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Influence of Radioactive Isotopes from Soil on the Growth and Development of Different Plant Cultures

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Abstract

This paper presents the results of a research on the natural and artificial radioactivity of agricultural land in the surrounding villages of the city of Vranje, in the south of Serbia. The characteristic values of specific activity of ^{226}Ra, ^{232}Th, ^{238}U and ^{235}U and ^{40}K were analyzed, as representatives of the natural radioactivity and of ^{137}Cs, as representative of artificial, human activity. The results of the research show the low values of radionuclides of some values are even below the detection limit, which is good for the population. Further research should be continued in the direction of a continued monitoring and development of new improved removal technologies, since small amounts of radionuclides in the soil, through plants, can adversely affect the human health and environment.

Keywords: Radionuclides ^{226}Ra; ^{232}Th; ^{238}U and ^{235}U; ^{40}K; ^{137}Cs; Land, Methods

Introduction

Radionuclides are unstable nuclei that decompose and emit ionizing radiation. They are formed also by nuclear reactions in the nuclear reactors, in which a series of anthropogenic radionuclides arise [1]. In order to free up their excess energy, the unstable atomic nuclei pass through a series of nuclear decay processes (α, β and/or γ-decay) until they come to a stable nuclear configuration. The energy released during radioactive decay can reach a value of several MeV. One of the main parameters that characterizes the radionuclides is their half-life time. The half-life is the characteristic of each radionuclide and ranges, for example, from 3x10-7 s (212Po) to 1.4x1010 yrs. (^{232}Th). A large contribution to the total gamma-radiation dose in the environment comes from natural radionuclides [2]. Gamma photons have no charge; may arise during radioactive decay, during the deexcitation of the nucleus, or in the process of annihilation of the pair of electron-positron pairs, whereby two gamma quanta of 511 keV energy are produced. Gamma photons have the lowest linear energy transfer, so in the interaction with the biological tissue they can cause changes in the genetic material, and even lead to the death of the individual, depending on the absorbed dose of radiation [3]. The life on Earth is exposed to gamma radiation due to external and internal exposures. In the interaction with living matter, the ionizing radiation causes changes in the cell and on subcellular levels. The resulting changes can be transient, long-term and/or such that can lead to cell death. All effects that occur at the cellular level can manifest themselves at the tissue and organs level and indirectly affect the individual. There is no sharp boundary between the different types of effects caused by ionizing radiation. It is therefore important to monitor the concentration of radionuclide activity in the environment and to analyze their effects on the living world in accordance with international recommendations and

guide lines. Natural radionuclides in the environment are divided into cosmogenic and terrestrial. For most natural terrestrial radionuclides characteristic are the α and β - radioactive decays [4]. The largest number of radionuclides belongs to some of the radioactive arrays, which in nature are three. In a series of successive radioactive decays from parents, the off-springs of the nucleus are also unstable and are subject to further radioactive decay. The decay process ends with a stable isotope, and for the above arrays, these are ^{206}Pb, ^{207}Pb and ^{208}Pb, respectively. Of the radionuclide that does not belong to any of the radioactive arrays, the most important land radionuclide is ^{40}K. Other soil radionuclides present in low concentrations in the soil are: 50V, 87Rb, ^{113}Cd, ^{115}In, ^{123}Te, ^{138}La, ^{142}Ce, ^{144}Nd, ^{147}Sm, ^{152}Gd, ^{174}Hf, ^{176}Lu, ^{187}Re, ^{190}Pt, ^{192}Pt and ^{209}Bi. Gamma radiation generated by the radioactive decay of uranium and thorium series, as well as from ^{40}K, contributes to the natural irradiation of the living world (man and biota), which can be external and/or internal (ingestion and inhalation). The natural concentrations of terrestrial radionuclides depend on the type of mother wall from which the soil was formed. The concentration of uranium and thorium is high in magmatic walls (eg granite), but also in some sedimentary walls (shards and phosphate walls). According to the UNSCEAR [5] report, the mean concentrations of activity of ^{238}U, ^{232}Th and ^{40}K in soil in the world are 5 33, 45 and 412 Bq kg-1, respectively. The concentration ranges for ^{238}U, ^{232}Th and ^{40}K in soil in Europe are 2-330, 2-190 and 40-1650 Bq kg-1. Artificial radionuclides were created as a result of human activity, in the process of nuclear reactions. More than hundreds of anthropogenic radionuclides are known, whose life-times are very different. The most famous artificial radionuclide is cesium ^{137}Cs. Cesium ^{137}Cs is a beta - emitter with a half - life of 30.17 years. This radionuclide of anthropogenic origin was thrown into the environment in overhead trials of nuclear weapons. Cesium - 137 is one of the radionuclides emitted in the environment in the normal regime operations of nuclear power plants, and a significant source is the resuspension of previously deposited particles and further transfer of ^{137}Cs to air currents [6]. Distribution of deposited radionuclides in the soil is usually non-homogeneous, since the transfer and deposition in a given period are influenced by numerous factors such as constant winds, thermal and barometric stratification of the atmosphere, season, precipitation, vegetation coverage [7]. The behavior and migration of isotopes in the soil depends on some chemical and mechanical properties of the soil and the specific behavior of a particular radionuclide. In the accident that occurred in Chernobyl (April, 1986), besides the strontium - 90 and other isotopes, significant relevance to life-long radioisotopes (the half-life period measured for years) was also the large amount of cesium - 137. By 1986, the specific activity of ^{137}Cs in the soil in Serbia Popovic and Spasic-Jokic [8] was less than5 Bq kg-1 and in most plants, except moss and lichen, cesium could not be detected. In 2007, samples from the same locations were analyzed and the average value of specific cesium activity - 137 amounted to 27 Bq kg-1 varying in the interval from 4 Bq kg-1 to 52 Bq kg-1. Stable cesium is a rare element in the Earth's crust. Concentrations are generally less than 1 mg kg-1 and rarely exceed values of 6 mg kg-1. Cesium has a pronounced affinity to alumina - silicates and is mostly concentrated in acidic magma walls and sediments formed from shale. Radionuclide 137Cs in the soil behaves very much like stable cesium. When it enters the soil, it migrates poorly because it is adsorbed on the clay fraction as well as on organic matter. Organic matter, especially those of higher molecular weights, accumulates cesium-137 and thus reduces its mobility in soil. Numerous studies Isaksson, Erlandsson and Mattsson [7]; Bossew and Kirchner [9] have shown that ^{137}Cs is bound to the surface layer of the soil up to 10 cm depth) and its concentration decreases with depth. Vertical migration of ^{137}Cs in the soil is a slow process and it is estimated to be about 0.1 to 1 cm per year. On the migration of cesium, besides the physical and chemical characteristics of the land, the local configuration of the terrain is also affected. The penetration rate is higher in sandy soils.

The land is a complex material consisting of mineral (inorganic), as well as an organic component that is mainly caused by the decomposition of plant material. The inorganic or mineral component of the soil consists of particles formed by the erosive action of various natural factors on the walls. As the rocks that are part of the earth's crust possess a certain concentration of natural radionuclides, they can be expected to be found in the soil caused by the decomposition of the rock [8].

The motivation of the present study is to determine the characteristic values of activity concentrations of ^{226}Ra, ^{40}K, ^{232}Th, ^{238}U, ^{235}U and ^{137}Cs in soil samples in a number of locations in the basin of Pčinja river, in Serbia. The content of each of these radionuclides has different concentrations; the obtained results show low values. The concentration of natural radionuclides varies depending on various factors such as relief, soil type, climatic conditions and agricultural practice [9]. Natural radionuclides of uranium and thorium are widespread in the Earth's crust [10].

Materials and Methods

During 2014, about 20 samples of agricultural arable and non-cultivated land from the surrounding villages in the Region of Vranje were sampled. Soil sampling was done with the aim of examining the soil and determining the concentration level of radionuclides ^{226}Ra, ^{232}Th, ^{238}U and ^{235}U, ^{40}K, ^{137}Cs.The specific activity of these radionuclides in the soils of great importance since the plant crops cultivated on

this soil are used as food for humans and animals. The level of health risk, due to the introduction of radionuclides from the soil through the product into the human organism can be large and depends on the concentration of radionuclides in the soil and the type of their specific effects on the living cells. The specific activities of radioactive clues of ^{226}Ra, ^{232}Th, ^{238}U and ^{235}U, ^{40}K, ^{137}Cs found in the soil, and later in the plant itself, depend on the geographical area.

In each location, soil samples were taken from the surface layer of of 0-5 cm, 0-10 cm and 0-20 cm depth, and in some locations samples were taken from the soil also at a depth of 0-40 cm (village Toplac). The testing of radioactivity of soil samples was carried out by the gamma spectrometric method, as well as the determination of total beta and alpha activity. Radioactivity of environmental parameters was examined at the Institute for Nuclear Sciences "Vinca," Belgrade.

For the samples of soil, the detectors were calibrated by a reference radioactive material - a silicone resin matrix, Czech Metrological Institute, Praha, 9031-OL-420/12, total activity 41.48 kBq on 31.08.2012 (^{241}Am, ^{109}Cd, ^{139}Ce, ^{57}Co, ^{60}Co, ^{203}Hg, ^{88}Y, ^{113}Sn, ^{85}Sr,^{137}Cs). For gamma-spectrometric measurements of radioactivity in soil samples was used and the ultra-low-background germanium detector type GMX (extended energy range from 10 keV to 3 MeV, manufactured by ORTEC, the nominal efficiency of 32% in passive and active protection). Active protection decreases the integral count down in the background by a factor of 3 for the range from 50 keV to 2800 keV, which lowers the threshold of detection and is suitable for the measurement of environmental samples [11]. The detector efficiency is determined using standard radioactive materials positioned in the same detection geometry used for sample measurements. For the calibration of gamma spectroscopy, IAEA - CU - 2006-03 world open knowledge test for the determination of γ emitters in soil samples was used. Correction due to the self-absorption effect was not necessary due to a very similar composition and approximately equal density of samples and reference materials.

r.b	Location	Type of soil	Depth of taking (cm)	Coordinates		Elevation (m)	Date of sampling
				X (SGS)	Y (IGD)		
1	Bujkovac	Arable	0-5	42°33'26"	22°00'35"	718	09.11.2014.
		Arable	0-10	42°33'26"	22°00'35"	718	09.11.2014
		Arable	0-20	42°33'26"	22°00'35"	718	09.11.2014
2	Korbevac	Arable	0-5	42°23'06"	21°44'24"	441	05.11.2014
		Arable	0-10	42°23'06"	21°44'24"	441	05.11.2014
		Arable	0-20	42°23'06"	21°44'24"	441	05.11.2014
3	Suvi Dol	Untrained	0-5	42°33'07"	21°56'05"	359	11.11.2014
		Meadow	0-10	42°33'07"	21°56'05"	359	11.11.2014
		Meadow	0-20	42°33'07"	21°56'05"	359	11.11.2014
4	Toplac	Meadow	0-20	42°32'18"	21°58'02"	528	17.11.2014.
		Meadow	0-40	42°32'18"	21°58'02"	528	17.11.2014.
5	Ranutovac	Meadow	0-10	42°34'06"	21°56'58"	359	18.11.2014
		Meadow	0-20	42°34'06"	21°56'58"	359	18.11.2014

Table 1: List of samples and coordinates of the guiding position

The timing of the samples is 60 hp. The measurement results are given with a measurement uncertainty expressed as an expanded measurement uncertainty for the factor k = 2, which corresponds to a confidence level of 95% for normal distribution.

Determining the specific activity of natural radionuclides ^{226}Ra, ^{232}Th, requires the analysis of the spectrum over descendants, in samples in which the radioactive balance has been established. The specific activity of ^{226}Ra is determined by the descendants ^{214}Pb, ^{214}Bi, that is, through the energies of 295 keV, 352 keV, 609 keV, 1120 keV, 1764 keV (using energies with high probability of passage) by determining the activity and calculating the mean value [12]. ^{226}Ra and ^{238}U are members of the same decay series; one can determine them from the same daughter radionuclides. ^{234}Th emits gamma-ray energy of 63 keV, but with very low probability and detection efficiency of HPGe for such low energy will be poor. The peak 1000 keV belongs to metastable ^{234}Pa, which is a product of ^{234}Th beta decay (and also has low probability of emission).

The second natural radionuclide ^{232}Th is determined by descendants ^{228}Ac, at energies of 338 keV, 328 keV and 911 keV. The activity of ^{226}Ra and ^{232}Th is determined by calculating the mean value of the activity of the offspring. Activity ^{40}K is determined based on its energy of 1460 keV. In the case of ^{238}U, the activity is determined by the descendant ^{234}Th, at a power of 63 keV and 1000 keV, since these two radionuclides are in balance. The ^{235}U is determined over the energy of 185 keV after correction to the contribution of ^{226}Ra to the given energy. The activity of the produced radionuclide ^{137}Cs was determined based on its energy of 661.6 keV [13].

Gama spectrometric testing of samples can be done in original fresh or dry samples after their necessary homogenization that requires special preparation, i.e., in concentrated samples [14]. Preparation of samples in fresh condition includes, homogenization and measurement in certain measurement geometry, in particular in plastic containers of 125 cm^3. In order to determine the content of natural radionuclides in the samples, a radioactive balance is established, by wiping with beeswax.

The total absorbed radiation dose D is important in evaluating the risk of human radiation. D was calculated using the conversion factor of the measured activity concentrations AU, ATh, and AK (Bq kg-1) for ^{238}U, ^{232}Th and ^{40}K, respectively, in the absorbed radiation dose (D) (nGy h-1) in the air at 1 m above the ground, according to the equation Saito and Jacob [15] where CRa, CTh and CK are the concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the soil, respectively.

The annual effective radiation dose (DE) (μSv) due to external exposure was calculated by multiplying the estimated total absorbed intensity of radiation dose D by the following factors: 0.7 Sv Gy-1 - the annual effective dose received by the population and the absorbed dose in the air; 0.2 - the duration of the residence of the population outside; 8760 - number of hours in one year. The unit for measured absorbed dose is (1Gy = 100 rad). In the case of consideration of the biological effect of different types of radiation, the absorbed energy is multiplied with the relative biological efficiency - RBE. The result of a quantitative input is that the dose is measured in sieverts or rems (1 Sv = 100 rem).

The effects of ionizing radiation on human health from natural sources are not particularly negative because it is never collected in the body. Natural radiation is constant and very bad. The human biological mechanism has been adapted to this radiation during the evolution. Radioactive material can penetrate the body by radiation to accumulate in it and thus become the source of radiation. The body can get radioactive particles through water and food. The total radioactive radiation that a person receives can reach high doses, which is dangerous to health. Acute illness may occur as a consequence of the current irradiation of the organism from large doses. Radiation and chronic radiological diseases occur as a result of long-term exposure to minor radiation doses. The human organism can be damaged by external radiation (when the organism is directly exposed to a radiation source) or by internal contamination (by water or food uptake or by breathing). The potential risk of radiation to the human body is particularly strongly manifested for certain of its parts: bone marrow 12%, bone area 3%, thyroid gland 3%, breast 15%, lungs 12%, ovaries and testicles 25%, other tissues 30%. Radiation disease varies widely depending on the strength of the dose received, the way and the sources of radiation: radiation burns the skin and mucous membranes, causes skin cancer, deterioration of blood counts (the number of leukocytes and platelets decreases), reduction of the number of stem cells in the bone marrow that produces erythrocytes, causes leukemia and bone cancer can occur with osteosarcoma, bloating of the eye lens (cataract) may occur, and decrease of quality and quantity of lung cells [16].

A single-factor analysis of variance (one-way Analysis of Variance) was used to examine the impact of the sampling depth on the distribution of radionuclide concentration in the investigated area. One-factor ANOVA examines the impact of an independent variable (in present paper it is the sampling depth) on the dependent variable (in this paper -the specific activity of radionuclides). The variance analysis compares the variance between and within groups; the ratio of these variances is the F factor. The larger the value of F, the larger the variability between the groups. The variability between the groups is larger than within each group [17].

Results and Discussion

Table 2 shows the results of radiation measurements of considered radionuclides in the soil samples obtained by analyzing the gamma emitter spectra. The same type of soil is analyzed in all locations.

At the given locations, the values of specific activities of natural radionuclides do not differ much, regardless of the fact that soil samples are taken at different depths. At the locations of Korbevac, SuviDol, Ranutovac and Bujkovac, the values of the specific activity of the detected natural radionuclides ^{226}Ra, ^{232}Th, ^{40}K, ^{238}U, ^{235}U do not differ with depth. The present differences in the values of the specific activity of the detected radionuclides are within the measurement uncertainty. The value of the specific activity of the produced radionuclide 137Cs does not differ with depth at the same location.

Land, depth (cm)	(Bq kg^{-1}.)						Ḋ (nGyh^{-1})	DE (mSv)
	^{226}Ra	^{232}Th	^{40}K	^{238}U	^{235}U	^{137}Cs		
Korbevac								
0-5	43 ± 3	55 ± 4	730 ± 50	47 ± 8	2.7 ± 0.2	16 ± 1	83.53	0.102
0-10	45 ± 3	54 ± 4	730 ± 50	51 ± 9	2.4 ± 0.2	16 ± 1	85.85	0.105
0-20	38 ± 3	51 ± 4	690 ± 40	40 ± 8	2.4 ± 0.2	15 ± 1	73.89	0.091
Suvi Dol								
0-5	38 ± 3	52 ± 4	490 ± 30	35 ± 8	1.7 ± 0.1	10.1± 0.7	69.39	0.085
5-10	33 ± 2	48 ± 3	470 ± 30	34 ± 9	1.7 ± 0.2	7.9 ± 0.6	63.84	0.078
10-15	37 ± 3	50 ± 3	460 ± 30	34 ± 8	1.9 ± 0.2	7.2 ± 0.5	66.48	0.081
Ranutovac								
0-10	33 ± 2	39 ± 3	560 ± 30	32 ± 8	1.7 ± 0.2	12.6 ± 0.8	62.15	0.076
0-20	32 ± 2	38 ± 3	550 ± 30	30 ± 7	1.6 ± 0.1	12.3 ± 0.8	60.67	0.074
Toplac								
0- 20	39 ± 3	52 ± 4	660 ± 40	35 ± 7	1.9 ± 0.3	7.6 ± 0.6	76.95	0.094
0-40	42 ± 3	54 ± 4	690 ± 40	50 ± 10	2.0 ± 0.2	7.6 ± 0.6	80.79	0.099
Bujkovac								
0-5	22 ± 2	30 ± 2	500 ± 30	25± 8	1.6 ± 0.2	17 ± 1	49.13	0.061
0-10	23 ± 2	30 ± 2	510 ± 30	25 ± 7	1.5 ± 0.1	18 ± 1	50.01	0.061
0-20	25 ± 2	29 ± 2	520 ± 30	22 ± 8	1.1 ± 0.1	17 ± 1	50.75	0.062

Table 2: Specific activities of detected radionuclides in soil [Bq kg^{-1}.]

It can be noticed in Table 2 that at the Toplac site only differences in the value of the specific activity of radionuclide ^{238}U at different depths of 0-20 cm and 0-40 cm are observed. The difference in the values of the specific activity of this radionuclide could be due to the large measurement uncertainty. It can also be estimated that these differences could be smaller if the soil samples were taken from 0-20 cm, and from 20-40 cm. Then the possibility of overlapping with the sample at a depth of 0-40 cm would be excluded.

The values of the specific activity of the radionuclide ^{226}Ra are in the range 22-45 Bq kg^{-1}, while the values of the specific activity of the radionuclide ^{232}Th are in the range 29-55 Bq kg^{-1}. In the case of ^{40}K values, the specific activity is in the range 460-730 Bq kg^{-1}, while the values of the specific activity of the radionuclide 238U are in the range 22-51 Bq kg^{-1}, and ^{235}U in the interval 1.1-2.7 Bq kg^{-1}. The values of the specific activity of the produced ^{137}Cs radionuclide are in the range 7.2-17 Bq kg^{-1}. Prolongation and relocation processes of Cesium-137 can lead to very uneven distribution of this radionuclide in one area. However, the obtained ^{137}Cs specific activity values are low, so there is obviously no accumulation of this produced radionuclide in the soil. The ratio of specific activities ^{235}U/^{238}U corresponds to that of natural uranium.

Based on the literature data Brereton RG [18], the value of the specific activity of the natural radionuclide ^{238}U ranges from 14 to 65 Bq kg^{-1} for non-agricultural and from 14 to 52 Bq kg^{-1} for agricultural lands. In the tested soil samples (Table 2) that is agricultural, the value of specific activity for the radionuclide ^{238}U is in the range of 22-51 Bq kg^{-1}, ie the obtained values are in the range of values characteristic for agricultural land.

Observed by locations, the detected values of natural radionuclides do not differ significantly (Table 2). The smallest values of specific activities for ^{226}Ra, ^{232}Th, ^{238}U and ^{235}U were obtained at the location of Bujkovac, and the largest values at the location Korbevac. Also, the obtained values of the specific activity of detected radionuclides are characteristic of the soil and correspond to values from other areas of former Yugoslavia [19]. For the produced radionuclide ^{137}Cs, the minimum values of the specific activity were obtained at the Toplac site.

The strength of the absorbed dose of gamma radiation is in the interval from 49.13 to 85.85 nGy h-1, and the annual effective dose is in the interval from 0.061 to 0.105 mSv hi of the same order of magnitude as in other locations in our

country.

The determination of total and annual effective radiation doses is done for the reason to see if the radiations of natural radionuclides from the soil of considered locations affect the health of human body, and, if yes, what are their values. This means that by determining the radiation doses one can see what part of the population in the considered locations is exposed to the effects of harmful radioactivity on human health. The effective dose that the human body receives from natural sources over one year is several hundred times smaller than 1 Sv, and therefore the radiation dose is expressed in thousand times smaller unit (mSv). In estimating the annual effective dose, account must be taken of (a) the absorption dose (absorption coefficient) from the air; and (b) the internal factor of occupancy. According to the results from Table 2, the effective radiation dose of the given radionuclides is significantly below 1mSv. (The Law on Protection against Ionizing Radiation (Published in "Official Gazette of FRY," No. 46/96).

The maximum values of the specific activity of all detected radionuclides were detected at the location Korbevac. Table 3 shows the mean values of the specific activity of radionuclides in the tested soil samples in the territory of the City of Vranje. From Table 3 it can be seen that the value of radionuclide 226Ra ranges from 24 to 44 Bq kg^{-1}, the value of ^{232}Th ranges from 29 to 54 Bq kg^{-1}, that of ^{40}K ranges from 473 to 730 Bq kg^{-1}, that of ^{238}U is in the range 23-49 Bq/kg, that of ^{235}U is in the range 1.35-2.55 Bq kg^{-1} and that of 137Cs in the range 7.6-17 Bq kg^{-1}. The obtained values of the tested radionuclides in the soil samples are in accord with the results of the samples tested in previous regional studies [20]. Using the Shapiro-Wilk's distribution assay Shapiro and Wilk [21] the specific activity of analyzed radionuclides it was noticed that their distributions, except for ^{40}K, do not show the form of a normal distribution.

On the basis of obtained results, it can be said that the specific activity of radionuclide ^{137}Cs, with respect to concentrations of other radionuclides in the soil at the same depths, is considerably smaller than those of ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K [22].

The values of Table 3 can be compared with the values measured in other countries in the region and beyond (Table 4). It can be noticed that the soil radioactivity approximately within the same range, while the deviation is influenced by the type of soil. The specific activity of the thorium ^{232}Th is slightly higher for the Indian country (Table 4), while the specific activity of ^{238}U uranium in Sicily (Stromboli) Brai [23] is greater than the Vojvodina soil (the possible explanation is the existence of stone of volcanic origin on Stromboli). The ratio of uranium/thorium ^{238}U/^{232}Th is approximately equal to the ratio for the other lands (Turkey, Ireland, and Japan) [6,24,25], as is the case with the land in the vicinity of the city of Vranje, indicating the absence of uranium contamination. However, if the use of phosphate fertilizers with increased uranium content is intensified, this balance may be disturbed.

Location	^{226}Ra	^{232}Th	^{40}K	^{238}U	^{235}U	^{137}Cs
Korbevac	44	54	730	49	2.55	16
Suvi Dol	36	50	473	34	1.77	8,4
Ranutovac	32	39	555	31	1.65	12.2
Toplac	40	54	675	42	1.95	7.6
Bujkovac	24	29	510	23	1.35	17

Table 3: Mean values of specific activity (averaged over the soil samples) of detected radionuclides from different locations (in Bq kg-1 units)

The name of radionuclide	India [24]	Egypt [14]	Istanbul [25]	Ireland	Japan
^{232}Th	104±77	6±3	35±7	26	54
^{238}U	34±11	13±9	27±11	37	32.4
^{40}K	217±145	433±130	322±87	350	794
^{235}U	2.89±0.1	3.2±1.1	2.1±0.3	1.78±0.1	1.97±0.2

Table 4: The content of radionuclides in the soil of other countries (in Bq kg-1)

Conclusion

The presence of ^{137}Cs was detected in all soil samples, but its specific activity was low. This is good because the processes of washing and relocation of cesium can lead to very uneven distribution of this radionuclide in one area and this can be harmful to the environment and human health. The allowed specific activity of the natural ^{238}U is in the ranges 15-55 Bq kg^{-1} for the non-agricultural and 14-82 Bq kg^{-1} for the agricultural land, respectively [26], so the obtained mean values in Table 3 for this radionuclide lie within the allowed range. In fact, the values of the specific activity of ^{238}U for all tested samples are within the allowed range (see Table 2). Table 2 also shows that almost in all tested samples the specific activity of ^{238}U, ^{235}U, ^{40}K as well as ^{232}Th is small.

The radiation doses of ^{238}U, ^{232}Th and ^{40}K gamma radiation, calculated on the basis of the concentration of these radionuclides, lie in the range 49.13-85.85 nGy h-1, with a mean value of 67.50 nGy h-1. The mean value of the overall dose strength is slightly higher than the world average (60 nGy h-1).

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