DE GRUYTER
OPEN

DOI: 10.2478/fv-2018-0006

FOLIA VETERINARIA, 62, 1: 38—43, 2018

MONITORING OF ^{137}CS AND ^{40}K IN THE LEVICE DISTRICT, SOUTHERN SLOVAKIA

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ABSTRACT

The contamination of the environment, soil and meat of wild animals with radionuclides can negatively affect human health. The aim of our study was to analyse the risk arising from post-Chernobyl contamination of the meat of wild boars (*Sus scrofa*) originating from the district Levice, southern Slovakia, with the radioactive artificial element ^{137}Cs. The level of natural radionuclide ^{40}K was also determined. We examined altogether 45 samples obtained from 9 wild boars hunted in this area during the period of 2013—2015. From each animal we collected and analysed samples from the thigh, stomach contents, stomach muscles and skin. We also examined samples of soil from the locations where these animals were shot. The activity values of radioactive caesium ^{137}Cs determined in this study were very low and therefore the consumption of wild boar meat originating from this location presents no risk to human health.

Key words: contamination; ^{137}Cs; ^{40}K; radionuclides; soil; wild boar

INTRODUCTION

The natural environment is exposed to various chemical contaminants, including the radioactive elements; some of them long-lived naturally occurring radionuclides. There are approximately 60 natural radionuclides and one of the most abundant elements in the Earth's crust is ^{40}K that remains to this point of time [9]. Another source of radioactivity has a cosmogenic origin and is the result of interaction between certain gases in the atmosphere and cosmic rays. Besides such sources of naturally occurring radiation exposure, the natural environment may be subjected to radioactive contamination caused by human activity including nuclear weapon tests, the accidents of nuclear power plants, and processing or storage of nuclear fuel and waste. Such contamination can have long term effects on some biocenoses [1].

Of the several catastrophic nuclear accidents that happened in the nuclear energy era, the Chernobyl was probably the worst. Due to the explosion and fire at the Chernobyl power plant on April 26, 1986, about 3.8×10^{16} Bq of radioactive caesium was released to the atmosphere. The

ratio of the escaped radioactive caesium ^{137}Cs and ^{134}Cs was approximately 2 : 1 [16]. The radioactive cloud released during the accident reached even very distant places all over Europe. With regard to the distance of the former Czechoslovakia from Chernobyl, the estimated 1986 effective dose for children was 0.36 mSv and for adults 0.22 mSv. The most affected regions of Europe included for example Norway where the ^{137}Cs activity reached levels as high as 500 kBq.m^{-2} [13].

With regard to the time lapse and the character of the nuclear accident, of all artificial radionuclides only ^{137}Cs, with a physical half-life decay of 30 years, occurs in the soil in Slovakia [6]. Generally, radionuclides show a very high mobility in soil [2]. The ^{137}Cs and ^{40}K isotopes belong to the same group of alkali metals, have similar chemical properties and are strong reducing agents. This is an explanation for competitive-sorption behaviour between ^{40}K and ^{137}Cs in mountain soils [8]. It was observed that with an increase in the soil density, which is related to the amount of organic matter, the concentration of ^{137}Cs decreased and at the same time the amount of natural ^{40}K increased. The features of upper soil layers including the content of organic matter and resulting concentration and immobilization of ^{137}Cs in soil may be affected also by other factors, such as altitude [9].

Plant uptake is the major pathway for the migration of radiocaesium from soil to animal and human diets. Caesium has a high mobility within plants. Although radiocaesium is most likely taken up by the K transport systems within the plant, differences in internal Cs concentration (on a dry matter basis) may vary by a factor of 20 between different plant species grown under similar conditions [17]. Uptake of ^{137}Cs from the environment by some plants is very high so these plants serve as bioindicators of contamination with this radionuclide [11]. Mosses are capable of taking up as much as 93 % of the incident radionuclides [3]. Other organisms that are able to accumulate ^{137}Cs to the largest extent are mushrooms [4]. Because radioactive caesium is continuously taken up and passed on by organisms in forest ecosystems, the animals and vegetation in the affected forests and mountains are especially contaminated. The level of radiopotassium in soil affects the absorption of radiocaesium by plants which then serve as food for wild boars and radiocaesium in wild boar meat which is a potential source of exposure of people to this radionuclide.

With raw materials, semi-products and final products originating totally or partially from forest ecosystems one must consider the presence of increased levels of radioactive caesium. Under central European conditions, the Chernobyl accident resulted in the highest contamination of game meat. With regard to the still persisting limit-exceeding levels of radioactive caesium in the meat of wild boars recorded in Germany and Czechia, this meat can act as the main source of radiation exposure to humans [1].

The aim of our study was to monitor the level of the radionuclides ^{40}K and ^{137}Cs in the meat of wild boars hunted in the Levice district in Slovakia, and in the soil from the locations where these animals were hunted.

MATERIALS AND METHODS

The samples were collected from 8 wild boars shot in the hunting grounds PZ Svätý Bartolomej Hontianske Trsťany in November-December of the 2013—2015 hunting season and from 1 male wild boar killed in August at the airport in PZ Hokovce. Altogether 45 samples were obtained from the boars, 5 samples from each animal: thigh muscle (0.5 kg); skin with hair (10 × 10 cm); the whole stomach with its contents. We also collected one sample from the surface horizon of soil (0.5 l) from the location where each animal was shot. Information about the boars (*Sus scrofa*) is presented in Table 1.

After removing twigs and leaves from soil samples, the samples were transferred to Marinelli vessels to a volume of 450 ml. Thigh and stomach muscles and skin were cut to small pieces of approximately 1—2 cm^3. The stomach contents were used for measurements without any processing.

All samples were transferred to Marinelli vessels and measurements of the individual radionuclides were performed using a gamma spectrometer equipped with HPGe detector (HPGeGC2020, 20 % effectiveness; 1.8 resolution) and an interpretation unit desktop Inspektor, validated by Czech Metrological Institute. The analysis of all spectra was performed using the software system Genie 2000 (Canberra). All measurements were carried out at the Veterinary and Pharmaceutical University in Brno, Czechia. The presented relative standard uncertainties ua were determined according to IOS Geneve [7].

Table 1. Information about the wild boars (*Sus scrofa*)

Boar number	Gender	Age	Weight [kg]	Hunting range	Location	Date of sampling
1	Male	7 years	140	Hontianske Trsťany	Ďapúš	30th Nov., 2013
2	Female	1 month	10	Hontianske Trsťany	Koryto	7th Dec., 2013
3	Female	8 months	60	Hontianske Trsťany	Stará hora	7th Dec., 2013
4	Male	2 months	15	Hokovce	Letisko	30th Aug., 2015
5	Male	3 months	30	Hontianske Trsťany	Hopkov	2nd Nov., 2015
6	Female	14 months	60	Hontianske Trsťany	Hopkov	11th, Nov., 2015
7	Female	4 months	20	Hontianske Trsťany	Nad baňou	12th Nov., 2015
8	Female	3 years	80	Hontianske Trsťany	Nad baňou	24th Nov., 2015
9	Female	4 years	90	Hontianske Trsťany	Slaný bok	24th Nov., 2015

RESULTS AND DISCUSSION

Results of measurements of the activity of radiocaesium ^{137}Cs and radiopotassium ^{40}K in Becquerel per kg are presented as relative standard means in Table 2.

Soil is the first link in the food chain. Soil is one of the few components of the environment in which the ^{137}Cs can be detected even today. This radionuclide is best retained by clayey materials [2]. Kubica et al. [9] investigated the radioactivity of artificial ^{137}Cs and natural ^{40}K in the soils collected from the main Ridge of the Flysh Carpathians and observed high variations with respect to individual regions and layers of soil cores. The lowest concentration of ^{137}Cs was 16 Bq.kg^{-1} and the highest reached was 1,127 Bq.kg^{-1}. They reported that fluctuation of the radionuclides concentrations in the soils could strongly depend also on the meteorological conditions. All sampling sites with high level of ^{40}K showed low concentration of ^{137}Cs.

Of the radiation emitted from the Chernobyl disaster, only ^{137}Cs is detected in the soil in the Slovak territory. The soil relief in the district Levice, southern Slovakia, is affected considerably by natural conditions. Despite the presence of illimerised soil, the radiocaesium activity in the soil samples measured in our study was low and did not exceed 68.7 ± 4.6 Bq.kg^{-1}. Except for the samples of soil related to wild boar No. 5, we did not observe relationship between the level of ^{40}K and ^{137}Cs.

In Central Europe, game meat showed the highest degree of radioactive contamination after the Chernobyl nuclear accident [13]. Radionuclides pass to the meat of wild boars particularly by consumption of mushrooms Elaphomyces granulatus, which are favoured by these animals. Dvořák et al. [1] investigated activities of various diet components of wild boars and reported that the activity of fruiting body of the above mushroom collected in location Šabrava, situated in the Odry Highlands and partly in the Nízký Jeseník mountains, was the highest and reached 4743 Bq.kg^{-1} and 2858 Bq.kg^{-1}. However, most components of food found in the stomach contents manifested specific activities lower than the minimum detectable activity [1].

While during the study conducted in Germany (1986—2003) the level of radiocaesium in the meat of roe deer gradually decreased, it persisted at relatively stable level in the meat of wild boars. In the period of 1998—2008, muscles from 656 wild boars hunted in the Ravensburg district (southern Germany) were analysed for ^{137}Cs. The activity varied from less than 5 up to 8 266 Bq.kg^{-1} in dependence on season, atmospheric conditions and the related feeding habits of wild boars and availability of feed [14]. Hohman and Huckschlag [5] observed that the highest concentration of ^{137}Cs in the muscles was detected in winter. The authors examined also stomach contents and found out that they were usually less contaminated compared to muscles; the median of the stomach content was 22 Bq.kg^{-1}, the maximum 1749 Bq.kg^{-1}, while the median of muscle was 129 Bq.kg^{-1}, and the maximum 5,573 Bq.kg^{-1}. No difference in the specific activities of female and male muscles was proved.

After a gradual decrease in the activity of radiocaesium in game meat in the 90s in north-eastern Moravia, its levels unexpectedly increased after floods [12]. The ^{137}Cs ac-

Table 2. The level of activity of radiocaesium and radiopotassium (relative standard uncertainties u_a) in the samples

		Thigh muscle	Skin + hair	Stomach muscle	Stomach content	Soil
Boar 1	^{137}Cs [Bq.kg^{-1}]	< 3.1 ± 8.0	< 3.6 ± 7.8	< 0.56 ± 4.6	3.54 ± 25.0	45.2 ± 3.8
	^{40}K [Bq.kg^{-1}]	< 80.0 ± 7.8	< 90 ± 7.8	11.6 ± 4.7	30.8 ± 7.9	389 ± 3.8
Boar 2	^{137}Cs [Bq.kg^{-1}]	< 14.0 ± 7.5	< 5.0 ± 7.8	0.23 ± 20.4	0.61 ± 10.5	39.2 ± 3.9
	^{40}K [Bq.kg^{-1}]	< 330 ± 7.8	< 120 ± 8.1	62.3 ± 2.46	58.7 ± 3.9	409 ± 3.8
Boar 3	^{137}Cs [Bq.kg^{-1}]	3.14 ± 25	< 4.2 ± 7.8	0.7 ± 23.3	0.87 ± 17.9	68.7 ± 4.6
	^{40}K [Bq.kg^{-1}]	< 76 ± 7.9	< 100 ± 7.8	16.6 ± 4.8	20.4 ± 4.8	341 ± 3.7
Boar 4	^{137}Cs [Bq.kg^{-1}]	< 11.0 ± 7.5	< 29 ± 7.8	< 3.4 ± 0.27	< 3.4 ± 0.27	41.5 ± 3.9
	^{40}K [Bq.kg^{-1}]	< 260 ± 7.9	< 740 ± 7.8	32.1 ± 8.0	< 86 ± 7.8	375 ± 3.8
Boar 5	^{137}Cs [Bq.kg^{-1}]	< 13 ± 7.8	< 6.3 ± 7.8	< 3.7 ± 7.8	0.33 ± 13.9	27 ± 3.9
	^{40}K [Bq.kg^{-1}]	< 320 ± 7.9	< 160 ± 7.9	< 91 ± 7.8	63.9 ± 3.9	30.7 ± 4.5
Boar 6	^{137}Cs [Bq.kg^{-1}]	2.0 ± 61.3	< 7.1 ± 7.9	< 0.76 ± 4.8	0.51 ± 10.9	65.3 ± 3.9
	^{40}K [Bq.kg^{-1}]	< 130 ± 10.1	< 180 ± 7.9	23.3 ± 4.8	73.1 ± 3.9	170 ± 3.9
Boar 7	^{137}Cs [Bq.kg^{-1}]	< 8.5 ± 7.8	< 6.7 ± 7.9	< 3.7 ± 7.8	0.86 ± 8.5	51.2 ± 3.8
	^{40}K [Bq.kg^{-1}]	< 210 ± 7.9	< 170 ± 7.7	< 95 ± 7.8	60.8 ± 3.9	358 ± 13.7
Boar 8	^{137}Cs [Bq.kg^{-1}]	< 6.7 ± 7.8	0.66 ± 34.2	0.12 ± 25.0	0.69 ± 10.1	59.6 ± 3.8
	^{40}K [Bq.kg^{-1}]	105 ± 7.8	30.7 ± 1.47	53.1 ± 4.0	57.6 ± 3.9	292 ± 3.8
Boar 9	^{137}Cs [Bq.kg^{-1}]	1.5 ± 44.0	0.59 ± 15.9	0.11 ± 20.5	0.47 ± 12.1	63.7 ± 4.6
	^{40}K [Bq.kg^{-1}]	21.9 ± 7.9	22.9 ± 4.5	41.2 ± 4.0	49.4 ± 3.9	243 ± 4.7

tivities in wild boar meat exceeded the acceptable limit of 600 Bq.kg^{-1}. This involved particularly the animals younger than 1 year. By year 2000, radiocaesium activity decreased again down to the levels measured before the flooding. Latini [10] called attention to the limit exceeding levels in wild boar meat in the region of Šumava where the level in the muscles reached 10 699 Bq.kg^{-1}.

Šprem et al. [15] investigated the ^{137}Cs and ^{40}K load in large mammal game species (10 brown bear, 9 wild boar, 7 roe deer, 21 red deer and 2 chamois) in the mountain forest region of Gorski Kotar in Croatia. The results indicated that herbivore game species show significantly lower ^{137}Cs concentrations than omnivore species (brown bear, wild boar), thereby confirming the hypothesis that

different dietary strategy impact caesium concentration in meat. The measured caesium load in brown bear meat was in the range of two orders of magnitude, while caesium load in wild boar meat was found in the range of one order of magnitude. The estimated effective equivalent dose showed that the highest caesium uptake would be with the consumption of brown bear and wild boar meat and much lower doses could be taken in by the consumption of the meat from herbivore species. In this study, the measured ^{40}K concentrations were uniformly distributed among the sampled species and none of the species stood out in terms of measured concentrations. A 7-year old male brown bear had significantly lower ^{40}K concentrations 83.0 $Bq.kg^{-1}$) and also the lowest load of ^{137}Cs (1.88 $Bq.kg^{-1}$), showing a similar parallel trend of the two radionuclides.

Our study showed considerable variation of results of both radionuclides in individual boars. The load of both ^{137}Cs and ^{40}K in the thigh of wild boar 2 was the highest; so was the ^{40}K soil load in the area where this boar was shot, but not the concentration of ^{137}Cs in the soil. The lowest load of ^{137}Cs was determined in the thigh, skin and hair, and stomach muscle of boar No. 9, but the ^{137}Cs level in the soil in its home range was close to the maximum level determined in our study.

In the study by Šprem et al. [15] the concentration of ^{137}Cs found in muscles of wild boar (n = 9) ranged from 6.34 to 58.7 $Bq.kg^{-1}$ (25.0 ± 19.6 $Bq.kg^{-1}$) and of ^{40}K from 104 to117 $Bq.kg^{-1}$ (113 ± 4.01 $Bq.kg^{-1}$). These levels were not far from those determined in our study. The highest level of ^{137}Cs determined in our study in thigh muscle was <14 ± 7.5 $Bq.kg^{-1}$, which is much lower than the acceptable limit of 600 $Bq.kg^{-1}$.

We observed no relationship between the stomach contents and meat contamination with Cs contrary to observations reported by Hohmann and Huckschlag [5], however the latter authors examined samples from much higher number of animals (2433).

Wild boars as non-specific omnivores are capable of adapting their eating habits to local and seasonal conditions. According to Hohmann and Huckchlag [5] the radiocaesium is more readily available to the organisms in the forest ecosystems than in agricultural areas owing to the differences in soil characteristics. Wild boars in the district Levice fed during the year on agricultural crops and in winter they were provided concentrate or bulk feed through game feeding. This is probably one of the reasons why the measured activity of ^{137}Cs in meat from wild boars living in district Levice was so low.

CONCLUSIONS

Despite considerable diversity of natural conditions in the district Levice, southern Slovakia, the consumption of meat from game living in this area poses no risk to humans as far as the activity of ^{137}Cs is concerned. This is indicated by our measurements of this radionuclide in samples from wild boars and soil. None of the samples exceeded or even approached the maximum acceptable level of 600 $Bq.kg^{-1}$. However, monitoring of the risk related to this radionuclide is still important as values exceeding this limit can be measured even today in some Germany and Czechia territories.

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Received October 11, 2017
Accepted December 14, 2017