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# Peculiarities of spatial structure of $^{137}$Cs contamination field in landscape toposequence: Regularities in geo-field structure

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**Abstract.** A study of spatial structure of $^{137}$Cs contamination field was performed 1,8 km north to set. St. Vyshkov, Bryansk oblast in pine forest on the Iput river terrace with sandy podzolic soils and pronounced relief. $^{137}$Cs was used as a tracer of atmospheric pollutant migration to test the hypothesis of a regular character of the secondary $^{137}$Cs redistribution in natural landscapes and its dependence on landscape structure. In 2005–2007 95% to 98% of the total $^{137}$Cs activity was still preserved in the upper 15–20-cm soil layer. Field gamma–spectrometry performed in nested grids (5 m for the whole area; 1 m for 5 × 5 m plot; 0,2 m for 1 × 1 m plot) revealed a system of $^{137}$Cs polycentric anomalies at different scales. Detailed cross-sections along and cross the slopes with the step of 0,5 m and 1 m showed specific wave-like variation of surface activity often inversely related to micro-relief that is believed to result from $^{137}$Cs involvement in water and snow-melting mass migration after the aerial fallout. In mosses $^{137}$Cs also showed regular spatial distribution related to that in topsoil. The study proved that technogenic radionuclides formed a definite spatial polycentric structure in natural landscapes that should be accounted of in sampling strategy and in estimates of spatial variation.

## 1. INTRODUCTION

Radioisotope fallout after the Chernobyl accident formed a macro-scale field of contamination with definite spatial structure including the two most contaminated near and distant zones and the areas of deposition with gradient structure of radionuclide concentration [1]. Our meso-scale investigations of 1987–1989 of the Chernobyl radionuclides ($^{134,137}$Cs, $^{144}$Ce, $^{106}$Ru) in toposequence of natural landscapes formed on different rock types showed both the soil fixation and the involvement of radioisotopes in redistribution processes (fixation on the ridges of the flood plain, burial in deeper layers due to erosion, accumulation in dry depressions and in soils of the forest belts, the tendency to vertical migration in the first years after the accident, etc.) [2].

The detailed studies of the spatial structure of $^{137}$Cs contamination field in natural landscapes performed by the other investigators at the selected test sites used random or regular measurement schemes and statistic or geo-statistic methods to explain the obtained spatial patterns [3–5]. Statistic application needs presumption of independent variables. However secondary distribution of a definite mass of radioisotopes in natural conditions was subjected to different directed processes (aerial, water and biogenous) that could hardly be treated as random. Superposition of these natural factors should lead to formation of the dispersion and accumulation zones of radionuclides that should not obligatory

coincide with the present landscape geochemical structure reflecting the long-term result of mass distribution but mark the short-term tendencies of its transformation.

The objective of our study performed in 2005–2007 was to reveal the spatial structure of $^{137}$Cs contamination field in natural conditions within similar parent rocks, to test the hypothesis of the regular character of the secondary $^{137}$Cs spatial structure in natural landscapes and to compare this structure with landscape topography as factor responsible for water and mass migration in conjugated landscapes.

## 2. STUDY SITE AND METHODS

The selected test site belonged to one of the radiation monitoring sites of the former Russian Scientific-Practical and Expert-Analytical Center of the State Chernobyl Committee (RNEC). It was located on the forested high terrace of the Iput river 1,8 km north to set. St. Vyshkov, Novozybkov region, Bryansk oblast. The terrace was covered by 50–70-year old pine forest with sandy podzolic soils formed on the river-reworked fluvioglacial sands. Topography, soil and vegetation cover and radionuclide contamination level were investigated by RNEC researchers (including one of the authors of the present publication) in 1991–1992. The forest litter and topsoil were collected in the envelope manner and two soil profiles were located at different geomorphological positions to characterized spatial variation and vertical distribution of radionuclides. The first field gamma–spectrometry of this site was performed in 1993 by V. Linnik and A. Govorun with the help of field gamma-spectrometer CORAD. The grid size was 20 m and 10 m, the estimated contamination density varied from 33 to 45 Ci/km$^2$. No regular spatial tendencies were found.

In 2005 we selected for a more detailed study a 70 × 100 m parcel with a pronounced relief (the elevation range reached 4,5 m) [6]. By that time $^{137}$Cs was accumulated in the overground vegetation, litter and soil cover. Overground vegetation was presented by green mosses, undershrubs, grasses and lichens (locally). Field measurements were performed using 5 m grid. Downscaling measurements (2 m, 1 m and 0.2 m between points) were made within nested plots sized 10 × 10 m, 5 × 5 m and 1 × 1 m respectively). Additional measurements were performed along and cross the northern and southern slopes, the slopes and thalweg of the hollow partly outside the site but suitable to follow water with a step of 0.5 and 1 m accompanied by elevation measurements by electronic theodolite DJ-30. In 2007 measurement points were located in the centers of the previous grid for verification of the spatial structure. Field spectrometry was performed with the help of gamma-spectrometer equipped with Na(Tl)I scintillated detector. Counting efficiency was approximately 15%.

To verify field data vertical distribution of $^{137}$Cs in soils was studied by core sampling to the depth of 40 cm. Soil samples were taken in increments of 2 cm (the top 20 cm layer) 5 cm (down to 30 cm), and 5 cm (30–35 and 35–40 cm). $^{137}$Cs specific activity was determined by Canberra gamma spectrometer with HPGe detector. Moss samples (*Dicranum sp.*, *Pleurozium schreberi*) and tree debris (brown needles, leaves and rare small branches) were collected from the area 15 × 15 cm in 10 m grid, each sample was divided into upper (green) and lower (brown) parts and analyzed for $^{137}$Cs in laboratory conditions. Laboratory determination error varied from 1% to 18%, reaching maximum in low-radioactive specimen.

## 3. RESULTS AND DISCUSSION

Field gamma-spectrometry revealed a system of $^{137}$Cs polycentric concentration areas (anomalies) with regular alternation of accumulation and depletion areas from the top to the bottom depression with a complicated relation to inclination of the slope and microrelief.

Contamination structure and its parameters studied at different scales is presented in Figure 1 and Table 1. The range of $^{137}$Cs activity decreased in its nested fragments downscale especially at minimum step (Table 1) that proved the definite structural organization of the anomaly. The step of 0.5–1 m was considered to be sufficient to perform cross-section measurements.

Measurement cross the slope with 0.5 m step (Figure 2, elevation and activity counting were measured at the same points) revealed the wave-shaped patterns of $^{137}$Cs redistribution often with a mirror-inversed tendency relative to elevation value. Variation periodicity step in $^{137}$Cs activity along the overgrown hollow thalweg line (Figure 3, measure step 1 m, topographic survey scale 1:200) was smaller at its head and wider at the lower part with a tendency of increase and maximum activity value at the lower points (Figure 3). Accounting of the strong affinity of $^{137}$Cs to sorption by soil particles such pattern is likely to be formed in the first period of radionuclide redistribution with surface run-off that was controlled by both micro- and mesorelief.

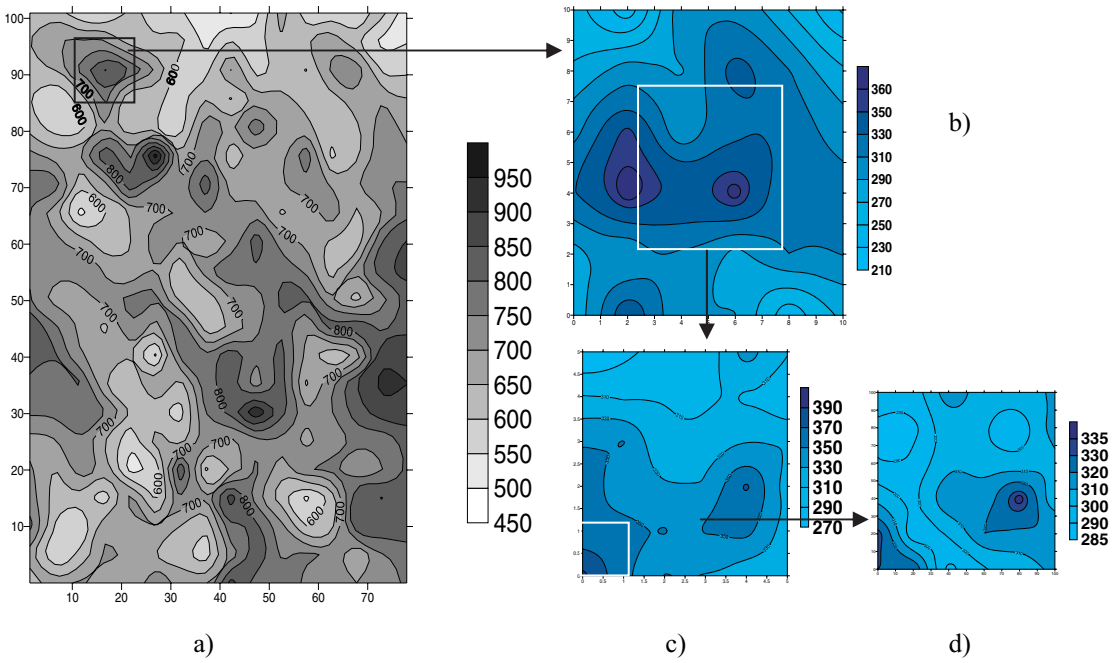


**Figure 1.** The structure of Cs-137 contamination field for the plots: 70 × 100 m, grid 5 m (a); 10 × 10 m, grid 2 m (b); 5 × 5 m, grid 1 m (c); 1 × 1m, grid 0.2 × 0.2 m (field measurement, cps). ested plots are marked by frame.

**Table 1.** $^{137}$Cs activity as determined on the soil surface (cps) using different grids (nested downscale measurement).

| Measured area, m$^2$ | Grid, m | Number of measurements | Activity in $^{137}$Cs peak area (imp/s) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Min | Max | Range | Mean value | STD | Me | Mo |
| 7000 | 5 | 326 | 167 | 382 | 215 | 264 ± 2 | 40 | 262 | 284 |
| 400 | 5 | 25 | 182 | 331 | 149 | 247 ± 8 | 38 | 241 | 232 |
| 100 | 2 | 36 | 217 | 369 | 152 | 300 ± 6 | 36 | 302 | 291 |
| 25 | 1 | 36 | 272 | 395 | 123 | 327 ± 5 | 27 | 324 | 329 |
| 1* | 0,2 | 36 | 329 | 379 | 50 | 353 ± 2 | 13 | 354 | 352 |

*2006.

Soil cores located in different geomorphological positions proved that in most cases the main inventory of $^{137}$Cs (73,9%–99,5%) is still in 10–20-cm top layer and confirmed the tendency of $^{137}$Cs higher contamination, deeper migration and higher variation of activity in water collecting accumulative localities (Table 2).

Spatial structure of $^{137}$Cs contamination of the mosses in the upper (green) and lower (brown) parts also had a regular character (Figure 4). There was no surprise in correlation between the upper and

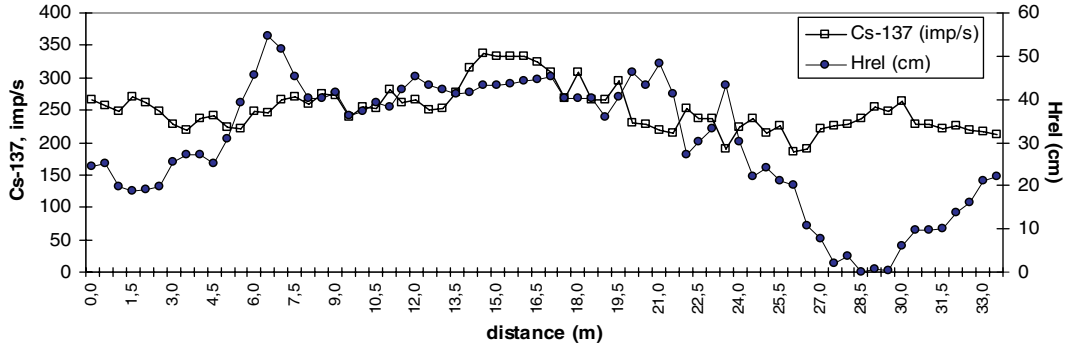


**Figure 2.** Cs-137 activity variation across the upper part of the northern slope in comparison with the variation of relative elevation of the measured points.

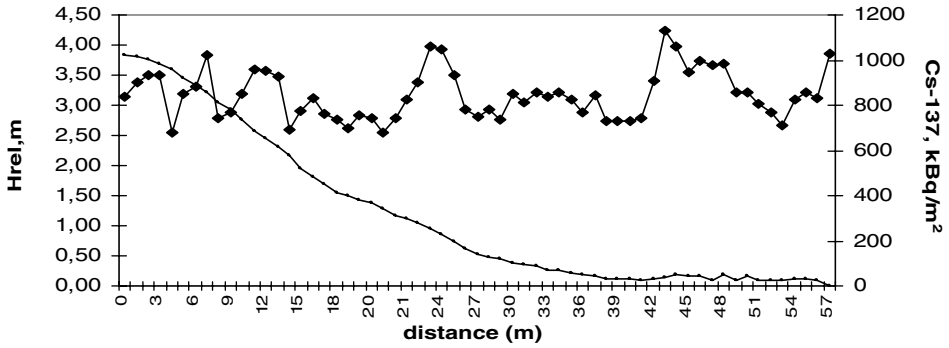


**Figure 3.** Cs-137 activity variation along talweg of the hollow and relative elevation of the measured points (contamination density estimated by V. Potapov, Kurchatov Insitute, basing on field data, topographic survey scale 1:200).

lower parts of the mosses (in general the lower part had similar or higher radionuclide concentration). Despite a coarser sampling grid and a small sampling plot there was definite correlation between $^{137}$Cs activity in moss and soil the moss upper and lower parts and spatial coincidence of the enhanced values (Figures 1 and 4).

Spatial discrepancy between the $^{137}$Cs geofield structure in mosses and soils was believed to be mainly due to the difference between the total $^{137}$Cs fixed in the soil and its availability to the biotic component of landscape rather than to coarser moss sampling grid.

## 4. CONCLUSION

Performed study showed that $^{137}$Cs radioisotopes formed in natural landscapes a complex heterogenic but regular spatial structure both in soil and vegetation cover.

Cesium radioisotope contamination field consisted of a system of polycentric anomalies that showed themselves at different scales (down to the distance of 100–50 and 20 cm between the measured points). A considerably smaller range of the counting rate for the grid $0.2 \times 0.2$ m proved 0.5–1 m distance between the measured points to be sufficient to describe the spatial structure of contamination field.

Amplitude of $^{137}$Cs activity variation along transects crossing the slopes both in transverse and lengthwise directions was in general lower than that of elevation but showed a some periodicity often inverse to the elevation of the points.

**Table 2.** Cs-137 inventory in different layers of the soil profiles depending upon their position in toposequence ($kBq/m^2$).

| Position of the core in toposequence | Depth, cm | Xmin | Xmax | Mean | STD | V,% | % to the total* |
|---|---|---|---|---|---|---|---|
| Hill top, the upper part of the slope (n = 9) | 0–4 | 177 | 653 | 378 | 174 | 46 | 54 |
| | 0–10 | 309 | 1198 | 635 | 294 | 46 | 88 |
| | 0–20 | 338 | 1312 | 702 | 311 | 44 | 98 |
| | 0–40 | 437 | 1477 | 1021 | 334 | 33 | 100 |
| Middle part of the slope (n = 8) | 0–4 | 185 | 881 | 504 | 274 | 54 | 48 |
| | 0–10 | 346 | 1431 | 937 | 341 | 36 | 91 |
| | 0–20 | 424 | 1462 | 1000 | 332 | 33 | 98 |
| | 0–40 | 344 | 3448 | 983 | 575 | 59 | 100 |
| The foot of the slope, depression (n = 11) | 0–4 | 44 | 2654 | 598 | 722 | 121 | 44 |
| | 0–10 | 278 | 3115 | 973 | 775 | 80 | 80 |
| | 0–20 | 594 | 3428 | 1127 | 805 | 71 | 95 |
| | 0–40 | 616 | 3448 | 1171 | 795 | 68 | 100 |

*Mean value.

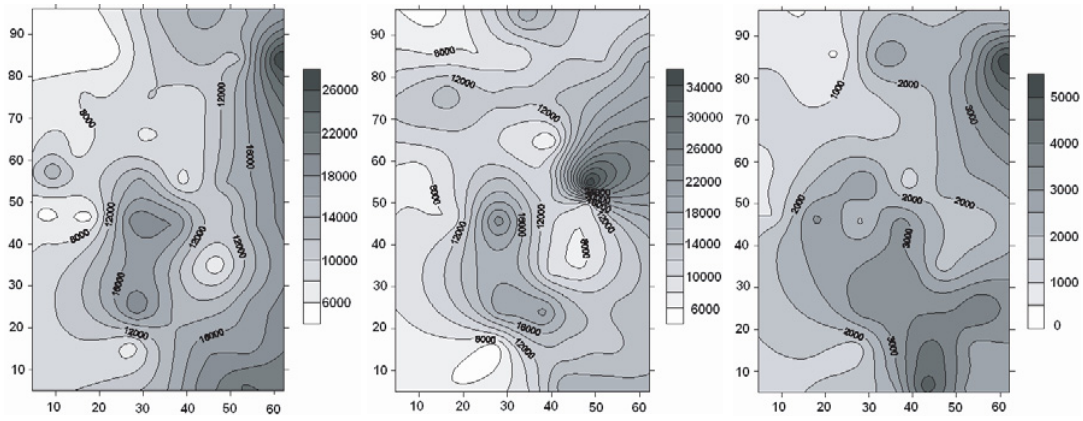


**Figure 4.** $^{137}Cs$ contamination field in mosses upper green (1) and lower brown (2) parts and in tree fall debris (Bq/kg, sampling grid – 10 m).

The absence of significant surface erosion in woodlands allow suggest that the observed spatial structure reflect the $^{137}Cs$ mainly short- but also medium-distance lateral and vertical migration with water masses in topsoils including lessivage both related to meso- and micro-scale relief and sloping features at the given soil granulometry. Even gentle sloping may cause redistribution of trace elements due to water migration since water is most sensitive to inclination. Observed structure seem to show the resulting vector of dynamic interaction between the spatially conservative but unclosed local phytogeochemical cycle and water regime and mass migration.

The study proved that spatial distribution of radioisotopes could be treated as geochemical fields of the matter dispersed in space and particular landscape components believed to mark the result of the modern dynamic migration of trace elements in natural landscapes. The concentration values of $^{137}Cs$ measured at particular points of space cannot be treated as independent (random values) due to the finite amount of the released radioisotopes and the regular mass migration processes in landscapes.

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