animal was 2 years old) – 0,14±0,07 Bq/kg. An average activity concentration of ^{90}Sr in all the samples analysed was 0,06±0,03 Bq/kg, for ^{137}Cs – 7,8±4,6 Bq/kg. The highest activity concentration of ^{137}Cs was measured in a sample of meat of moose from Matuiza forest near Varėna district – 30,8±2,0 Bq/kg. The "cleannest" from ^{137}Cs is meat of wild boar, from ^{90}Sr – meat of red dear. The style of living, food consumption have an influence on the intake of radionuclides because radionuclides are located at a different depth in the soil and uptake by vegetation is various.

The results obtained during this study are similar to those from State Veterinary and Food Service, National Veterinary Laboratory [18]. An average activity concentration of ^{137}Cs in meat of game analysed in 2001 was 7,82±9,78 Bq/kg of fresh weight, and activity concentration was in the range of 1÷37 Bq/kg (17 samples were analysed). In 2002 some higher activity concentrations of ^{137}Cs were measured in meat of game [19]. An average activity concentration of ^{137}Cs in meat of game analysed in 2002 was 19,9±47,8 Bq/kg of fresh weight, and activity concentration was in the range of 2÷147 Bq/kg (49 samples were analysed).

These results show that ^{137}Cs still remains in the forest soil at a depth available for vegetation roots, so meat of game still contains much more ^{137}Cs than pork or beef [20]. The results of radiological monitoring of foodstuffs at Radiation Protection Centre show that an average activity concentration of ^{90}Sr in meat (pork and beef) in 2005 was 0,08±0,09 Bq/kg, for ^{137}Cs – 0,08±0,07 Bq/kg. It was due to the style of living of these animals and less contaminated feeding stuffs by ^{137}Cs and more contaminated by ^{90}Sr (typically grain is main feed of pork, and it contains more ^{90}Sr [20]).

Dose estimation gave results that an annual effective dose due to ^{90}Sr in meat of game is in the range from 5,6·10^{-10} Sv up to 3,6·10^{-8} Sv, due to ^{137}Cs – in the range from 5,2·10^{-8} Sv up to 3,3·10^{-6} Sv. Average dose values are shown in Table 2.

Total dose due to ^{90}Sr in meat of game is 0,06 μSv, due to ^{37}Cs – 4,7 μSv.

These values indicate that when the consumption of meat of game is smaller (totally 25 kg per year) in comparison to meat (pork and beef), typically 51±2 kg per year, dose due to ^{137}Cs in meat of game may be much higher, and the value is higher than dose due to ^{90}Sr and ^{137}Cs in the whole daily food (1,3 μSv) [20]. The components of the total dose due to ^{90}Sr and ^{137}Cs in meat of game are shown (in percent) in Fig 2.

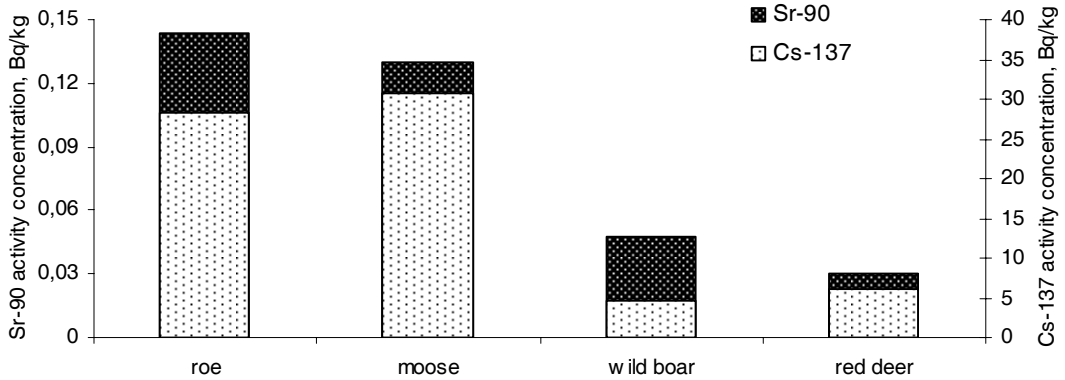

Fig 1. Average activity concentrations of ^{90}Sr and ^{137}Cs measured in samples of meat of game in Lithuania during two hunting seasons in 2003–2005, Bq/kg of fresh weight

Table 2. Average annual effective dose due to ^{90}Sr and ^{137}Cs in samples of meat of game hunted in 2003–2005, μSv

Radionuclide	Average annual effective dose, μSv			
	Red dear	Moose	Roe	Wild boar
^{90}Sr	(1,9±0,8)·10^{-3}	(3,6±3,0)·10^{-3}	(3,6±0,6)·10^{-2}	(1,7±0,8)·10^{-2}
^{137}Cs	(1,6±0,7)·10^{-1}	(4,0±0,2)·10^{-1}	3,3±0,3	(7,9±1,2)·10^{-1}

Fig 2. Components of total average annual effective dose for hunters and members of their families due to ^{90}Sr and ^{137}Cs in meat of game, in percent

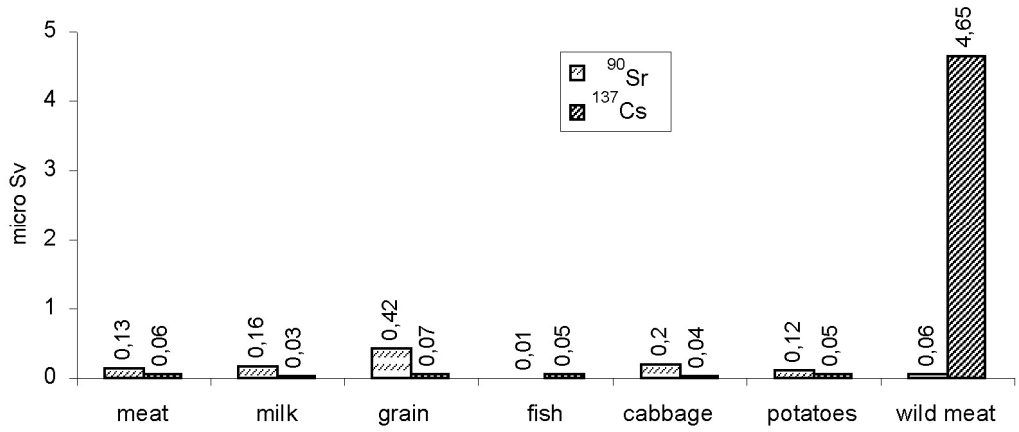

Fig 3. Components of total dose for hunters and members of their families due to ^{90}Sr and ^{137}Cs in daily food (data for 2005 [20]) and in meat of game (data for two hunting seasons in 2003–2005), μSv

The components of the total dose for hunters and members of their families due to ^{90}Sr and ^{137}Cs in daily food (data for 2005 [20]) and meat of game are shown (in μSv) in Fig 3.

Dose due to ^{90}Sr and ^{137}Cs in meat of game for hunters or members of their families in Lithuania is less than that estimated for some people in Finland [9] due to a less contaminated environment in Lithuania by fallout during nuclear bomb tests and the accident at ChNPP [3, 5, 21]. An average concentration in moose meat in the fallout area in Finland in 1986 was 300 Bq/kg. The ^{137}Cs concentration in small game was the same or higher than in moose, depending on local fallout and the animals' way of living [7]. The main forage of reindeer in winter is lichen which absorbs almost all the radioactive substances in fallout. In general, the reindeer herding area in Finland received little fallout. However, reindeer meat reaching consumers in the winter of 1986–1987 contained on an average 700 Bq/kg of ^{137}Cs. ^{137}Cs still remains in meat of game. In 2004 in Finland 6 samples of meat of venison were analysed, and the activity concentration of ^{137}Cs in the samples was 11–120 Bq/kg, the highest concentration was in samples from Tampere. The same year meat of reindeer contained 240–300 Bq/kg of ^{137}Cs (3 samples were analysed from Rovaniemi, North of Finland) [8]. In 2005 the situation was mainly the same. Analysis of 4 samples of venison showed the ^{137}Cs activity concentration of 8–130 Bq/kg, meat of reindeer from Rovaniemi contained much more ^{137}Cs – 180–380 Bq/kg (4 samples were analysed) [9]. Measurements of activity concentrations of ^{90}Sr and ^{137}Cs in reindeer meat in Greenland in 1992 showed that ^{137}Cs activity concentrations were in the range 16–54 Bq/kg, for ^{90}Sr – in the range 0,14–0,58 Bq/kg [10]. The activity concentrations of ^{137}Cs due to food chain reached the human body. The results of the whole-body counting of people from more contaminated areas in Finland show that the body of some persons may contain up to 1,5 kBq of ^{137}Cs [9], and mean internal radiation dose from ^{137}Cs in 2005 was estimated to be 0,01 mSv.

Nevertheless, it is true that the activity concentrations of ^{137}Cs in meat of game hunted in Lithuania are less than in Finland, but an annual effective dose due to this radionuclide in meat of game consumed by hunters are higher than the total dose due to ^{90}Sr and ^{137}Cs in the whole daily food. These results indicate the need of radiological monitoring of meat of game to be performed, and dose estimation based on the results of measurements is necessary to protect public from harmful effects of ionizing radiation.

4. Conclusions

1. The results of measurements of the activity concentrations of ^{90}Sr and ^{137}Cs in samples of meat of game showed that the activity concentration of ^{90}Sr was less than for ^{137}Cs.

2. An average activity concentration of ^{90}Sr in all the samples of meat of game analysed was 0,06±0,03 Bq/kg, of ^{137}Cs – 7,8±4,6 Bq/kg.

3. The highest activity concentration of ^{137}Cs was measured in the sample of meat of moose from Matuiza forest near Varėna district, and it was 30,8±2,0 Bq/kg.

4. An annual effective dose due to ^{90}Sr in meat of game is in the range from $5{,}6\cdot10^{-10}$ Sv to $3{,}6\cdot10^{-8}$ Sv, due to ^{137}Cs – in the range from $5{,}2\cdot10^{-8}$ Sv to $3{,}3\cdot10^{-6}$ Sv.

5. The total dose due to ^{90}Sr in meat of game is 0,06 μSv, due to ^{37}Cs – 4,7 μSv.

6. Dose due to ^{137}Cs in meat of game may be much higher than the total dose due to ^{90}Sr and ^{137}Cs in the whole daily food (1,3 μSv).

7. Radiological monitoring of meat of game is needed periodically, and dose estimation based on the results of measurements is necessary to protect public from the harmful effects of ionizing radiation.

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MEDŽIOJAMŲJŲ GYVŪNŲ MĖSOS RADIOLOGINIAI TYRIMAI IR MEDŽIOTOJŲ BEI JŲ ŠEIMŲ NARIŲ GAUTŲ APŠVITOS DOZIŲ ĮVERTINIMAS

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Santrauka

Nagrinėjama medžiojamosios gyvūnijos mėsos tarša dirbtinės kilmės ilgaamžiais radionuklidais ^{90}Sr ir ^{137}Cs bei įvertinama, kokią šių radionuklidų jonizuojančiosios spinduliuotės sukeltą apšvitos dozę gauna medžiotojai bei jų šeimos nariai. Remiantis Šiaurės šalių radiologiniais tyrimais, nustatyta, kad medžiojamųjų gyvūnų mėsoje yra palyginti didesni nei kitų, namų sąlygomis auginamų, gyvūnų mėsoje šių radionuklidų kiekiai, nes miško paklotėje šie radionuklidai yra migravę iki 20 cm gylio, kurį lengvai pasiekia augalijos šaknys. Per augaliją mitybos grandinėmis ^{90}Sr ir ^{137}Cs patenka į žmogaus organizmą, sukeldamas vidinę apšvitą. Šio darbo tikslas ir buvo radiologiškai ištirti Lietuvoje sumedžiojamų gyvūnų mėsoje esančių ^{90}Sr ir ^{137}Cs savituosius aktyvumus bei įvertinti, kokias apšvitos dozes dėl ^{90}Sr ir ^{137}Cs medžiojamųjų gyvūnų mėsoje jonizuojančiosios spinduliuotės gauna daugiausia šios mėsos vartojantys gyventojai – medžiotojai bei jų

šeimos nariai. Buvo tirta briedžių, tauriųjų elnių, šernų ir stirnų mėsos mėginiai. Gyvūnai buvo sumedžioti Varėnos, Druskininkų, Ignalinos, Ukmergės ir Lazdijų rajonų apylinkėse 2003–2004 ir 2004–2005 metų medžioklės sezonų metu. Tyrimai buvo atlikti Radiacinės saugos centre. Nustatyta, kad ^{90}Sr savitasis aktyvumas visuose tirtuose mėginiuose yra mažesnis už ^{137}Cs savitąjį aktyvumą. Vidutinė ^{90}Sr savitojo aktyvumo vertė medžiojamųjų gyvūnų mėsoje buvo 0,06±0,03 Bq/kg, ^{137}Cs – 7,8±4,6 Bq/kg. Didžiausias ^{137}Cs savitasis aktyvumas buvo išmatuotas briedžio, sumedžioto Matuizų miške Varėnos apylinkėse, mėsos mėginyje – aktyvumas siekė 30,8±2,0 Bq/kg. Įvertinta, kad vidutinė metinė efektinė apšvitos dozė dėl ^{90}Sr medžiojamųjų gyvūnų mėsoje jonizuojančiosios spinduliuotės svyruoja nuo $5{,}6\cdot10^{-10}$ Sv iki $3{,}6\cdot10^{-8}$ Sv, dėl ^{137}Cs – nuo $5{,}2\cdot10^{-8}$ Sv iki $3{,}3\cdot10^{-6}$ Sv. Visa apšvitos dozė dėl ^{90}Sr medžiojamųjų gyvūnų mėsoje jonizuojančiosios spinduliuotės lygi 0,06 μSv, dėl ^{37}Cs – 4,7 μSv. Apšvitos dozė dėl ^{137}Cs medžiojamųjų gyvūnų mėsoje jonizuojančiosios spinduliuotės yra daug didesnė negu apšvitos dozė gyventojui nuo ^{90}Sr ir ^{137}Cs visame maiste jonizuojančiosios spinduliuotės – 1,3 μSv. Ši apšvitos dozė šalies gyventojui 2005 m. įvertinta pagal maisto radiologinių tyrimų rezultatus, gautus Radiacinės saugos centre. Duomenys, gauti tiriant medžiojamosios gyvūnijos mėsą, įrodo, kad medžiojamųjų gyvūnų radiologinius tyrimus reikia vykdyti nuolat, įvertinant, kokias apšvitos dozes gauna ar gali gauti tam tikros grupės, vartojančios sumedžiotų gyvūnų mėsą maistui, gyventojai, saugant juos nuo žalingo jonizuojančiosios spinduliuotės poveikio.

Reikšminiai žodžiai: jonizuojančioji spinduliuotė, apšvitos dozė, radiologiniai tyrimai, medžiojamieji gyvūnai.

РАДИОЛОГИЧЕСКИЕ ИЗМЕРЕНИЯ ПРОБ МЯСА ДИКИХ ЖИВОТНЫХ И РАСЧЕТ ДОЗ ОБЛУЧЕНИЯ, ПОЛУЧАЕМЫХ ОХОТНИКАМИ И ЧЛЕНАМИ ИХ СЕМЕЙ

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Р е з ю м е

Анализируется загрязнение мяса диких животных долгоживущими радионуклидами ^{90}Sr и ^{137}Cs и проводится расчёт доз ионизирующего облучения вышеуказанными радионуклидами, получаемых охотниками и членами их семей. На основании данных радиологических измерений, полученных в Скандинавских странах, установлено, что в мясе диких животных, по сравнению с животными, выращиваемыми в домашних условиях, имеется наибольшее количество радионуклидов по той причине, что эти радионуклиды проникли в почву лесов на глубину до 20 см и стали доступны растениям. По цепочкам питания ^{90}Sr и ^{137}Cs попадают в организм человека и становятся источником внутреннего облучения. Целью работы было радиологическим путем измерить активность ^{90}Sr и ^{137}Cs в пробах мяса диких животных и рассчитать дозы облучения людей, которые употребляют наибольшее количество мяса, – охотников и членов их семей. Дикие животные стали добычей охотников в Варенском, Друскининкском, Игналинском, Укмергском и Лаздийском районах во время двух охотничьих сезонов 2003–2004 и 2004–2005 гг. Радиологические измерения проводились в Центре радиационной защиты. Установлено, что активность ^{90}Sr во всех пробах была ниже активности ^{137}Cs. Средняя активность ^{90}Sr в пробах мяса диких животных составила 0,06±0,03 Bq/кг, а ^{137}Cs – 7,8±4,6 Bq/кг. Наивысшая активность ^{137}Cs была зафиксирована в пробе мяса лося, который был убит в лесу Матуйзай в Варенском районе, и составила 30,8±2,0 Bq/кг. Рассчитано, что среднегодовая эффективная доза ионизирующего облучения ^{90}Sr в мясе диких животных составляла от $5{,}6\cdot10^{-10}$ Sv до $3{,}6\cdot10^{-8}$ Sv, а ^{137}Cs – от $5{,}2\cdot10^{-8}$ Sv до $3{,}3\cdot10^{-6}$ Sv. Суммарная среднегодовая эффективная доза облучения от ионизирующего облучения ^{90}Sr в мясе диких животных составила 0,06 μSv, ^{37}Cs – 4,7 μSv. Среднегодовая эффективная доза облучения от ионизирующего облучения ^{137}Cs в мясе диких животных намного выше, чем суммарная годовая эффективная доза облучения от ^{90}Sr и ^{137}Cs во всей пище – 1,3 μSv. Данные, полученные при радиологических измерениях проб мяса диких животных, показывают, что такие измерения должны проводиться периодически и также периодически должны рассчитываться дозы облучения жителей ионизирующим облучением.

Ключевые слова: ионизирующее облучение, доза облучения, радиологические измерения, дикие животные.

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