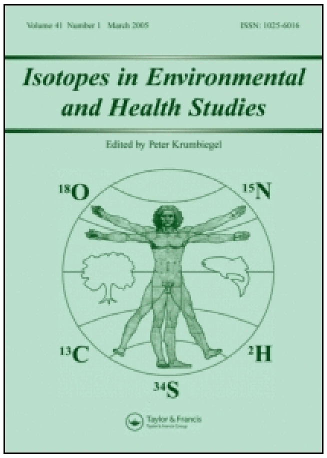

Isotopes in Environmental and Health Studies

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Radioactivity levels in some wild edible mushroom species in Turkey

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Eleven different wild-growing edible mushroom species collected from various regions of Turkey were analysed for their content of ^{137}Cs, ^{40}K, ^{226}Ra and ^{232}Th using a high-resolution gamma-ray spectrometry. Specific activities of ^{226}Ra and ^{232}Th were generally below detection limits. The specific activities of ^{137}Cs and ^{40}K ranged from 2.4 ± 0.3 to $109.0 \pm 7.3\,\mathrm{Bq\,kg^{-1}}$ with a mean of $28.4 \pm 27.2\,\mathrm{Bq\,kg^{-1}}$ (dry matter) and 715.5 ± 50.1 to $1779.0 \pm 163.7\,\mathrm{Bq\,kg^{-1}}$ with a mean of $1150.8 \pm 315.2\,\mathrm{Bq\,kg^{-1}}$ (dry matter), respectively. The mean annual effective dose of ^{137}Cs and ^{40}K through mushrooms were estimated to be $(7.0 \pm 6.0) \times 10^{-3}\,\mu$Sv and $0.13 \pm 0.03\,\mu$Sv, respectively. The overall intake of ^{137}Cs is quite low and no significant contamination was found in collected mushroom species. The highest contents of ^{137}Cs and ^{40}K among the analysed mushrooms were in *Morchella esculenta* and *Stropharia coronilla*, respectively.

Keywords: Cesium-137; Effective dose; Gamma ray; Mushrooms; Potassium-40; Radium-226; Specific radioactivity; Thorium-232

1. Introduction

The wild-growing mushrooms are thought to be one of the most important bio-indicators for the ecology of the natural ecosystems because mushrooms can accumulate great concentrations of toxic elements such as mercury, cadmium, lead, copper, arsenic, etc., and radionuclides such as fallout radiocesium (^{137}Cs, ^{134}Cs) [1–4].

It is well known that atmospheric deposition of man-made radionuclides occurred as a consequence of the major series of nuclear weapon tests and the nuclear accidents such as the Chernobyl disaster in 1986. The main source of artificial radionuclides in Turkey is the fallout from the Chernobyl accident [5–8]. After the Chernobyl accident, especially radiocesium levels in mushrooms become a public matter of concern. There are many papers on the specific activities of ^{137}Cs in mushrooms in various countries [for a review see 3, 9–22]. However, little attention has been paid to the radioactivity of mushrooms collected in Turkey and to

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dose for the population due to ingestion of mushrooms depending on their radioactivity [23]. To address this, we analysed the contents of ^{137}Cs, ^{40}K, ^{226}Ra and ^{232}Th present in different species of mushrooms.

The consumption of wild edible mushrooms has been increasing, especially in Central and Eastern Europe, in which the average annual consumption may exceed 10 kg for some individuals [3, 4], due to a delicacy with a specific smell and taste as well as nutritional value. Turkey has a large edible mushroom potential and is becoming an important exporter of wild mushrooms [24]. However, Turkey consumes significantly fewer wild-growing mushrooms than those from some European countries, Russia, North America and Japan. In Turkey, the average annual consumption per person is about 0.22 kg, whereas in Europe and Japan the average annual consumption per person are about 2 and 3.9 kg, respectively [9, 25].

The aim of the present study is to determine the specific activities of important natural and artificial radionuclides such as ^{226}Ra, ^{232}Th, ^{40}K, ^{7}Be, ^{137}Cs and ^{134}Cs in 11 wild mushroom species gathered from 15 locations belonging to different ecosystems in Turkey and, moreover, to estimate the annual effective dose received by individuals from the ingestion of edible wild-growing mushrooms. It is not known in this moment that only ^{137}Cs and ^{40}K are the important sources of radioactivity.

2. Experimental Method

2.1 *Sampling and sample preparation*

In this study, the wild-growing mushrooms corresponding to 11 mostly edible species collected from different regions (Mediterranean, Aegean, Marmara, Black Sea, Central and Eastern Anatolia) in Turkey were analysed. Mushroom species include *Morchella esculenta, Boletus edulis, Craterellus cornucopioides, Cantharellus cibarius, Nectria cinnabarina, Lepiota cristata, Stropharia coronilla, Lycogola epidendron, Agaricus porphyrocephalus, Marasmius oreades* and *Agaricus bisporus*. Edible wild-growing mushroom species such as *M. esculenta*, *B. edulis*, *C. cornucopioides*, *C. cibarius*, *S. coronilla*, *M. oreades* and *A. bisporus* have been a very popular delicacy in Turkey. Five samples of each species were collected between 2004 and 2005. One complete fruiting body of a mushroom was taken as a sample. The fruiting bodies were cleaned, cut, pulverized with a cooking blender and dried in a temperature-controlled furnace at 105 °C for 20–24 h to remove moisture. After moisture removal, these samples were cooled in a moisture-free atmosphere. Each sample was then filled into cylindrical plastic containers ($\phi = 4$ cm, $h = 4$ cm), weighed and hermetically sealed. The geometrical dimensions of the samples were kept identical to that of the reference materials. The sealed samples and the reference materials were stored for more than 30 days before counting to allow ^{226}Ra and its short-lived decay products to reach the secular equilibrium.

2.2 *Radiometric analysis*

The radioactivity measurements were performed with a high-resolution HPGe gamma ray spectrometry system, which was equipped with a coaxial p-type HpGe detector (GC11021) with an active volume of 451 cm^3 manufactured by Canberra Inc. The HpGe detector has a relative efficiency of 110%, an energy resolution of 2.1 keV at 1332.5 keV of ^{60}Co and of 1.3 keV at 122 keV of ^{57}Co, and a peak-to-Compton ratio of 85:1. For gamma ray shielding a front opening split-top shield (Canberra Model 767) is used to reduce background. It features 10 cm lead thickness, which is jacketed by a 9.5 mm steel outer housing. The graded liner comprises a tin layer of 1 mm thickness and a copper layer of 1.5 mm thickness to prevent mainly interference by lead X-rays. To minimize scattered radiation from the shield, the detector is centred in it. The detector is interfaced to the DSA-1000 Digital Spectrum Analyser, which is a full featured 16 K channel Multichannel analyser on advanced digital signal processing techniques (DSP). DSA-100 operates through Genie-2000 gamma spectroscopy software including peak searching, peak evaluation, energy/efficiency calculation mode, nuclide identification *etc.*

Energy calibration of the detector was performed using point sources (^{60}Co, ^{137}Cs and ^{241}Am). Absolute efficiency calibration of the gamma spectrometry system was carried out using the IAEA reference materials RGU-1 (U-ore), RGTh-1 (Th-ore) and RGK-1 (K_2SO_4) and Soil 375. The reference material and the sample containers were placed on top of the detector for counting. The same geometry was used to determine peak area of samples and references. Background measurements were taken and subtracted in order to get net counts for the sample. The counting time for each sample and background was 60,000 s to obtain the gamma ray spectrum with good statistics. The specific activity ^{137}Cs and ^{40}K were measured directly by its own gamma-ray at 661.7 (85.2) keV and 1460.8 keV (10.7), respectively, while activities of ^{226}Ra and ^{232}Th were calculated based on the weighted mean value of their respective decay products in equilibrium. The specific activity of ^{226}Ra was measured using the 295.2 (18.2), 351.9 (35.1) keV gamma rays from ^{214}Pb and the 609.3 (44.6), 1764.5 (15.1) keV from ^{214}Bi. The specific activity of ^{232}Th was measured using the 338.4 (11.3), the 911.2 (26.6) keV from ^{228}Ac and 583.2 (30.6) keV from ^{208}Tl [26].

3. Results and discussion

It is well known that for environmental applications, the minimum detectable activity (MDA) in a nuclear analytical method is another important parameter. Therefore, the MDA of the present measurement system was calculated as follows [27]:

$$\mathrm{MDA} = \frac{1.645\sigma_{\mathrm{NB}}}{\varepsilon \cdot P \cdot t \cdot m} \tag{1}$$

where MDA is in Bq kg^{-1} (confidence level 95%), $\sigma_{\mathrm{N_B}}$ is the standard deviation of the background in the region of interest and equals square root of the number of counts for the background spectrum, ϵ is the absolute efficiency of the used HPGe detector, P is the absolute emission probability of the gamma decay, t is the measurement time in seconds and m is the dried sample weight (kg dw). The MDA was calculated for ^{137}Cs (range from 0.4 to 0.9 Bq kg^{-1} dw with a mean of 0.5 Bq kg^{-1} dw), ^{40}K (from 7.2 to 15.5 Bq kg^{-1} dw with a mean of 9.8 Bq kg^{-1} dw), ^{226}Ra (from 1.1 to 2.4 Bq kg^{-1} dw with a mean of 1.5 Bq kg^{-1} dw) and ^{232}Th (from 0.9 to 1.8 Bq kg^{-1} dw with a mean of 1.2 Bq kg^{-1} dw).

The specific activities of ^{137}Cs, ^{40}K, ^{226}Ra and ^{232}Th were analysed for the mushroom samples collected at the different locations in Turkey. The obtained results corrected for gamma ray self-attenuation effects due to differences in density and composition of both sample and reference material. For this, the elemental concentrations (in % wt.) of the samples and reference materials were determined using X-ray fluorescence technique. According to the known elemental concentrations of the mixture, the mass attenuation coefficients in a given energy were determined from the XCOM Database in the NIST web page [28]. Then, using mass attenuation coefficients and density values the gamma ray self-attenuation factors were simply estimated from the well-known equation:

$$F = \frac{\mu \cdot t}{1 - \exp(-\mu \cdot t)} \tag{2}$$

where μ(cm^{-1}) is the linear attenuation coefficient and t is the effective sample thickness.

Table 1. Range- and mean-specific activities of ^{137}Cs and ^{40}K of different mushroom species examined.

Species	Edibility	Location of sampling	Specific activity (in $Bq\,kg^{-1} \pm 1\sigma$ dw)			
			^{137}Cs		^{40}K	
			Range	Mean ± SD	Range	Mean ± SD
M. esculenta	Edible	Maraş/Denizli	43.1 ± 3.4–109.0 ± 7.6	79.9 ± 33.6	1491.8 ± 116.4–1531.7 ± 137.9	1517.8 ± 22.5
B. edulis	Edible	Kırklareli	25.1 ± 1.4–35.9 ± 1.5	29.0 ± 6.0	836.3 ± 18.8–1200.9 ± 24.4	1018.6 ± 257.8
C. cornucopioides	Edible	Çanakkale	35.9 ± 1.3–50.0 ± 1.5	43.0 ± 9.9	1173.8 ± 21.3–1683.7 ± 28.5	1428.8 ± 360.5
C. cibarius	Edible	Samsun	31.8 ± 1.3–33.9 ± 2.0	32.9 ± 1.5	881.5 ± 14.1–1352.7 ± 16.4	1171.1 ± 333.2
N. cinnabarina	Inedible	Muğla	45.7 ± 3.5–46.7 ± 3.9	46.2 ± 0.7	1086.0 ± 76.3–1350.7 ± 116.2	1218.4 ± 187.2
L. cristata	Suspect	Mersin	22.9 ± 1.5–24.4 ± 1.7	23.7 ± 1.1	765.0 ± 68.1–803.0 ± 77.1	784.0 ± 26.9
S. coronilla	Edible	Kırşehir	2.4 ± 0.3–5.0 ± 0.4	3.7 ± 1.8	1339.3 ± 140.6–1779.0 ± 163.7	1559.1 ± 310.9
L. epidendron	Poisonous	Tokat	4.4 ± 0.5–7.6 ± 0.8	6.0 ± 2.3	856.7 ± 162.5–1083.3 ± 74.7	970.0 ± 1160.3
A. pophyrocephalus	Inedible	Isparta	2.9 ± 0.2–4.3 ± 0.5	3.6 ± 1.0	715.5 ± 50.1–798.8 ± 72.7	757.2 ± 58.9
M. oreades	Edible	Ankara	3.7 ± 0.4–5.2 ± 0.6	4.5 ± 1.1	900.1 ± 78.3–1172.6 ± 116.1	1036.4 ± 192.7
A. bisporus	Edible	Erzurum	15.3 ± 1.2–19.0 ± 1.4	17.1 ± 2.6	900.7 ± 55.8–1235.8 ± 89.0	1068.2 ± 236.9

Table 2. Range- and mean-specific activities of ^{226}Ra and ^{232}Th of different mushroom species examined.

Species	Edibility	Location of sampling	Specific activity (in $\mathrm{Bq\,kg^{-1}} \pm 1\sigma$ dw)			
			^{226}Ra		^{232}Th	
			Range	Mean ± SD	Range	Mean ± SD
M. esculenta	Edible	Maraş/Denizli	<MDA		<MDA	
B. edulis	Edible	Kırklareli	<MDA		2.6 ± 0.2–4.3 ± 0.3	3.4 ± 1.2
C. cornucopioides	Edible	Çanakkale	4.4 ± 0.2–5.2 ± 0.4	4.8 ± 0.6	1.9 ± 0.2–2.2 ± 0.2	2.0 ± 0.2
C. cibarius	Edible	Samsun	<MDA		2.8 ± 0.2–3.9 ± 0.3	3.3 ± 0.8
N. cinnabarina	Inedible	Muğla	<MDA		<MDA	
L. cristata	Suspect	Mersin	<MDA		4.7 ± 0.5–9.8 ± 0.9	7.2 ± 3.6
S. coronilla	Edible	Kırşehir	<MDA		<MDA	
L. epidendron	Poisonous	Tokat	<MDA		<MDA	
A. pophyrocephalus	Inedible	Isparta	<MDA		<MDA	
M. oreades	Edible	Ankara	<MDA		<MDA	
A. bisporus	Edible	Erzurum	<MDA		<MDA	

Among the above-mentioned radionuclides, only ^{137}Cs and ^{40}K were detected with activities significantly above the corresponding detection limits. No ^{134}Cs and ^{7}Be radionuclides were detected in any of the mushroom samples. Table 1 and 2 present the range (maximum and minimum) and mean specific activity values of radionuclides measured on each of the mushroom samples in terms of Bq kg^{-1} dw, together with the total uncertainty (1σ) and standard deviation (SD). It may be observed in table 1 that the ^{137}Cs and the ^{40}K were detected in all the studied mushroom samples. Decay corrections were made to the sampling date for ^{137}Cs. The mean value of ^{137}Cs was 28.7 ± 26.7 Bq kg^{-1} dw. The highest ^{137}Cs activity level detected (109.0 ± 7.6 Bq kg^{-1} dw) corresponds to the species *M. esculenta*, while the lowest ^{137}Cs value (2.4 ± 0.3 Bq kg^{-1} dw) corresponds to the species *S. coronilla*. The specific activity values of ^{40}K varied from 715.5 ± 50.1 to 1779.0 ± 163.7 Bq kg^{-1} dw with a mean of 1150.8 ± 315.2 Bq kg^{-1} dw. These values were comparable to the values reported by other authors [3, 9, 12–14, 23]. As can be seen from table 2, ^{226}Ra and ^{232}Th were measured above detection limits in a few mushroom species. The mean specific activity values of ^{226}Ra and ^{232}Th are 4.8 ± 0.6 Bq kg^{-1} dw and 4.0 ± 2.5 Bq kg^{-1} dw, respectively.

3.1 *Estimation of the annual effective dose*

The annual effective dose (H in Sv) from internal exposure is estimated to evaluate a possible risk of radioactivity for human health. A contribution to the yearly effective dose to an adult from mushroom consumption may be calculated as follows [3, 29]:

$$H = A \cdot F \cdot C \cdot r \tag{3}$$

where A is the specific activity (Bq kg^{-1} dw) of each of the radionuclides that the mushroom contains. F is the effective dose conversion factor by ingestion of radionuclide (Sv Bq^{-1}). The values of this conversion factor for adults are: 1.3×10^{-8} and 6.2×10^{-9} Sv Bq^{-1}, for ^{137}Cs and ^{40}K, respectively [29]. C is the annual intake of fresh mushrooms (kg fw) and r is the ratio between the dry and fresh mass of each mushroom species, which in this study has a mean value 0.08 kg dw/kg fw. The average annual consumption of mushrooms by adult Turkish people is about 0.22 kg fw [25].

Table 3 gives the range and mean of the annual effective dose of each edible mushroom species due to ^{137}Cs and ^{40}K radionuclides. The annual effective dose values due to ^{137}Cs and ^{40}K vary from 4.8×10^{-4} to 2.2×10^{-2} μSv with a mean of $(7.0 \pm 6.0) \times 10^{-3}$ μSv

Table 3. The range and mean values of the annual effective dose due to ^{137}Cs and ^{40}K from ingestion of the edible wild mushroom species examined in Turkey.

Edible mushroom species	Annual effective dose (in μSv)			
	^{137}Cs		^{40}K	
	Range	Mean ± SD	Range	Mean ± SD
M. esculenta	1.2×10^{-2}–2.2×10^{-2}	$1.7 \times 10^{-2} \pm 5.1 \times 10^{-3}$	0.14–0.20	0.16 ± 0.03
B. edulis	5.1×10^{-3}–7.1×10^{-3}	$5.8 \times 10^{-3} \pm 1.1 \times 10^{-3}$	0.08–0.12	0.10 ± 0.03
C. cornucopioides	6.4×10^{-3}–1.1×10^{-2}	$8.5 \times 10^{-3} \pm 3.1 \times 10^{-3}$	0.12–0.14	0.13 ± 0.02
C. cibarius	6.4×10^{-3}–8.7×10^{-3}	$7.5 \times 10^{-3} \pm 1.7 \times 10^{-3}$	0.11–0.13	0.12 ± 0.01
S. coronilla	4.8×10^{-4}–1.1×10^{-3}	$8.1 \times 10^{-4} \pm 4.7 \times 10^{-4}$	0.15–0.17	0.16 ± 0.02
M. oreades	8.6×10^{-4}–1.1×10^{-3}	$9.6 \times 10^{-4} \pm 1.5 \times 10^{-4}$	0.08–0.12	0.10 ± 0.03
A. bisporus	3.9×10^{-3}–4.3×10^{-3}	$4.1 \times 10^{-3} \pm 3.1 \times 10^{-4}$	0.11–0.13	0.12 ± 0.02
Mean ± SD		$(7.0 \pm 6.0) \times 10^{-3}$		0.13 ± 0.03

and 0.08–0.20 μSv with a mean of 0.13 ± 0.03 μ Sv. It may be concluded that the annual effective dose in Turkey due to eating mushrooms mainly comes from the naturally occurring ^{40}K radionuclide because the mean annual effective dose due to ^{137}Cs is about 19 times lower than that of ^{40}K, mainly due to the low level of contamination from this radionuclide in the mushroom species that were collected.

4. Conclusion

For each mushroom sample in this study, the specific activity of ^{137}Cs, ^{40}K, ^{226}Ra and ^{232}Th were determined to assess the radiological risk from these mushroom species. It was observed that the mean annual effective dose due to ^{137}Cs is considerably lower than that of ^{40}K. Therefore, the annual effective dose from eating mushrooms in Turkey is mainly due to the naturally occurring ^{40}K and is far below the level of 1000 μ Sv. The levels are in any case so low that the consumption of mushroom species examined in Turkey does not represent any significant contribution to the annual effective dose from ingestion.

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