MAPPING OF RADIONUCLIDE CONTAMINATION IN RUSSIA

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Compilation and publication in 1998 of the "Atlas of radioactive Contamination of the European part of Russia, Belarus and Ukraine" [1] is the main result of developing a new scientific branch of subject cartography – **radioactive contamination mapping**. The maps of ^{137}Cs terrain contamination were published repeatedly after the Chernobyl accident with the storage of new information [2,3,4,5,6,7,8]. The Atlas [1] shows a complete data collection on the radioactive contamination, and it is based on the theoretical background of spatial providing of this original information.

An important feature of radionuclide mapping is the unity of principles of compiling information on the contamination, based on combination of the airborne-gamma-spectrum survey data, and laboratory methods of the soil samples analyses. Another considerable feature of the Atlas maps is the use of a differential approach to the ways of computer mapping of different parts of the contaminated areas depending on their contamination levels, relief, extent of forest cover and ploughing.

In the initial period of the Chernobyl accident the radioactive contamination of the territory was essentially due to the release of short-lived radionuclides which later lost their ecological significance. In a year after the accident the radiation situation on the largest part of the European territory of the Former USSR was determined by long-lived isotopes of Caesium: ^{137}Cs and ^{134}Cs, and in three years - by ^{137}Cs. Therefore much attention was given to mapping of environmental contamination with just ^{137}Cs, special state finance was provided for investigations and making state maps of ^{137}Cs contamination.

In accordance with the Russian Law "On special protection of persons exposed to radiation from the catastrophe at Chernobyl NPP", the isoline 1 Ci/km^2 (37 kBq/m^2) for ^{137}Cs is the lower threshold for establishing privileges for the population. The law specifies the dwelling zone with a privileged socio-economic status 1-5 Ci/km^2 (or 37-185 kBq/m^2); the dwelling zone with the right of settling out (5-15 Ci/km^2 or 185-555

kBq/m^2); zone of obligatory settling out (more than 15 Ci/km^2 or more than 555 kBq/m^2). The annual dose of internal and external irradiation of the population must not exceed 1 mSv (100 mrem). Similar laws have been adopted in Ukraine and Belarus.

In the European part of the Former USSR 800.000 complete spectra of airborne-gamma-spectrum survey (by the European part of Russia 440.000 spectra were used) were obtained and used. A special ground test accompanying the airborne-gamma-spectrum survey was carried out at several thousands of points. A great amount of work was carried out for obtaining the information on the contamination levels in settlements. In Russia 11457 settlements in 23 administrative regions were inspected from 1986 to 1995. For the whole post-accident period about 90000 soil samples were taken which were subjected to the gamma-spectrometric and partly to radiochemical analysis. Basing on these data it has been established that the levels in excess of 1 Ci/km^2 or 37 kBq/m^2 are observed in 4581 settlements. The calculations revealed that the excess of the permissible irradiation level in 1 mSv (0.1 mrem) can be expected in 527 settlements in 1995 [1].

The relative mean-square deviations in the ^{137}Cs contamination values taken from the airborne-gamma-spectrum survey and ground data did not normally exceed 40%, being as a rule, 20-25%. The systematic discrepancy were taken into account in mapping.

On the territories with the contamination levels exceeding 0.2 Ci/km^2 (7.4 kBq/m^2) the deposition due to the Chernobyl accident are notoriously present. This contamination was recorded on an area of 1.011.400 km^2, which constitutes about 23% of the European part of the former USSR. It should be pointed out that the territories of Russia, Ukraine and Belarus with the contamination levels above 1Ci/km^2 (higher than 37 kBq/m^2) constitute 145.300 km^2, i.e. about 3.3% of the European territory of the ex-USSR.

The summary data on the distribution of the cesium-137 contaminated areas over the whole European part of the former USSR (1995) are listed in Table 1 and shown on Fig.1.

Table 1. Cesium-137 contaminated areas of the Former USSR European territory, thousand km^2 (1995)

Region	Contamination level, kBq/m^2 (Ci/km^2)						
	3,7 -7,4 (0,1-0,2)	7,4-19 (0,2-0,5)	19-37 (0,5-1)	37-190 (1-5)	190-555 (5-15)	555-1850 (15-40)	>1850 (>40)
European part of Russia	877,5	365,3	112,8	48,8	5,72	2,1	0,3
Ukraine	142,8	186,8	72,5	37,2	3,2	0,9	0,6
Belarus	14,8	67,2	26,4	29,9	10,2	4,2	2,2
Moldavia	10,4	23,0	0,15	0,06	-	-	-
Baltic countries	81,6	11,9	-	-	-	-	-
TOTAL:	1127,1	654,2	211,9	115,9	19,1	7,2	3,1

Region	Contamination level, kBq/m^2 (Ci/km^2)						
	3,7 -7,4 (0,1-0,2)	7,4-19 (0,2-0,5)	19-37 (0,5-1)	37-190 (1-5)	190-555 (5-15)	555-1850 (15-40)	>1850 (>40)
Note: The total area of the European part of the Former USSR is 4.45 million km^2							

The Atlas of radioactive Contamination of the European part of Russia, Belarus and Ukraine [1] contains five sections.

Small-scale view maps (1:10 000 000 and 1:2 500 000) of the three states territory are presented in the first section, which is the most contaminated area as a result of the Cernobyl accident, as well as maps of the territories, contaminated mainly by global fallout of nuclear explosions products before the CNPP accident.

The second section shows maps (at 1:500 000 scale) of radioactive terrain contamination in the close-in zone of the Chernobyl NPP. The results of the γ-spectrum measurements, as well as those of the radiochemical analyses of the soil samples, provided a possibility to present a number of maps on the terrain contamination by the following radionuclides: ^{137}Cs (the main widespread long-lived artificial radionuclide); ^{134}Cs, ^{144}Ce, ^{106}Ru, ^{90}Sr, and transuranium radionuclides. These data were received in the framework of the indivisible programme, carried out in the Former USSR.

The third section shows maps at 1:1 000 000 scale of 19 subjects of the Russian Federation where the levels of Caesium-137 contamination over 1 Ci/sq.km were observed as of August 1995.

The fourth section presents the maps at 1:500 000 scale with increased radioactive contamination zones in European Russia with levels of 1 Ci/sq.km., showing details of their inner structure. The maps of this section are the base to ensure Russian Federation Law “On social protection of citizens affected by radiation as a result of Chernobyl NPP disaster”.

The fifth reference section presents materials and maps complementing the maps content of the main sections of the Atlas, as well as helping to make a preliminary ecological interpretation.

^{137}Cs contamination of lands - is the important social-ecological problem, formed after the Chernobyl accident. The conclusions on the average Caesium-137 contamination levels in the natural (climatic) zones and physico-geographical regions of Russia were received. The integral data on the areas with the different contamination levels of the natural and anthropogenic geosystems of East-European plain are shown in the Table 2.

The contaminated areas with the levels above 4 kBq/m^2 on the Eastern-European Plain are shown in the Table 2. The Eastern-European Plain include all territory of Belarus, Ukraine (without the Carpathian Mountains and the Crimea peninsula) and European

part of Russia (without the Caucasus and Ural Mountains). Let us note, that the lands with the high contamination levels above 555 kBq/m^2 are situated only on the territories of Belarus, Russia and Ukraine in the geographical zone of the mixed forests. Based on the Lows of these 3 countries, the areas with the same levels are named “non-living zone”, where the landuse has not now the industrial mean and is reduced to the minimum. People, refused of the evacuation from these territories, must be provided completely by the imported food-stuffs. Unfortunately, this requirement is not carried out everywhere caused by the modern economic crisis, and people continue to cultivate your gardens and take the domestic animals.

Table.2. ^{137}Cs contamination of lands on the East-European Plain, surface in 10^3 km^2

Geographical zone	^{137}Cs, kBq/m^2						
	>1480	555-1480	185-555	40-185	20-40	10-20	4-10
	Land use is interdicted		Land use is reduced	agricultural products are cheecked	Lands with the small contamination		
Mixed forest zone	3,03	6,99	15,9	58,1	83,5	147	86,1
Broad-leaved forest zone	-	-	2,3	30,7	42,6	85,6	23,5
Forest-steppe zone	-	-	0,53	24,1	60,5	233,8	26,9
Steppe zone	-	-	-	3,04	23,6	83,9	61,2
Dry steppe zone	-	-	-	0,15	0,24	11,6	33,7
	3,03	6,99	2,83	116,1	210,4	561,9	231,4

About 80 % of the landuse areas in the mixed forest geographical zone is occupate by the forests, lagely used by population to gather berries, mushrooms, herbs etc. The large river valleys with the water-meadows (about 10 % of the total landuse area) are used by tradition as pasture (milk stock-breeding), and the arable lands occupate comparatively small area (also about 10 %) - for the cultivation of the potatoes, flax and rye to satisfy local needs of the population. The small area of the arable lands is the consequence of the predominance of the unfertile soils - podzols on the fluvio-glacial sands.

The same type of landuse is prevailing also on the area of 15900 km^2 with the ^{137}Cs levels 185-555 kBq/m^2 in the same geographical zone. Here the reception by somebody of the effective equivalente dose of 1-5 mSv/year is possible in the very unfavourable conditions. The state cheecking of the agricultural products is carrying out here, the population has a system of social privileges. The main recommendation to the population is a rejection of the forest food.

The landuse on the territories with the ^{137}Cs contamination levels 40-185 kBq/m^2 was not changes after the accident. The population has some privileges, and the selective checking of the agricultural products shows, that anybody can’t receive the dose of more than 1 mSv/year.

The considerable influence of the Chernobyl accident on the lands is in the broad-leaved forest geographical zone. The spots with the ^{137}Cs levels more than 555 kBq/m^2 are very small areas (<500 m^2) within the large territories of 2300 km^2 with the levels 185-555 kBq/m^2. The levels of 40-185 kBq/m^2 are measurated on the area of 30700 km^2. These areas are prevailed in Russia (Briansk, Kaluga, Riazan and Penza districts) and in Ukraine (Kiev, Chernigov district). The type of landuse here is another, than the landuse in the mixed-forest zone. The sod-podzolic and sod forest soils are more fertile than podzols for cultivation of the rye, wheat, buckwheat and potatous for the export in the another regions of the country. So, about 60 % of lands are arable here, more than 20 % of lands are used as pasture on the water- and dry-meadows (meet-misk stock-breeding). The forests occupate only about 10-20 % of landuse and are the recreation significance. Here the cheecking of the milk and potatous is important: these products are in a base of people food and these products are exporting to the another regions of the country.

The same type of landuse is in the forest-stepp geographical zone, where 530 km^2 is contaminated with the ^{137}Cs levels of 185-555 kBq/m^2 and 24100 km^2 - with the levels of 40-185 kBq/km^2. The main contamination spots in this zone - are the Plavsk caesium spot (Russia, Tula district), Belaya Tzerkov and Vinnitza caesium spots (Ukraine, Kiev and Vinnitza districts). Here the area of arable land is bigger than in the forest zone caused by the prevailing of the nothern kinds of Chernozems, very fertile. The agricultural products, as wheat, sugar-beet, fruits, have the export meaning. So, the cheecking of the exportaion products and of the main products of the people food (milk, vegetables) is important here.

Some areas with the ^{137}Cs contamination levels of 40-185 kBq/m^2 are situated in the stepp and dry-stepp geographical zone. The main spots are in Ukraine. The arable lands occupate about 80 % of these areas. Here the wheat, sugar-beet, maize, sunflower are cultivating on the very fertile Chernozems. All these products have the exportation meaning. But, the radionuclide transfer from soil to plants is not significant in the Chernozems. So, it is not important to cheeck all products cultivating in theses areas, but the selective cheecking is very usefull.

The **evaluation of the radioactive contamination** was studied using the forecasting mapping of assessments for 60-years period after the Chernobyl accident (60 years is a period of twice half-life of the ^{137}Cs). The change of the areas with the different contamination levels for European part of Russia is shown in the Table 3. The forecasting mapping is based on the knowledge on the radioactive decay and on the models of soil erosion.

Table 3. Change of the areas with the different 137Cs contamination levels, km2

Year	Areas (km2) with the different levels of 137Cs, kBq/km2			
	>1480	555-1480	185-555	37-185
1986	580	2070	5780	56260
1996	310	1900	5330	48980

2006	40	1280	3540	26260
2016		850	2780	18920
2026		625	2700	15040
2036		190	2340	12500
2046		100	1500	10930

In developing of the content of the Atlas a **map of Caesium contamination of territory of Russia (including Ural region and Siberia)** were worked out in 1999. It is aimed to the presentation of the modern radioactive contamination state, summarising the Caesium deposition resulted from the nuclear tests (mainly during the 1950-60s), the Chernobyl accident of 1986, as well as the accidents and events having regional consequences (Industrial Enterprise "Mayak", Totsk military exercises, Krasnoyarsk-26, Tomsk-7, etc.). The data on the ^{137}Cs were received after the Chernobyl accident on the Asia part of Russia in 130.000 of points. The 1000 measurements were used for the mapping in the valley of the Techa-river and 3500 mesurements - in the valley of Enisey-river.

The results of 3 last years were received under the RFBR support (projects # 98-05-64512 & 00-05-64936). The investigation of the modern spatial regional peculiarities of the Caesium-137 contamination of Russia on the end of the XX century is completed. The author copy of the map of Caesium-137 radioactive contamination of Russia on 1999 was created and compiled in isolines of the terrain contamination density, Ci/sq.km, in the scale 1:4.000.000. The geo-infomative radiation data-base of the Institute of Global Climate and Ecology was modernized and supplemented in the result of the work with the retrospective information of 60-70th years. The conventional boundary of the Chernobyl accident influence was mapped by the isoline of 0,1 Ci/sq.km on the Russian plain and by the isoline of 0,075 Ci/sq.km on the Eastern-Siberian low plain, the Eastern Chernobyl pattern is established to the altitude of Krasnoyarsk.

The total amount of Caesium-137, deposited on the territory of Russia, on the end of 90th of XX century is estimate as 1,53 x 10^{9} Ci, 58 % of this amount forms the global contamination from the atmospheric nuclear explosions, uniformly distributed over the territory, 38 % of this amount is a result of depositions after the accident on the Chernobyl NPP (about 90% of this amount is deposited on the European part of country), 3,6 % - is the result of the accidents and the another events in the region of the Industrial Complex «Mayak» in the Southern Ural, and 0,4 % - is the result of the release of the liquid radioactive waste into the Enisey-river by the Krasnoyarsk Mining-Chemical Industrial Complex. The contribution of the another sources of contamination was estimated as < 0,1 %.

The peculiarities of the spatial distribution of the Caesium-137 contamination of the territory of Russia caused by the Chernobyl accident were described by the geostatistic methods of data analyse. The exponent decrease of the contamination levels along the Eastern Chernobyl pattern were revealed

$$Q(r) = 29 \cdot \exp(-r/60) + 1 \cdot \exp(-r/450).$$

The two most widespread dimensions of the contamination spots were established: with the radius of 50-80 km and 400 km. The quantity of the spots smaller than 80 km reduces on the big distance from the place of the accident (more than 700 km). The first spot's dimension is manly connected with the diameter of the current of contaminated air, transported to the big distances, the second dimension - with the typical regions of precipitations. The conclusion on the main influence of the meteorological aspects, but not of the dimension and nature of the released particles, on the forming of the regional and global contamination fields was drawn.

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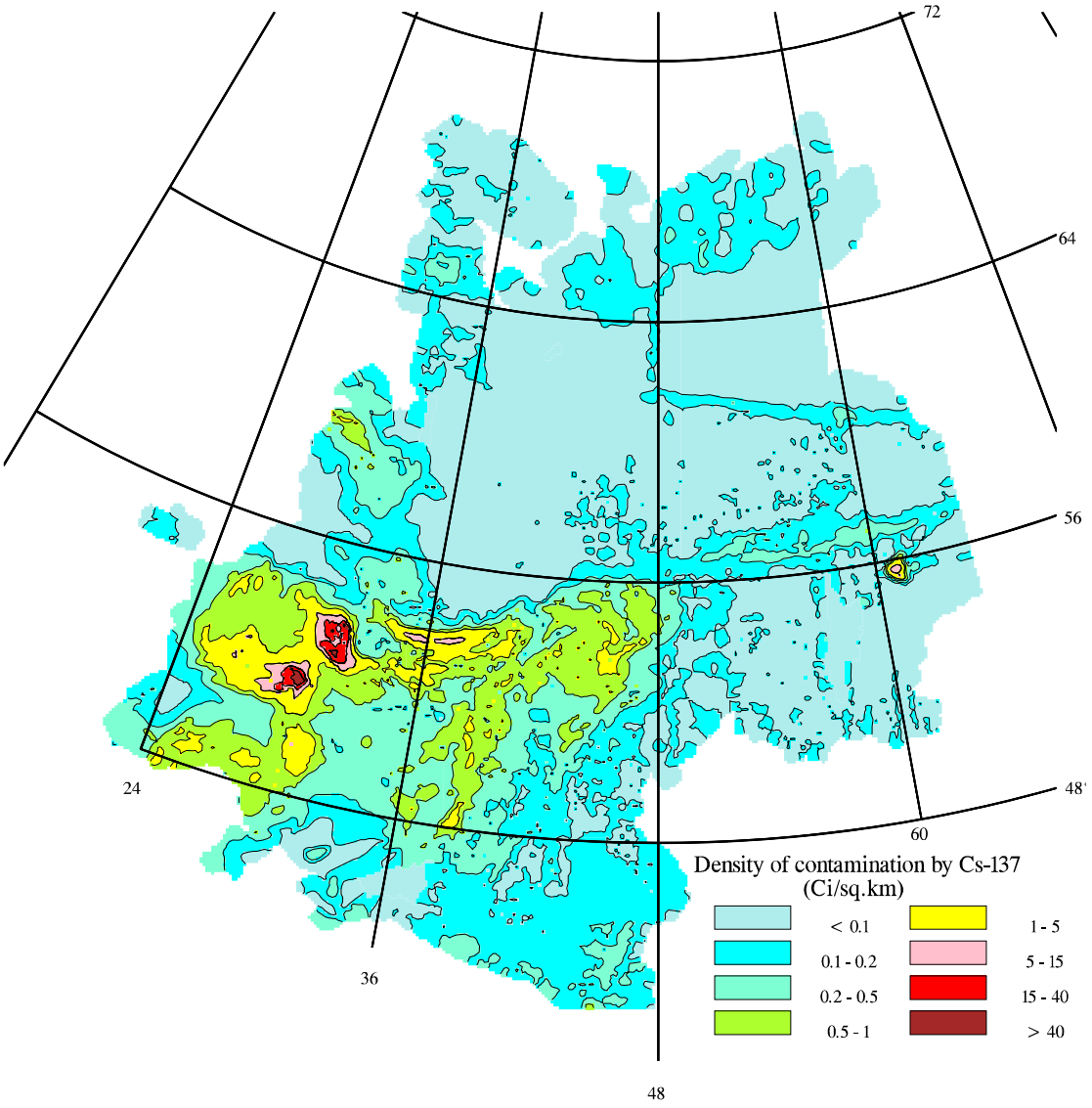

Fig.1. Caesium-137 radioactive contamination of the European part of Russia, Belarus and Ukraine on the end of XX century
(by Izrael Yu.A., Kvasnikova E.V., Nazarov I.M., Stukin E.D. & Sudakova E.A., 2001)