RADIOLOGICAL HAZARDS OF ^{137}Cs IN CULTIVATED AND UNDISTURBED AREAS

by

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The exposure of human beings to ionizing radiation from ^{137}Cs is a continuing and inescapable feature of life on Earth. Artificial radio nuclides are widely distributed in various geological formations and ecosystems such as rock, soil, groundwater, and foodstuffs. In the presents study, the distribution of ^{137}Cs was measured in soil samples collected from different lithological units of the Rudovci, Lazarevac, Serbia. Analysis of the vertical soil profiles indicated that the activity of ^{137}Cs was not extremely changed with depth. The activity concentrations of the ^{137}Cs in measured soil samples ranged from below minimal detectable concentrations up to 38.1 Bq/kg. In order to evaluate the radiological hazards due to ^{137}Cs in the samples, the absorbed dose rate and the annual effective dose were calculated in accordance with recommendations given in the UNSCEAR 2000 report. The distribution of radionuclides depends upon the rock composition, chemical and physical properties of the soil. The external absorbed gamma dose rates due ^{137}Cs were found to vary from 0 to 1.16 nGy/h.

Key words: absorbed dose rate, annual effective dose, ^{137}Cs, radiological hazard

INTRODUCTION

As a consequence of nuclear probes and nuclear accidents (the largest one was Chernobyl at 1986) a certain amount of ^{137}Cs was ejected into the atmosphere, from where it was deposited on the soil. After the Chernobyl accident at 1986, large-scale contamination occurred in Europe and some other parts of the northern hemisphere. The main mechanism of ^{137}Cs deposition was rain fallout, although there was some dry deposition also. Chernobyl's contamination was inhomogeneous in space and time, and was dependent on local weather and other conditions. Being biologically important, the fission product ^{137}Cs (gamma emitter with energy of 661,6 keV and half-life of 30.17 years) was extensively investigated in the past [1]. From the soil, ^{137}Cs penetrates into food chains and humans, where it irradiates sensitive tissues.

The ^{137}Cs concentration in surface soil decreases under the influence of various processes like decay, mechanical removing with rain water, vertical migration and diffusion into deeper layers of soil. Several models have been developed to describe ^{137}Cs migration in soils and to explain its vertical distribution. [2-5].

Soil is the upper layer of the unsaturated zone of the Earth, and very diverse in composition and behavior. The soil phase consists of mineral particles of various sizes, shapes and organic matter in various stages of degradation. In addition, soil is one of the important components in the evaluation of radionuclide migration behavior and distribution of ^{137}Cs in a terrestrial ecosystem. Migration of ^{137}Cs and natural radionuclides has been investigated in rocks, drainage water, bottom sediment, soils, and plants in different regions by determination of the spatial distributions of radionuclides in samples of interest [6-9]. Measurements of radionuclide concentrations in environmental samples have recently received a great deal of attention. Moreover, gamma ray spectrometry is widely used in the studies related to the health, mineral exploration, geological, agricultural, and environmental explorations. Since the β decay of ^{137}Cs is followed by emission of gamma ray with energy of 661.6 keV, content of this radionuclide in various types of samples could be determined with great accuracy and precision by high resolution gamma ray spectrometry. In gamma

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ray spectrometry method, preparation of the samples consider only mechanical treatment and desirable accuracy can be achieved by adequate selection of measurement time and geometry.

The goal of this paper was to the determinate radiological hazards originated from ^{137}Cs in cultivated and undisturbed areas.

EXPERIMENTS

The soil samples were taken during the winter of 2009. Three locations, characterized with different soil types, were chosen in the vicinity of Lazarevac city in central Serbia. The soil was considered as undisturbed since the owners claimed that soil was uncultivated for a long period of time, since World War II, although some naturally occurring mixing certainly took place even without cultivation. The list of locations, soil types and characteristics is given in tab.1. In all the locations the soil was covered with grass and mostly used for pasture. A special tool that was used earlier in military applications was applied for soil sampling, so that disturbance and mixing was avoided. The samples were taken in rectangular blocks 10 cm

10 cm up to the depth of 1 m and cut in horizontal layers of 13-25 cm thick. Minimum two samples were taken at each location, and the composite sample for a given depth was formed. Stones and plant roots were removed before the treatment. Soil samples were dried at 105 °C during 24 hours, minced, sifted through the sieve and prepared for gamma spectrometry. Prepared soil samples were measured by means of a Schlumberger coaxial HPGe spectrometer (the Laboratory for Nuclear and Plasma Physics, Vinča Institute) with resolution of 2.1 keV and relative efficiency of 15% at 1332.5 keV associated with standard beam supply electronics units. The time of measurements ranged from 80 000 s to 230 000 s, depending on ^{137}Cs activity in the samples. The samples were measured in Marinelli geometry, and the mass of each sample was approximately 0.5 kg. All the spectra were recorded and analyzed by using the Canberra's Genie 2000 software; net areas of the peaks were corrected for the background, dead time and coincidence summing effects, applying the corrections calculated by Debertin and Schötzing [10, 11]. The obtained specific activities, expressed in Bq/kg of dry soil mass, are given in

Table 1. GPS co-ordinates and physical and chemical characteristics of the soil samples

Site		Sample co-ordinate		Organic matter [%]	Clay [%]	Silt [%]	Sand [%]	pH
Profile	Horizon depth [cm]	Latitude (N)	Longitude (E)					
I	0-13	44°22'46.2"	20°24'27.38"	1.6	55.48	0.6	2.7	5.3
	13-30			1.2	59.19	0.3	1.6	6.1
	30-60			1.0	61.11	0.4	2.2	6.6
	60-100			0.75	64.95	0.7	2.4	7.3
II	0-25	44°22'50.97"	20°24'56.51"	1.4	56.40	0.7	2.3	4.6
	25-50			1.17	58.75	0.5	3.1	5.5
	50-75			0.9	61.80	0.7	2.4	5.2
	75-100			0.65	65.02	0.6	2.6	6.1
III	0-20	44°22'49.54'	20°24'56.27"	1.35	55.63	0.7	2.8	7.2
	20-40			1.13	59.18	0.1	1.8	7.6
	40-70			0.85	61.78	0.4	1.9	7.4
	70-100			0.55	65.03	0.2	1.5	7.1

Table 2. Activity concentrations and radiological hazards indices of soil samples

Profile	Horizon thickness [cm]	Activity concentration of ^{137}Cs [Bq/kg]	Absorbed dose rate [nGy/h]	Annual effective dose [Sv]
I	0-13	37.2 2.6	1.16	14.20
	13-30	7.0 0.6	0.21	2.55
	30-60	0.09 0.02	0.00	0.00
	60-100	0.19 0.03	0.01	0.09
II	0-25	38.1 2.7	1.14	13.95
	25-50	1.0 0.1	0.03	0.34
	50-75	0.09 0.01	0.00	0.00
	75-100	0.28 0.04	0.01	0.09
III	0-20	30.8 2.2	0.92	11.25
	20-40	0.42 0.08	0.01	0.09
	40-70	0.13 0.03	0.00	0.00

tab. 2. Quoted uncertainties (the confidence level 1 σ) were determined by error propagation calculation. The combined standard uncertainties included the efficiency calibration uncertainty and the statistical uncertainties of the recorded peaks.

RESULTS AND DISSCUSION

The sampling sites co-ordinates (tab. 1.) were determined by a global positioning system (Garim, GPS XL-45). The contents of organic matter, clay, silt, sand and the pH values of the surface soils, for the sampling sites in which the core samples were taken, were determined by standard chemical methods and pipette method and are given in tab. 1. The interaction between radionuclide and the soil matrix is an important parameter in estimating radionuclide transfer processes. ^{137}Cs activity values changes depended on soil type and texture [12].

The values of pH were in the range between 4.6 and 7.6, meaning that soils were mostly acidic.

The vertical distributions of the ^{137}Cs activity at the three measuring sites are presented in fig. 1. The results show a wide range of specific activity values.

^{137}Cs is present in the environment due to atmospheric fallout from the Chernobyl accident. The measured soil samples were collected in the vicinity of Lazarevac, and obtained specific activity of ^{137}Cs ranged from 0,09 Bq/kg (the third horizon of the first and the second profile) to 38.1 Bq/kg (the first horizon of the second profile).

As it is shown in fig. 1, the most significant migration of ^{137}Cs was at profile II. It was in the range from 38.1 2.7 Bq/kg at the first horizon 0-25 cm to 0.09 0.01 Bq/kg at the third horizon 50-75 cm. The difference is smaller at profile III, and it shows a step by step behavior. At the first horizon (0-20 cm), the measured value was 30.8 202 Bq/kg. At the second horizon 20-40 cm, this value was 0.42 0.08 Bq/kg,

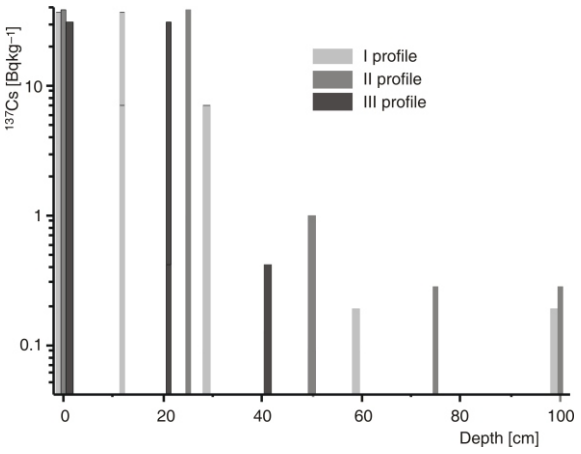

Figure 1. Vertical distribution of ^{137}Cs at tree examined profiles

and this trend continues at the third horizon 40-70 cm to 0.13 0.03 Bq/kg. At the last deepest horizon 70-100 cm, the value decreases to 0 Bq/kg. Profile I showed a minor deviation for radioactivity values. The measured values for the horizons 0-13 cm, 13-30 cm, 30-60 cm, and 60-100 cm were 37.2 2.6 Bq/kg, 7.0 0.6 Bq/kg, 0.09 0.02 Bq/kg, and 0.19 0.03 Bq/kg, respectively. Profiles I and II present cultivated areas and profile III presents an undisturbed area.

Even 25 years after the Chernobyl accident, the presence of ^{137}Cs can be determined in some samples due to its long half-live (30.05 years).

The total absorbed dose rate D [nGyh^{-1}] in air at 1 m above ground level due to the presence of ^{137}Cs in the samples was estimated using the following formula [13]

$$D \quad aC_{\mathrm{Cs}} \tag{1}$$

where a denotes the dose rate per unit activity concentrations of Cs ($0.30 \cdot 10^{-10}$ (Gy/h)/(Bq/kg) and C_{Cs} denotes the activity concentrations of ^{137}Cs [Bqkg^{-1}].

The annual outdoors effective dose was calculated utilizing a conversion coefficient of 0.7 Sv/Gy to convert the absorbed dose in air in the effective dose in the human body. This calculation takes in account that people spend about 20% of the time outdoors (outdoor occupancy factor p is 0.2) and t is 8760 hours annual exposure time.

The annual effective dose, D_{E}, due to gamma radiation from soil was calculated as [13]

$$D_{\mathrm{E}} \quad 0.7Dt\,p \tag{2}$$

The calculated annual effective dose and absorbed dose, as it is shown in fig. 2, shows almost linear dependence with ^{137}Cs content. Results obtained by gamma-ray spectrometry, given in tab. 2, clearly show that ^{137}Cs is mainly located in soil surface layers. In the first and second profiles, which represent cultivated areas, increased concentrations are obtained. In the third profile the increase is only in the first horizon. It could be concluded that by cultivating the soil, radionuclides migration has been enhanced.

CONCLUSIONS

The obtained results show that even 25 years after Chernobyl accident the most significant radiological contamination is present in the soil surface layers, regardless of the soil treatment, *i*. *e*. no matter whether it was from cultivated or undisturbed areas. The higher specific activity of ^{137}Cs was obtained from cultivated soils in the second horizon, and that could be explained by mechanical migration. Absorbed doses were in the range from 0.92 nGy/h up to 1.16 nGy/h, while the annual effective dose was in the range from 11.25 Sv up to 14.20 Sv. Considering previous statements it can be concluded that the radiological hazards in our region, due to the Chernobyl accident,

are negligible in comparison with the dose from natural sources.

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РАДИОЛОШКА ОПАСНОСТ ОД ^{137}Cs У ОБРАДИВИМ И НЕОБРАДИВИМ ЗЕМЉИШТИМА

Изложеност живих бића на Земљи јонизујућем зрачењу које потиче од ^{137}Cs је неизбежна чињеница. Вештачки радионуклиди су широко распрострањени у многим геолошким структурама и екосистемима попут стена, земљишта и подземних вода. У овом раду мерена је распрострањеност ^{137}Cs у земљишту са различитих локација у области села Рудовци у општини Лазаревац. Анализом вертикалних профила земљишта утврђено је да се активност ^{137}Cs не мења пуно са дубином. Концентрације ^{137}Cs у узоркованом земљишту се крећу од испод границе детекције па све до 38,1 Bq/kg. У циљу процене радиолошке опасности од ^{137}Cs, израчунате су јачина апсорбоване дозе и годишња ефективна доза према препорукама од стране UNSCEAR извештаја из 2000 године. Расподела радионуклида зависи много од састава стена и хемијских и физичких особина земљишта. Вредности апсорбованих гама доза које потичу од ^{137}Cs су у интервалу од 9 nGy/h до 1,16 nGy/h.

Кључне речи: јачина апсорбоване дозе, годишња ефективна доза, цезијум – 137, радиолошка опасност