CAESIUM-137 BEHAVIOUR IN SMALL AGRICULTURAL CATCHMENTS ON THE AREA OF THE CHERNOBYL CONTAMINATION

E. V. Kvasnikova, E. D. Stukin

Academy of Science of Russia, Institute of Global Climate and Ecology, 20-b Glebovskaya str., 107258 Moscow, Russia

V. N. Golosov, N. N. Ivanova, A. V. Panin

State University M. V. Lomonosov, Department of Geography, Vorobiovy Gory, 119899 Moscow, Russia

The vertical distribution of ^{137}Cs from the Chernobyl accident in soils of the basin of the Gusinaya Lapka dry river, situated in the Eastern region, 550 km from the reactor, has been investigated. In this area the ^{137}Cs contamination levels range between 250 and 502 kBq m^{-2}. In the accumulation zones, at the bottom of the valley, the sediment deposits over the last ten years represent a layer of not more than 10 cm. On arable lands, the erosion processes are limited and no perceptible redistribution of ^{137}Cs could be observed, except at the transition between ploughed lands on the inter-rivers and meadows on the balka slopes. This study demonstrates the potential use of the ^{137}Cs from the Chernobyl accident for the quantification of the soil erosion process.

1 Introduction

The Chernobyl accident on 26 April 1986 resulted in the radioactive contamination of large territories, mainly by the long-lived artificial radionuclide caesium-137. The total area in Europe, affected by ^{137}Cs deposits above 40 kBq m^{-2}, is estimated to 240300 km^2, i.e. some 2 % of the continent [1]. This area is mostly represented by agricultural lands and forests. Radiological assessments [2] have shown that the averaged effective equivalent dose to the population living on territories with ^{137}Cs contamination levels of 40 kBq m^{-2} can reach 1 mSv; within territories with ^{137}Cs deposits above 555 kBq m^{-2}, the effective equivalent dose can reach and exceed 5 mSv. In most cases, ^{137}Cs appears as the main contributor to the radiological dose; therefore its behaviour must be thoroughly understood to allow reliable dose estimates [2].

The Central Russian Upland belongs to those regions severely affected by the deposit from the Chernobyl accident. One peculiarity of the relief in this region is that it combines relatively gentle inter-rivers slopes with steep bulging slopes in river valleys and "balkas" (dry valleys created by the intermittent flow of waters from thaw and rainstorms). The arable land occupies about 70 % of the total area and, thus, in many of the small catchments the relatively steep slopes in the low parts of the valleys are also ploughed [3]. However, steep slopes are generally occupied by meadows; they do not usually represent more than 10% of the total length of the balka slopes. Such landscapes are periodically submitted to intensive erosion caused by snow melting in spring or after heavy rains. These erosion processes act on the soil redistribution and fertility, but also promote the horizontal redistribution of atmospheric radioactive deposits, they modify the vertical distribution of radionuclides in soil and, hence, the external dose rate from the ground [4,5].

2 Methods of investigation and analytic techniques

The investigated territory is located near the city of Plavsk (Tula region), about ‑0 km from Chernobyl, (53,5^{0}N; 37^{0}E). Field observations carried-out (1995-97) identified in this region a caesium contamination spot characterised by contamination levels ranging from 150 to 740 kBq m^{-2}. The centre of this contamination spot, chosen for our investigations, consists of catchments of balkas flowing into the Lokna river.

The spatial distribution of the ^{137}Cs contamination in the basin of the Gusinaya Lapka dry river (balka and adjacent inter-rivers of which most of the surface consists of ploughed fields) was determined using soil core sampling and *in situ* γ-spectrometry (Fig. 1). Soil cores were taken along several transect lines between the dry river bed and the limit of arable land at the edge of the balka, to cope with the diversity of profiles in the basin. The location of the sampling sites on these transects was chosen according to the topography to take into account the different elements of the landscape and their role in the erosion process (mobilisation, transit and accumulation). The sampling sites along the balka bottom were situated in zones characterised by different intensities of erosion and accumulation processes. Sampling was also carried out in the inter-rivers zone where no, or limited, erosion and accumulation takes place. According to an erosion model the mean accumulation intensity should not exceed 1 cm y^{-1} in the bottom and 0.5 cm y^{-1} on the slopes. The soil exportation from the inter-rivers area is estimated to 5-10 ton ha^{-1} y^{-1} [6].

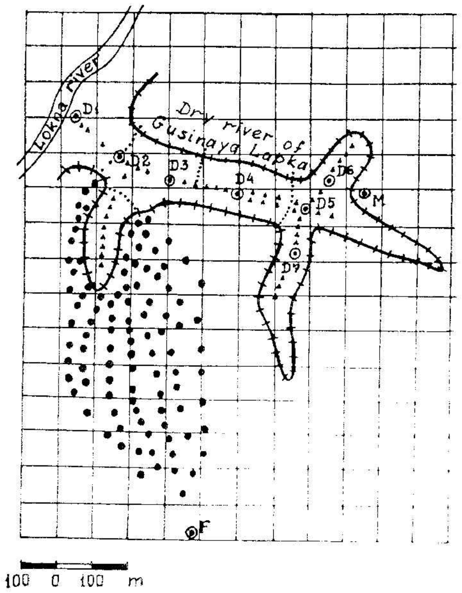

Fig. 1. The sampling site positions
- sampling sites along the transect lines between the dry river bed and the the edge of the balka
• – sampling sites along the slopes in the inter-river zone, ▲ – sampling sites along the balka bottom. ⊙ – "layer by layer" sampling sites: D1-D7 – in the dry river bottom; F- in the forest of the inter-river; M – in the meadow of the inter-river

Soil sampling was performed with augers (∅ 68 or 95 mm) equipped with a depth-gauge. The augers were driven into the soil to the required depth to remove the corresponding soil layer. In ploughed areas, the plough layer (0-30 cm) was sampled as a whole as well as 10 cm below the plough-sole (30-40 cm). Seven soil cores from the balka bottom were collected in five successive layers (0-5, 5-10, 10-15, 15-20 and 20-30 cm); those from the balka slopes with the signs of accumulation were divided into three layers, namely 0-5, 5-10 and 10-20 cm.

Prior to the determination of their radioactivity content, the soil samples were dried 24 h at 105^{0}C and homogenised with a ceramic ball-mill. ^{137}Cs and ^{134}Cs activities in soil samples were measured by γ-spectrometry, using a high resolution, low background, low energy, HPGe ORTEC detector. The detector, coupled to a spectrometric amplifier and multichannel analyser, has a 30 % relative efficiency and a resolution of 1.8 keV.

3 Results & Discussion

a) *Spatial redistribution of the ^{137}Cs contamination in the basin of the Gusinaya Lapka dry river*

The flat top of the inter-rivers are not subject to the erosion processes. Therefore, if we neglect the limited exportation of radiocaesium with crops harvests and soil adhering to farming tools (tractor wheels, plough) as well as the redistribution by bioturbation, we may reasonably assume that the spatial distribution of the radioactivity, as observed nowadays, still gives a reliable image of the variability of the initial deposit. To estimate the initial variability of the deposit, five soil cores (30 cm depth) were sampled on the flat top of the inter-rivers: four samples were taken in the corners of a 20 m x 20 m square and one at the centre of this square. They provided a mean ^{137}Cs deposition density of 289 ± 70 kBq m^{-2} (± σ). The calculated coefficient of variation (CV = s . 100/$\bar{x}$) was 24 %.

The variations of the spatial distribution of the ^{137}Cs contamination on the slopes of the basin of the Gusinaya Lapka dry river and adjacent inter-rivers slopes are presented in Table 1. Ten years after the accident the mean values of ^{137}Cs contamination densities (per unit area) increase from the elevated zones on the slopes of the inter-rivers towards the bottom of the balka. This increase reflects the horizontal transport of contaminated soil material from the intensively cultivated slopes of the inter-rivers towards the accumulative zones in the bottom of the valley. The variability of the ^{137}Cs contamination density, as represented by the variation coefficient (CV), is the highest on the balka slopes that correspond to the transit zones along the transport path of the eroded material. In these parts the CV value (23 %) is comparable to that observed for the flat top of the inter-rivers (24 %). On the contrary, the variability of the radiocaesium spatial distribution is lowered at the balka bottom (CV = 12 %) and on the slopes of the inter-rivers (CV = 16 %). In other words, the horizontal redistribution of soil material by erosion processes smoothes the heterogeneity of the initial deposit, essentially in areas showing high accumulation (balka bottom) or exportation (inter-rivers slopes). The variability of the radionuclides spatial distribution in the transit zone (balka slopes) is not affected.

The zone between the ploughed smooth slopes of the inter-rivers and the steeper balka slopes occupied by meadows is the site of a high ^{137}Cs accumulation with density

Table 1. Variation of ^{137}Cs density in the balka of the Gusinaya Lapka dry river and adjacent inter-rivers landscapes (Plavsk, Tula region, Russia), 1996

Geosystem	N^{0} of samples	$\bar{x}$ (kBq m-2)	σ (kBq m^{-2})	CV (%)
Interrivers	101	317	49	15.5
Balka slopes	31	354	81	22.8
Balka bottom	50	386	48	12.3

levels increasing up to 740 kBq m^{-2} (range: 590-740 kBq m^{-2}). These radiocaesium increases correspond to zones of high sedimentation and occupy a ground band of 2-5 m width along the land use transition line. Similar phenomena were also observed in hollows on the balka slopes. These abrupt transitions in the landscape (changes in land use or in slope angle) creates geomorphological barriers that trap sediments.

b) *Estimation of the vertical migration of ^{137}Cs in the natural geosystems of the Gusinaya Lapka balka and adjacent inter-rivers*

The vertical profiles of ^{137}Cs in the soil from the never ploughed balka bottom are presented in Fig. 2. In most profiles, we observe an increase of the ^{137}Cs content in the 5-10 cm layer which contains 33 to 50 % of the total caesium. The upper 0- 5 cm layer is less contaminated and accounts for only 20 to 36 % of the total radiocaesium activity. Such a distribution is generated by the progressive burial of the layer which was on top in 1986 under sediments eroded from the ploughed inter-rivers (D2). The ^{137}Cs contamination level in the third layer (10-15 cm) increases gradually from the balka head to the balka mouth. However, at the level of the balka mouth (D1), the ^{137}Cs distribution is almost homogenous in the upper 0 to 15 cm soil layer due to the more intensive burial of the 1986 soil top layer directly contaminated by the ^{137}Cs fall-out from Chernobyl, under the deposits of sediments eroded from the highly contaminated soil surface from more elevated, remote areas. In the samples D3-D7, taken in the middle and upper parts of the balka, the vertical profile is similar to that usually observed in natural landscapes, undisturbed by agricultural activities, with a reduced ^{137}Cs content in the upper 0-5 cm layer [7,8,9]. Let us note that the 0-20 cm layer of the soil in unploughed geosystems of the balka bottom contains more than 90 % (92 to 98 %) of ^{137}Cs. In the inter-rivers plough-land, the 30-40 cm layer under the plough sole contains less than 5.5% of the total ^{137}Cs and less than 3% of the soil ^{134}Cs. This demonstrates that the penetration of the Chernobyl radiocaesium to such depths is not so significant. The ratios $^{134}Cs/^{137}Cs$ in the plough layer range between [illegible] and [illegible] (autumn 1996). This is about twice higher than in the layer under the plough sole (range = 0.010 – 0.016). According to the change in the $^{134}Cs/^{137}Cs$ ratio between the plough layer and the soil immediately below, we conclude that the most of ^{137}Cs in the 30-40 cm layer does not originate from Chernobyl but from the global fallout.

c) *Vertical radiocaesium migration and distribution in typical natural landscapes*

Table 2 presents the vertical radiocaesium distribution in soils (kBq m^{-2}) from two natural landscapes, a birch forest growing on a grey forest soil and a meadow developed on a chernozem. Both sampling sites are located on the smooth slope of the inter-rivers area and represent typical landscapes of the investigated region. It

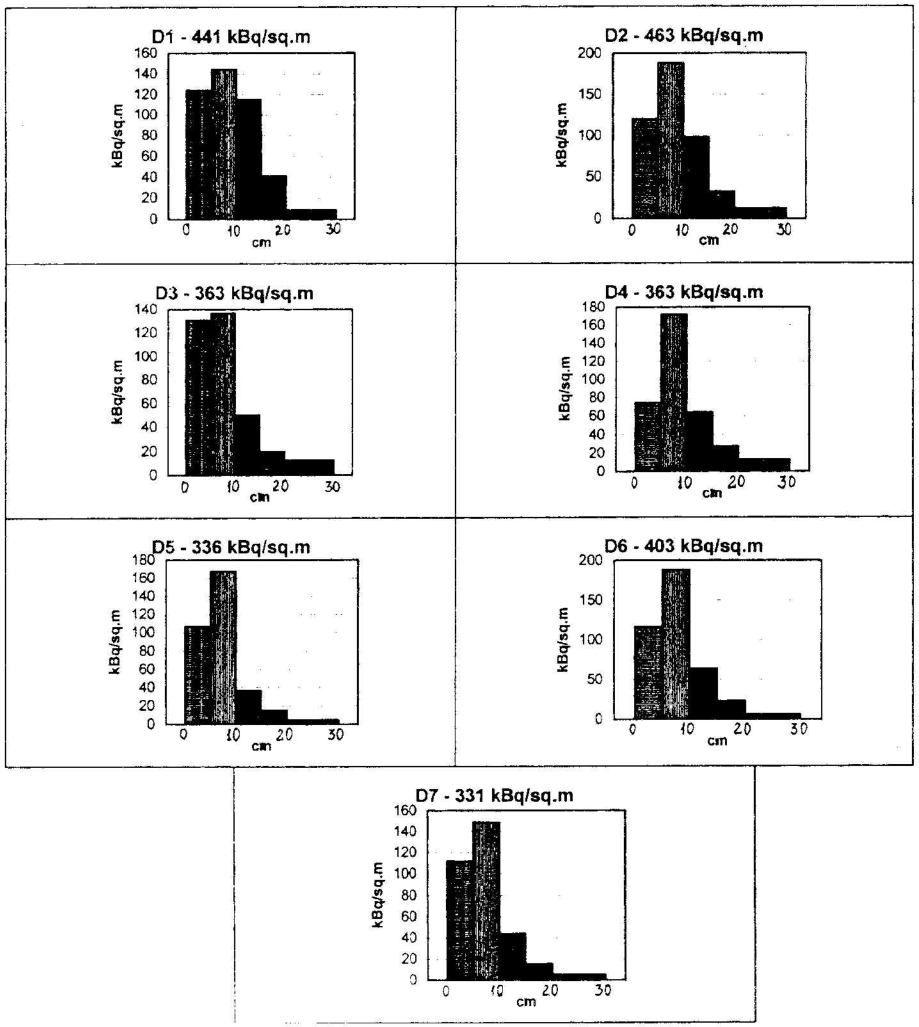

Fig. 2. The ^{137}Cs vertical distribution in soil of different attended landscapes of balka Gussinaya Lapka (October 1996)

Comments: each depth layer is 5 cm; the total activity is indicated at the top of each diagram; D1 – erosion part of the balka bottom, place of the water discharge; D2 – accumulative part of the balka bottom; D3 – transition-accu-mulative part of the balka bottom; D4 – transition part of the balka bottom; D5 – accumulative part of the balka bottom in the place of a joint of 3 affluents; D6, D7 – transition-accumulative parts of the affluent bottoms.

Table 2. Vertical distribution profile in soil cores from different unploughed landscapes, 1996

Sample	Layer (cm)	^{134}Cs* (kBq m^{-2})	^{137}Cs* (kBq m^{-2})
Forest	0-2	1.98	99.2
	2-5	1.37	62.9
	5-10	0.54	25.5
	10-15	0.18	5.62
	15-20	0.06	2.74
Σ	0-20	4.13	196
Meadow	0-2	0.89	42.6
	2-5	4.44	202
	5-10	3.26	151
	10-15	0.52	35.7
	15-20	0.33	16.0
Σ	0-20	9.44	447

*) Uncertainties of all measurements are <10 %.

appears from the data that more than 80 % of the Cs deposit in the forest is still concentrated in the top 5 cm layer of the soil including the litter. The limited penetration of Cs into the soil is explained by the high Cs retention by the organic horizon [7,8,10]. In the meadow sample, vertical migration proceeds faster; the Cs peak is found at around 5 cm depth after 10 years, representing an average migration rate of about 0.5 cm y^{-1}.

4 Conclusions

Ten years after the Chernobyl accident, the comparative analysis of soil profiles in remote areas contaminated by the deposition of condensed forms allows us to estimate the intensity of erosion processes and the redistribution of the eroded material. In the basin of the Gusinaya Lapka dry river, located in the Eastern region, 550 km from the reactor, where ^{137}Cs deposition rates ranged between 250 and 502 kBq m^{-2}, the erosion, transit and accumulation zones could be clearly identified on the basis of the ^{137}Cs distribution in the soil profiles. In the accumulation zones, at the bottom of the valley, the sediment deposits over the last ten years represent a layer of not more than 10 cm. On arable lands, the erosion processes are limited and no perceptible redistribution of ^{137}Cs could be observed, except in the transition zone be-tween ploughed lands on the inter-rivers and meadows on the balka slopes. These discontinuities constitute physical barriers to the transport of alluvia and the site of intensified accumulation. The meadows on the balka slopes are transition areas where accumulation, but also remobilisation, of sediments take place according to the seasonal water flow and local geomorphological sub-structures. Along the balka bottom an accumulation gradient could also be observed, with higher sedimentation in the lower part of the balka.

This study demonstrate the potential use which can be made of the ^{137}Cs from the Chernobyl accident to quantify the processes of soil erosion.

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References

[1] Yu. A. Izrael et al.: Meteorology and Hydrology (1996) 8.
[2] A. Karaoglu et al.: *The radiological consequences of the Chernobyl accident*, Office for Official Publications of the European Communities, Luxembourg, 1996
[3] Sh. D. Fridman et al.: Meteorology and Hydrology (1997) 45.
[4] V. A. Baturin: Atomic energy (1997) 44.
[5] A. V. Konoplev et al.: Sci. Total Environment. **137** (1993) 147.
[6] G. A. Larionov: *Soil erosion and deflation*, MGU, Moscow, 1993.
[7] F. I. Pavlotzkaya: *Migration in soils of the products of global fallout*, Atomizdat, Moscow, 1974.
[8] G. N. Romanov et al.: Geochemistry (1993) 995.
[9] Bulgakov et al.: Soil Science (1990) 14.
[10] S. K. Nair et al.: Helth Physics **71** (1996) 896.