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Cs-137 distribution in forest floor and surface soil layers from two mountainous regions in Bulgaria

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Abstract

The functional characteristics of forest soils in the mountainous regions in Bulgaria were assessed in order to obtain a better understanding of cesium distribution in soil. The aim of this paper is to describe the small-scale spatial variability of Cs-137 contamination in forest floor and surface soil layers in relation to regional and local characteristics. The mountainous regions of Bulgaria were strongly and inhomogeneously contaminated with cesium-137 due to the Chernobyl accident in 1986. The study confirmed that the cesium in forest soils from two mountainous regions of Bulgaria, SW Rila Mountain and Central Balkan, is located in the forest floor and upper 0–5 cm of soil. In a few cases from Central Balkan the maximum activities are found at a soil depth 5–10 cm. The measured values of cesium activity concentration in Aoh in Rila Mountain region are between 287.9 and 827.1 Bq kg^{-1}. Greater variations in cesium activity concentration in forest floor are determined for the plots from Central Balkan, where the measured values in Aof are between 85.7 and 2543 Bq kg^{-1}. The contamination density of Cs-137 in fine soil (<1 mm) from Rila varies from 0.6 to 6.0 kBq m^{-2} while in the Central Balkan plots it is between 1.2 and 19.6 kBq m^{-2}. The forest floor remains the main reservoir for cesium even years after pollution. The profile distribution of Cs-137 in soil systems shows a tendency of decrease toward deeper layers. The mountainous ecosystems with different types of vegetation were compared on the basis of estimated factor of accumulation (FA). The FA for conifers in Rila Mountain is from 0.28 to 0.69 and in the Central Balkans the FA is from 0.20 to 0.61. The data showed that the spatial distribution of Cs-137 in soil system depends on type of vegetation, humus type and altitude. Due to their low clay content and the high content of organic matter, the mountain forest soils can be considered an excellent ecosystem in which to study the mobility and behaviour of Cs-137 and its transfer into the soil-plant system. Due to the high levels of radiocesium contamination within the mountainous regions of the Central Balkan and the characteristics of soils, the highland mountain herbaceous ecosystems located in this region, in the authors' opinion, could be considered as risk zones to easier soil-to-plant transfer of cesium.

Keywords: Mountainous ecosystems; Forest floor; Forest soils; Cs-137 distribution

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1. Introduction

The knowledge about the radionuclides behaviour in natural and semi-natural ecosystems has a very important ecological role for better understanding of element fluxes and has implications in contaminant related risk assessment. In terms of radiation biology Cs-137 is one of the most dangerous isotopes. It is formed in relatively large amounts in atomic bomb explosions and with a physical half-life of 30.2 years remains in the environment for a long time (Katcoff, 1958). The cesium-137 is alkaline element, chemical analogue of potassium and rubidium with high mobility in biological systems. Its chemical and metabolic-physiological reactions are similar to those of potassium (Davis, 1963) that is essential for many organisms and is enriched intracellular. However, Cs cannot replace K in its metabolic functions and is usually not taken up by organisms in the same proportion as potassium (Kornberg, 1961). It also participates in the augmentation of the total radioactivity received by the population. In the cycle of Cs-137 the soil system together with the vegetation constitute the most important reservoir of this pollutant (Strebl et al., 1999; McGee et al., 2000).

The deposition of radionuclides on the European Continent after the nuclear accident at the Chernobyl NPP in April 1986 resulted in higher radioactive contamination of soil, vegetation and other ecological compartments. As with many European countries, Bulgaria has been affected by the radioactive depositions in relatively high degree. Studies in Bulgaria show that the mountainous regions were strongly polluted with Cs-137 (Klein et al., 1994, 1995; Pourchet et al., 1995; Lucot et al., 1998; Zhiyanski et al., 2005, 2006). Mishev (1997) concluded that before 1992 there was a lack of systematically radioecological investigations in mountainous regions in Bulgaria.

Forests are complex environments with great capacity to intercept and to retain radionuclide deposition for a long time (Prister et al., 1991). The retention capacity depends on soil properties and vegetation type (Ehlken and Kirchner, 1996). The forests restrict radioelement transfer out of the polluted zones (Adriano et al., 1981). The efficiency of radionuclide fixation depends on species, stand density and age of forests as well as on climate conditions (Adriano et al., 1981; Hird et al., 1996; Strebl et al., 1999; Kruyts and Delvaux, 2002). Kruyts et al. (2004) suggested that humus type might be an important parameter in classifying forest soils with respect to their ability to transfer radiocesium to the above standing vegetation.

The migration depth of cesium-137 in forest soils is very low and even many decades after deposition the majority of Cs-137 activity concentration is retained in the surface organic soil layers (Fawaris and Johanson, 1994; Rafferty et al., 2000; Zhiyanski et al., 2005). Arapis et al. (1997) underlined that the speed of cesium migration varies according to the soil type and is estimated between 0.4 and 1.2 cm.year^{-1} that corresponds to 6 and 18 cm in depth for the period of 15 years. Graham and Simon (1996) concluded that 80% of the cesium-137 from Chernobyl is located within the upper 15 cm of soils. In undisturbed soils the Cs-137 is distributed especially in the forest floor layers and the migration toward mineral horizons is function of mineralization of humus substances. In the mineral horizons the migration is very slow and is strong dependent on soil type (Barisic et al., 1999), principally on soil texture (Forsberg et al., 2000) and soil organic matter content (Rosen et al., 1999). The migration of cesium-137 in forest soils depends on its concentration in soil solution, the pH of soil, the percent of organic matter, the type of mineral composition and the transfer of the element in soil-to-plant system (Fawaris and Johanson, 1994). According to Mamikhin et al. (1997) the vertical migration of radioelements in soil could be characterized with processes with abiotic origin (diffusion, sorption, desorption, mineral composition, soil type, leakage and water fluxes) and biotic origin (root functioning, activities of fungi and mesofauna in soils etc.). These abiotic and biotic factors vary significantly in the upper soil layers. Still more important is that these variations can exist at a local scale much more in the vertical than in the lateral direction and can explain the differences in cesium activity (Isaksson and Erlandsson, 1995). In addition, the local scale heterogeneity of cesium distribution could be explained by the heterogenic deposition and the passage of radioactive cloud. Both the local precipitation and the natural obstacles like mountains contribute cesium deposition on very restricted zones and its high variability. A hypothesis of the great variability was expressed by Aslani et al. (2003) where the influencing factors also include erosion, precipitation, and sylvicultural practices. Nabyvanets et al. (2000) showed that the strong heterogeneity in spatial distribution of cesium is complicated by the difficulties in understanding of the cesium cycle.

The aim of this study was to describe the small-scale spatial distribution of Cs-137 contamination in forest floor and in surface layers of forest soils from two mountainous regions in Bulgaria in relation to regional and local characteristics.

2. Materials and methods

The objects of this investigation were forest soils — Cambisols dystric, eutric and modic (FAO, 1991) from mountainous ecosystems in Bulgaria. The plots are located in the highest Mountain of Balkan Peninsula–Rila Mountain and in the Central Balkan Mountain, which presents a barrier for the air fluxes in a north–south direction.

Eleven representative plots in mountainous ecosystems were chosen in 2005. They present forest ecosystems with different modes of sylviculture, located in a relatively small range of altitude in mountainous zones.

Six plots were chosen in southwest Rila Mountain from an altitude of between 1450 m and 1700 m (Table 1). The climate is mountainous with mean annual temperature of 4.9 °C and mean annual precipitation of 900 mm. The studied ecosystems are formed on Cambisols dystric and eutric. The underlying geology is granite. Four plots (PR1, PR2, PR3, PR4) were chosen from the Biosphere Reserve “Parangalitza” in the territory of National Park “Rila” and are representative of natural forest ecosystems with different dominant tree species — Norway spruce (*Picea abies* Karst.), Silver fir (*Abies alba* Mill.), Scot’s pine (*Pinus silvestris* L.) and mountainous meadow. The experimental plots PR5 and PR6 are plantations of *P. silvestris* L., created in 1987 and 1964 respectively and located in the National Park near to the Biosphere Reserve “Parangalitza”.

The experimental plots from Central Balkan Mountain were chosen from an altitude of between 1050 and 1500 m. The climate is also mountainous with mean annual temperature 6.1 °C and mean annual precipitation 942 mm. The ecosystems are developed on Cambisols dystric, eutric and modic. The underlying geology is shale. Five representative ecosystems were chosen with different dominant tree species — Scot’s pine, Norway spruce, Common beech (*Fagus silvatica* L.) and mountainous meadow used as a pasture.

Three representative soil profiles in each experimental plot were prepared for profile description and sampling in order physical and chemical analyses and cesium activity measurement (in 2003-Rila Mountain and in 2005-Central Balkan). They were used also for forest floor sampling, carried out with a 25/25 cm frame.

The selected profiles in forest plots are developed on Cambisols with three different humus types — dysmoder, hemimoder and dysmull. The humus types were described *in situ* according to the guidance of Jabiol et al. (1995).

The samples from each humus layer, mineral soil layer and horizon were collected in plastic bags and dried in laboratory where the plant components were separated. The soil profiles were used both for determination of soil characteristics and cesium activity. In order to study the vertical distribution of Cs-137 in accordance with the soil properties at small-local scale in the plots from Rila Mountain the following depths were sampled: forest floor Aof and

Table 1
Characteristics of the studied sites

Plot	Cambisols (FAQ, 1991)	Ecosystems type, origin and location	Altitude [m]	Age of stand [years]	Aspect and slope [°]	Humus type (Jabiol et al., 1995)	Thickness of forest floor [cm]
SW Rila Mountain							
PRI	Dystric	*Picea abies* Karst. natural in BR “Parangalitza”	1500	>150	W-NW, 15	Dysmoder Aol, Aof, Aoh	4.8
PR2	Dystric	*Abies alba* Mill. natural in BR “Parangalitza”	1560	55	N-NW, 16	Dysmoder Aol, Aof, Aoh	4.6
PR3	Dystric	*Pinus sylvestris* L. natural in BR “Parangalitza”	1650	>150	NW, 12	Dysmoder Aol, Aof, Aoh	4.5
PR4	Eutric	Meadow vegetation natural in BR “Parangalitza”	1700	–	NW, 6	–	15
PR5	Eutric	*Pinus Sylvestris* L. plantation in NP Rila	1500	19	S–SW, 11	Dysmoder Aol, Aof, Aoh	4.1
PR6	Dystric	*Pinus sylvestris* L. plantation in NP Rila	1450	42	S–SW, 20	Dysmoder Aol, Aof, Aoh	4
Central Balkan Mountain							
PB1	Modic	Meadow vegetation natural	1500	–	N, 4	–	13
PB2	Modic	*Picea abies* Karst, plantation	1420	35	W, 12	Dysmull Aol, Aof	4
PB3	Eutric	*Fagus Silvatica* L./ natural	1240	40	N, 15	Hemimoder Aol, Aof	2.5
Pb4	Dystric	*Picea abies* Karst, plantation	1300	45	N, 15	Dysmoder Aol, Aof, Aoh	4.5
PB5	Dystric	*Pinus sylvestris* L. plantation	1050	55	W, 21	Dysmoder Aol, Aof, Aoh	3.8

Table 2
Soil physical characteristics in forest ecosystems from Rila Mountain and Central Balkan (Bulgaria)

Plot	Horizon depth [cm]	Bulk density [g cm^{-3}]	Mechanical composition [%]			Skeleton >1 mm [%]	Volume of fine soil [%]
			Sand 0.05–1 mm	Silt 0.001–0.05 mm	Clay <0.001 mm		
Rila Mountain							
PR1	A0-18	098	12.83	79.82	7.35	30	86
PR2	A0-17	0.89	16.42	77.11	6.47	42	79
PR3	A0-22	0.73	75.05	24.95	6.52	12	96
PR4	A0-24	0.94	2034	75.31	4.35	34	84
PR5	A0-13	095	64.63	35.37	4.07	31	85
	$B_1$13-45	1.12	7338	26.62	4.05	78	40
PR6	A0-10	1.13	73.87	26.13	4.02	23	88
	$B_1$10-34	135	69.65	30.35	4.02	29	83
Central Balkan							
PB1	A0-38	0.84	12.74	78.77	8.49	20	93
PB2	A0-31	095	12.49	79.19	8.32	21	91
PB3	A0-18	095	45.17	26.08	28.74	35	84
PB4	A0-22	097	28.72	54.86	16.42	34	84
PB5	A0-14	0.89	73	20.2	6.8	36	84
	$B_1$14-35	1.06	65.7	22.08	12.22	37	80

Aoh and soil layers D1 — 0–5 cm and D3 — 10–15 cm. Respectively in Central Balkan Mountain the following depths were sampled: forest floor Aol, Aof, and Aoh and soil layers D1 — 0–5 cm, D2 — 5–10 cm and D3 — 10–15 cm. The cesium activity detection was carried out in three replicates at all depths. All samples were noted and preserved. In the laboratory the materials were air dried, and sieved through 2 mm and the plant compounds were separated by hand.

The soil characterisation was carried out in 2005. The following characteristics were determined: mechanical composition (ISO 11277), bulk density (Katchinski method), skeleton elements (weight method), mechanical composition (pipette method with HCl), soil acidity (with pH-meter “Pracitronic, MV 88”), soil organic carbon (ISO 10694), total nitrogen (Kjeldhal method) and Exchangeable K (method UNEP-UN/EC 910651 by AAS Perkin Elmer 370 A) were analyzed in the laboratory. The estimation of volume of skeleton elements in the soils the densities of granite (2675 kg m^{-3}) and shale (2691 kg m^{-3}) were used (http://www.simetric.co.uk/si_materials.htm).

Table 3
Soil chemical characteristics of forest ecosystems from Rila Mountain and Central Balkan Mountain (Bulgaria)

Plot	Horizon	pH (H_2O)	C [%]	N [%]	Ratio C/N	Exch.k Cmol+/1
Rila Mountain						
PR1	A 0-18	4.9	6.49	032	20	0.32
PR2	A 0-17	4.9	5.91	024	25	0.36
PR3	A 0-22	5.2	5.02	035	14	0.52
PR4	A 0-24	4.9	6.63	028	24	0.56
PR5	A 0-13	5.3	3.72	0.30	12	0.46
	$B_1$13-45	5.4	1.57	0.13	–	–
PR6	A 0-10	5.2	1.59	0.16	10	0.49
	$B_1$10-34	5.3	1.02	0.14	–	–
Central Balkan						
PB1	A 0-38	4.6	5.82	0.6	10	0.23
PB2	A 0-31	4.5	8.24	055	15	0.12
PB3	A 0-18	4.4	4.97	059	8	0.47
PB4	A 0-22	4.1	6.06	057	11	0.59
PB5	A 0-14	4.7	2.91	021	14	0.47
	$B_1$14-35	4.6	1.58	0.1	–	–

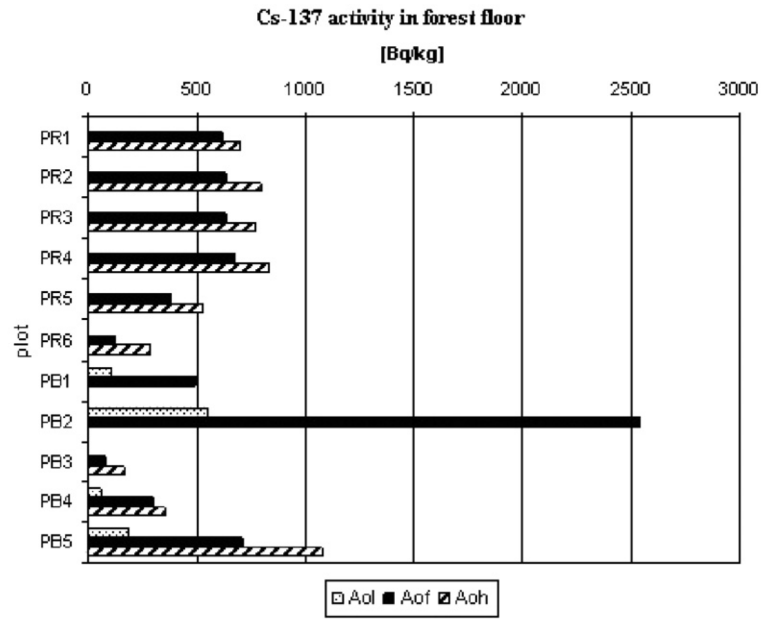

Fig. 1. Cesium-137 activity concentration in forest of ecosystems from the regions of Rila Mountain and Central Balkan.

The activities of Cs-137 in the samples (humus and soil) were measured in accordance with the international standard IEC 1452 (CEI, 1995). It was used a standard gamma spectrometry system containing high purity p-type coaxial Germanium (of relative efficiency—28.1% and resolution 1.75 keV for the pick 1332 keV of the element Co-60) connected to a multi-channel analyzer. The multi-channel analyzer with 8192 channels (Gamma Port, Eurisys Mesures) joined together with Porter (Eurisys Mesures) allows the acquisition of the spectrum. The software used for the treatment of the spectrum and data was InterWinner 4.0 L (Eurisys Mesures). The time of acquisition varied between 7 and 72 h to obtain counting uncertainty of $\leq 10\%$. The uncertainty was generally near 5% for the more contaminated samples. The mean value is presented. The contamination density of cesium, presented per unit area in Bq m^{-2}, was obtained through conversion using the bulk density and the depth of sampled layer and gives clearer picture of the level of contamination. The Cs-137 density in Bq m^{-2} was determined for the fine soil (excluding the skeleton elements).

The Factor of accumulation [FA] was used for determination of the influence of forest vegetation on the radiocesium contamination in mineral soil (Ronneau et al., 1987). In our study we used the soil depth 0–15 cm

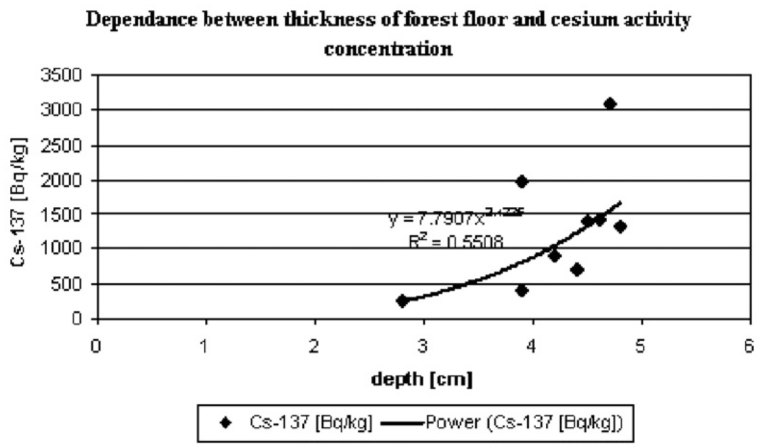

Fig. 2. Dependence between the activity concentration of cesium in forest floor and the thickness of forest floor in studied ecosystems.

and the estimates are done as a ratio between the sums of contamination densities for the different soil depths D1 + D2 + D3.

$$FA = \frac{\text{total activity of Cs} - 137 \quad \text{in forest plot } 0 - 15\ \text{cm}\,[\text{kBq m}^{-2}]}{\text{total activity of Cs} - 137 \quad \text{in control plot (meadow)} 0 - 15\ \text{cm}\,[\text{kBq m}^{-2}]}$$

3. Results

3.1. Characteristics of soil system

For the region of southwest Rila Mountain the humus type was identified as dysmoder (Table 1) in all forest plots. In the profiles from the region of Central Balkan the humus type was identified as hemimoder in beech stand (PB3), dysmull (PB2) and dysmoder in other plots. In the plot PB3 the humus type was hemimoder that and characterized with absence of Aoh horizon. The dysmoder and hemimoder types are characterized with progressive transition to the mineral A-horizon. The processes of decomposition in dysmull humus type pass

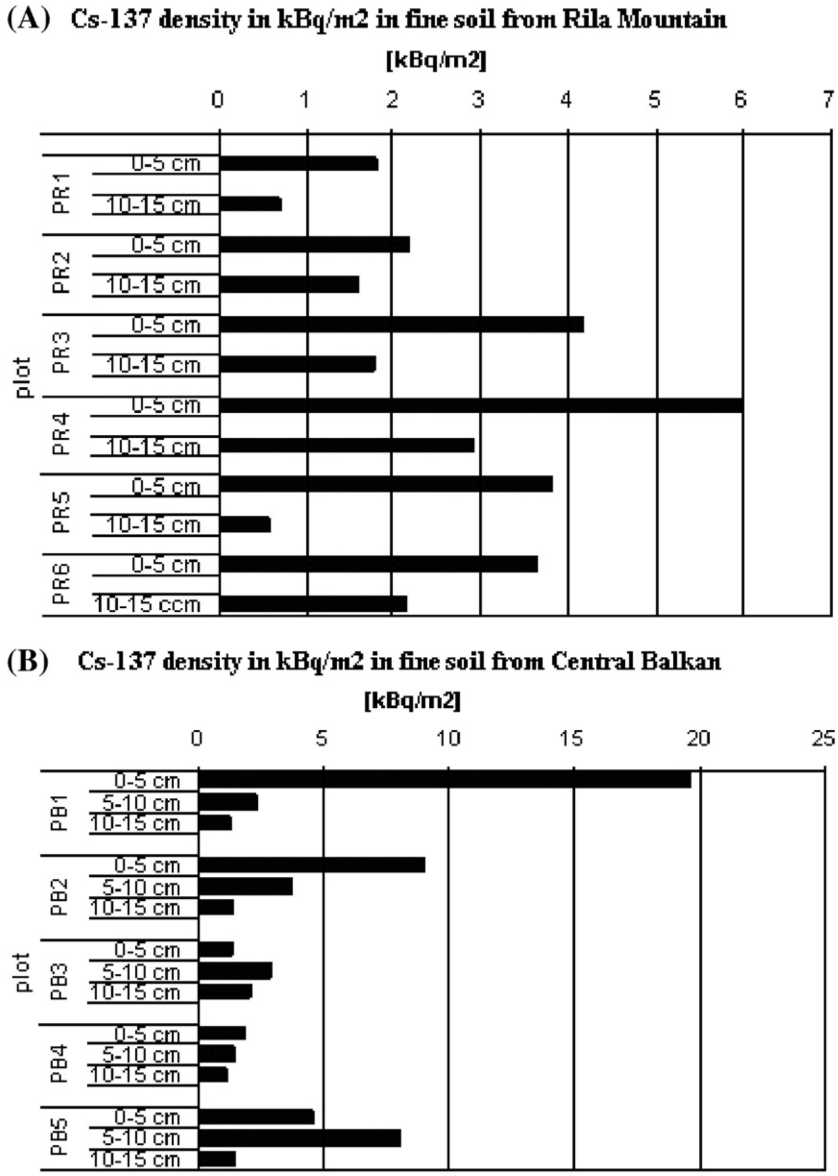

Fig. 3. Depth profile of Cs-137 density [kBq m^{-2}] in fine soil from experimental plots in Rila Mountain (A) and in Central Balkan (B).

slowly because of the severe climate conditions and lack of enough light under the slope. The debris in Aof horizon was figured through the activities of mesofauna (arthropods, worms etc.). The humus types formed under herbaceous vegetation in mountainous meadows (PB1 and PR4) is specific and it could be referred as a turf. The humus was characterized with many roots of herbaceous vegetation and this has contributed the formation of a nappy on the mineral soil.

The brown forest soils (Cambisols dystric/eutric) in the pine ecosystems have high content of sandy fraction (Table 2). The silt fraction predominates in the other plots. The clay content is higher in the superficial organic horizons in the plots from Central Balkan Mountain, especially in plots PB3 and PB4. All soils have relatively high content of skeleton elements. The bulk density in A-horizon varies between 0.73 g cm^{-3} and 1.13 g cm^{-3} for the plots in Rila Mountain and between 0.84 g cm^{-3} and 0.97 g cm^{-3} for the plots in Central Balkan. Some chemical characteristics of studied soils are presented in Table 3. The superficial horizons of forest soils are characterized by acid conditions. The soil organic carbon content is higher in the superficial horizons of all plots located in the territory of Biosphere Reserve “Parangalitza” (PR1, PR2, PR3, and PR4). In the plantations this content in A-horizon is significantly lower. In Central Balkan the organic carbon content in A-horizon shows high variations (2.91% in PB5–8.24% in PB2). The nitrogen content follows the tendencies of carbon and is within the limits 0.16–0.35% in Rila, and 0.21%–0.59% in Central Balkan. The exchangeable potassium in A-horizon in Rila Mountain plots has small variations, while the variation of this parameter for the soils from Central Balkan are higher.

3.2. Cs-137 distribution at small-local scale

The Cs-137 activities in layers of forest floor are presented in Fig. 1.

The activity concentration of the studied nuclide in forest floor from natural ecosystems in Rila Mountain (PR1, PR2, PR3, and PR4) varies from 624 Bq kg^{-1} (Aof) to 827 Bq kg^{-1} (Aoh), while in the plantations (PR5 and PR6) the measured activity concentration is lower. In forest floor from the plots in Central Balkan the values show high variations in different layers (11 Bq kg^{-1} in Aol-2543 Bq kg^{-1} in Aof). The tendency of cesium accumulation in deeper horizons Aof and Aoh is clear presented for all studied plots.

The dependence between the cesium activity concentration in all layers of forest floor and the total thickness of humus for forest ecosystems is presented in Fig. 2. The two parameters form significant exponential dependence (R^2 = 0.5508).

The cesium-137 density in surface soil layers is shown in Fig. 3.

The cesium deposition presented per unit area in [kBq m^{-2}] describes the level of spatial contamination. The contamination density of Cs-137 in fine soil in Rila Mountain is from 0.57 to 6.0 kBq m^{-2} while in Central Balkan the registered values vary from 1.2 to 19.6 kBq m^{-2}.

The cesium is located in the upper 0–5 cm of forest soils and in a few cases the maximum contamination density is determined for the deeper layer D2 (PB3 and PB5). The highest densities in the upper 0–5 cm of soils are measured in PB1 and PB2, respectively 9 and 19.6 kBq m^{-2}. For the soil layer D2 the density varies from 1.5 to 8.1 kBq m^{-2} while in the deeper D3 layer it decreases. The estimated contamination density of Cs-137 in surface soil layers D1 from Rila Mountain plots varies from 1.8 (PR1) to 6.0 kBq m^{-2} (PR4) and decrease in depth. The highest cesium densities in soils are measured in the herbaceous mountainous ecosystems. The Cs-137 in soil is higher in 0–5 cm layer (D1) in all studied plots and decreases in deeper 5–10 cm layer (D2) and 10–15 cm (D3).

3.3. Role of vegetation in cesium distribution

As a result of the processes in ecosystems a part of the deposited cesium-137 was included in the turnover and the values of estimated FA for mineral soil layers give only principal tendencies (Fig. 4). The herbaceous ecosystems (PR4, PB1) from the two mountainous

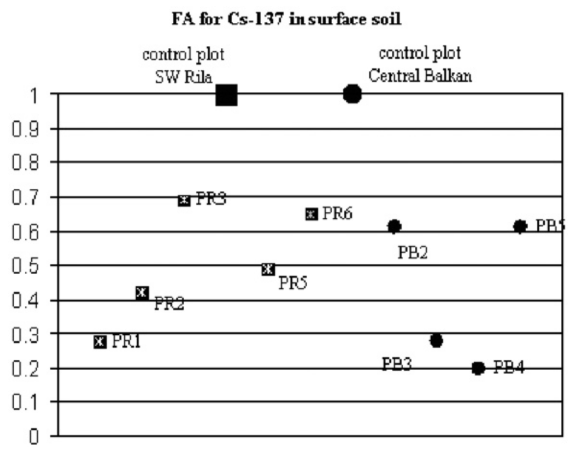

Fig. 4. Factor of accumulation (FA) for cesium-137 in surface soil layers in studied plots.

regions were chosen as control plots in estimating the factor of accumulation.

The obtained results show that FA in studied ecosystems from Rila Mountain is: spruce = 0.28; fir = 0.42; Scot's pine in PR3 = 0.69 and in the plantations PR5 = 0.49 and PR6 = 0.65. The estimated FA in studied plots from Central Balkan is between 0.20 and 0.61. The FA values in beech (PB3) and spruce (PB4) ecosystems are relatively similar, but comparatively the value in PB3 is higher. In the pine plantation PB5 the factor of accumulation is 0.61.

4. Discussion

The humus is an important and integral part of forests and gives information about species and soil conditions in these ecosystems. The main factor for humus formation is the climate. However its role can be modified by the parent material, type of vegetation, human impact, and by the historical change of ecology (Sokolovska et al., 2002). All factors are inter-related with each other. The two studied regions are characterized with mountainous climate. The differences between the plots are determined by the type of vegetation and human activity. The microclimate conditions in Spruce ecosystems characterize with worse light regimes determined by the higher stand density (PR1, PB2, and PB4) and the lack of sylvicultural activities (PR1 and PB2). In the experimental plots formed by beech and Scot's pine (PB3, PB5, PR3, PR5, and PR6) the light regime is better and the decomposition of forest litter passes more intensively. In the meadow ecosystems (PB1, PR4) the microclimate conditions are different and the process of decomposition of organic substances passes completely different compared with the processes in forest plots. The dependence between cesium-137 activity concentration and thickness of forest floor was established ($R^2 = 0.5508$). In present study three different humus types are presented, respectively dysmoder (Rila Mountain and Central Balkan), hemimoder and dysmull (Central Balkan) (see Table 1). The forest floor is stronger contaminated with cesium compared with the surface soil layers in all studied plots. There is a tendency for cesium accumulation in Aoh layer or in Aof in the plots without formed transitional Aoh layer. Nineteen years after Chernobyl accident the forest floor remains the main reservoir of cesium-137 (Rühm et al., 1999; Soukhova, 2000). The human activities and microrelief characteristics in the plantations influence the humus formation and indirectly the accumulation of cesium-137 in forest floor. The tendency of cesium distribution in forest floor in natural ecosystems from Rila Mountain is quite similar in contrast to the plantations, where the activity concentration of Cs-137 in forest floor is lower. In Central Balkan the layers of forest floor are stronger contaminated with cesium. For this region we can distinguish also two groups in respect to tendencies in Cs-137 distribution in forest floor: on one hand PB1 and PB2 and on other hand PB3, PB4, and PB5. From all studied plots the forest floor in PB2 is the most contaminated (2543 Bq kg^{-1}). Our results suggest that the humus type plays a role in cesium accumulation in forest floor.

The obtained results for the southwest parts of Rila confirm the measured values for cesium activity concentration presented in other studies for the same region (Klein et al., 1995; Pourchet et al., 1995). Nevertheless the results obtained for Central Balkan show very strong and higher contamination of soil. The main content of cesium is accumulated in the forest floor as was shown before (Klein et al., 1995; Scheglov, 1999; Zhiyanski et al., 2005) and in the most of cases the main content of Cs-137 is located in the superficial 0–5 cm of soils that confirm the conclusions of Soukhova (2000) and Rafferty et al. (2000). Agapkina et al. (1998) and Rafferty et al. (2000) have also determined a cesium fixation in the upper soil horizons. This is related with the higher organic matter content and the better hydrological conditions in the upper layers of soil system (Ritchie and Rudolph, 1970; Kühn, 1982; Fawaris and Johanson, 1994; Zibold et al., 1997; Rafferty et al., 2000). The soil organic matter content influences the cesium distribution in soils, especially in Cambisols that are characterized with light mechanical composition (Strobel, 2001; Zhiyanski et al., 2005). The highest organic carbon content is determined in the mountainous meadows and in spruce ecosystems. Comparatively in the plots from Central Balkan the soil organic carbon is higher than in the plots from Rila Mountain. The lower C/N ratio is determined in all plots from Central Balkan and in the plantations PR5 and PR6 from Rila Mountain and shows that the processes of mineralization and decomposition of organic matter pass more intensively. The lower values of the ratio in these plots could be explained with the young age of stands and their more intensive growth related with active nitrogen assimilation (Jönsson et al., 2003).

The different human activities and sylvicultural practices could modify the concentrations and the cesium distribution in ecosystems. The human activity affects directly some physical soil characteristics influencing the cesium density in mineral layers. The data show that the bulk density of A-horizon in the plantations is relatively higher compared with the plots with natural origin. The human activities during cultivation can alter soil bulk density, porosity, aggregation and mechanical impedance according to Gill and Vanden Berg (1967) and Cassel (1982). This could contribute an additional increase of cesium-137 density in deeper soil layers, as was established in plots PR6 and PB5.

The obtained results for the cesium density in Central Balkan show different soil profile distribution in PB3 and PB5 with higher values in D2 layer. A probable explanation for the higher values and the relatively stronger contamination of D2 in these plots could be the influence of soil micro-and mesoflora and micro-and mesofauna, erosion processes (Andrello and Appoloni, 2004) or differences in the initial cesium contamination before Chernobyl due to other sources. If we observe the plots from Central Balkan the tendencies in cesium profiles in plots PB1 and PB2 are quite similar and the content of cesium decreases clearly in depth. This contrasts to plots PB3, PB4, and PB5 where the tendency of cesium contamination density has different trend. We could express hypothesis for the stronger contamination before Chernobyl accident in the plots located on lower altitude and/or with variations in abiotic and biotic factors in vertical direction at small-local scale (Isaksson and Erlandsson, 1995).

Regarding to the cesium content in soil layers in Central Balkan the differences between studied plots with respect to altitude are good expressed despite of the relatively small range of altitude. The differentiation is also relatively good expressed in Rila Mountain. In the plots located on lower altitude the determined cesium in layers of forest floor and in surface soil layers was comparatively lower. This could be related also with the specifics of mountainous climate and the higher precipitation (respectively deposition) in higher altitude and also with the specifics of the stands. This suggestion was expressed in studies of other authors (Semerdjieva and Dimchev, 1983; Yovtchev et al., 1997).

The forest vegetation influences directly and indirectly the cesium distribution in soil systems. On one hand it restricts the radioactive deposition and on the other hand it participates in humus formation and in biological transfer of radionuclides. Ronneau et al. (1987) underlined the important role of forests in retention of radioactive fallout. A confirmation for this hypothesis is the estimated factor of accumulation (FA). In the Scot's pine ecosystems the factor of accumulation is higher compared with other forest ecosystems in the region, despite of differences in the age. In 1987 the young plantation PR5 has been created by planting of 2-years old trees. Actually at the time of Chernobyl accident this experimental plot has been an open-air herbaceous ecosystem. The relatively lower value of FA in this plot compared with PR4 could be explained on one hand by the lower altitude and micro-climate peculiarities and on the other hand by the human activity during cultivation and mixture of soil layers. The FA is relatively high for the fir ecosystem PR2. The lower value of FA in beech forest ecosystem PB3 could be explained by the fact that the decomposition of forest litter in this plot passes more intensively and part of accumulated cesium in forest floor layers was moved toward the upper soil layer. In the pine plantation PB5 and spruce plantation PB2 the factor of accumulation is 0.61 and the value is comparable with the values obtained for pine forests from Rila Mountain. The result show that spruce forests has higher retention capacity to deposited cesium and we could suggest that the type of vegetation and forest floor influence the cesium accumulation in soils.

The intense dispersion of cesium-137 deposition in mountainous regions in Bulgaria is confirmed. The northern slopes of Central Balkan are very strong contaminated with Cs-137. There is established inhomogeneously cesium contamination in relatively restricted mountainous zones. This conclusion was expressed also from Klein et al. (1995) in their study in the north part of Rila Mountain. In particular for the studied mountainous regions the lower zones were less contaminated with cesium. With augmentation of the altitude the activity concentration of Cs-137 increases and this determines high small-scale variability of soil system contamination.

5. Conclusions

The measurements and comparative analysis showed that the studied two mountainous regions in Bulgaria are strong contaminated with Cs-137. The region of Central Balkan Mountain is stronger contaminated compared with the southwest part of Rila Mountain. High variability in spatial distribution and heterogeneity of cesium-137 in soil systems of mountainous ecosystems was established. Due to the high levels of cesium contamination within the mountainous regions of the Central Balkans and the characteristics of these forest soils, the highland pastures located in this region, in the authors opinion, could be considered as risk zones for easier cesium soil-to-plant transfer. Due to their low clay content and the high content of organic matter, the mountainous brown forest soils can be considered an excellent natural object to study the behaviour of Cs-137 with PCA application.

The profile distribution of Cs-137 in soil systems has a tendency of decrease toward deeper layers. Meanwhile the forest floor remains the main reservoir for cesium even years after fallout. On the base of estimated factor of accumulation (FA) we conclude that the type of vegetation is a factor influencing the vertical distribution of Cs-137 in soil system and the spruce forests has higher retention capacity to deposited cesium. Other factors that could modify the cesium distribution in soils are the human activities in forests and implemented sylvicultural practices.

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