MAPPING OF DOSE-RATE OF GAMMA-IRRADIATION BY ^{137}Cs OVER THE EARTH SURFACE FOR THE TERRITORY OF RUSSIA

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^{137}Cs is a most widespread long-lived dose-forming artificial radionuclide. The contamination by this radionuclide formed mainly in result of nuclear explosions in the atmosphere of 50-60th and of Chernobyl accident of 1986. Dose-rate of gamma-irradiation by ^{137}Cs is one of the important parameters described the radioactive contamination field. The calculation of dose-rate values, formed by ^{137}Cs, is necessary, because the dosimetric devices can measure only a summary dose-rate from all sources of gamma-irradiation, including the irradiation by natural radionuclides and cosmic irradiation. Methodology of the selective dose-rate estimation was reliably worked out in Russian science, but the attention to the dose-rate mapping increases in the modern time. The geo-informative dose-rate mapping is based on the data on the ^{137}Cs deposition and on the study of the vertical distribution of this radionuclide in soils. Maps of the calculative dose-rate of gamma-irradiation by ^{137}Cs give a possibility to estimate risk of the artificial radioactivity in the environment in comparison with the data on the dose-rate of natural radionuclides. Map of ^{137}Cs contamination of territory of Russia, prepared in 1999 by our team, give a basis to the mapping of the dose-rate of gamma-irradiation by ^{137}Cs over the earth surface for the territory of Russia. The following results of this mapping were received. At the main area ^{137}Cs forms very low dose-rate levels on the height of 1 m over the surface - $<1 \times 10^{-8}$ Sv/hour; at the areas of caesium spots with considerable contamination levels of 40-200 kBq/m^2 (there are large agricultural areas with the permanent population) – 3×10^{-8} -30×10^{-8} Sv/hour – depending of the migration the of this radionuclide in soils. The such dose-rate levels, as a rule, cannot form a dangerous external dose exposure to population. The map of all Russia was compiled for the first time thanks to the financial support of RFBR N 00-05-64936.

The unity used for indicating of the gamma-irradiation dose rate in Russia is 10^{-6} Roentgen/hour (R/h) = 10^{-8} Sv/hour.

The multi-crystal and mono-crystal γ-spectrometers are using during the airborn-γ-spectrum survey to receive data on the spatial ^{137}Cs distribution on the large territory.

Simultaneously the dose-rate of the total gamma-irradiation is measured by this device by determining the account rate in the large diapason of energies (0,2-3,0 MeV). The scale is usually calibrated on the Radium standards. The results (in the situation, when the artificial radionuclides are absent) permit to estimate the dose-rate of gamma-irradiation by the natural radioactive elements with a good precision. At the same time a considerable error in the dose-rate estimation can appear, when the artificial radionuclides (the energetic contain of which differs from the Radium spectrum of gamma-irradiation) are present in the γ-spectrum. A calibration of γ-spectrometers over the sites with the uniformly distributed radionuclides, when the dose-rate is measured by the certificated dosimeters, cannot help, because dosimeters measure the total effect formed by the contribution of the natural radionuclides, artificial radionuclides and by the ionized component of the cosmic rays. So, the reliable measurement of dose-rate of the artificial radionuclides during the airborne-gamma-spectrum survey using the detectors on crystalls NaI(Tl) is not possible. So, it is need to calculate the dose-rate values.

For the pellicle source of gamma-irradiation the dose-rate P on the height h is calculated using the ***integral function*** $\varepsilon_i(x)$ [2,3,4]:

$$P = 2\pi K_г \cdot Q[A_1\varepsilon_1(\mu_1 h) + (1 - A_1)\varepsilon_1(\mu_2 h)] \qquad (1)$$

when $K_г$ = 3,10 (R/hour)/(mCi/cm^2) - γ-constant; A_1 – a middle quantity of acts of irradiation diffusion in the endless environment; ε_1(x) = -ε_1(-x) - ***integral function of the first kind***; h – height over the point of dose-rate estimation, g/cm^2; $\mu_1 = \mu(1+a_1)$ = 0,0788 см^2/г и $\mu_2 = \mu(1+a_2)$ = 0,0667 см^2/г – coefficients of the decrease of irradiation, corrected on the photons reproduction; Q – radionuclide inventory, mCi/cm^2. A numerical values are shown for ^{137}Cs [3].

A simplified variant of this function (1) is known:

$$P = KQ[\varepsilon_1(\mu h) + b / a \cdot \exp(-a_1 \mu h)] \qquad (2)$$

when K = 1,95 (10^{-6} R/hour)/(mCi/cm^2), a=0,86, b/a=1,50, μ=0,078 cm^2/g. For the height 1 m h = 0,128 g/cm^2, and μh=0,02. It is possible to estimate using the function (2), that 10,8 x 10^{-6} R/hour on the height of 1 m over a pellicle is corresponded to 1 Ci/km^2 (37 kBq/m^2).

A real vertical distribution of radioactive elements in soil differs from the pellicle immediately after deposition. The 2 main kinds of vertical profiles are choosing for estimation of dose-rate for mapping. There are exponential profile for the undisturbed soils and uniform profile for the agricultural soils. The first of these profiles is determined by the vertical migration index β:

$$q(z) = Q\ \beta\ \exp(-\beta z)$$

where q(z) – a radionuclide concentration in soil, Bq/g; z – a depth, g/cm^2; Q – radionuclide inventory, Bq/cm^2; β - vertical migration index, cm^2/g.

A uniform profile due to the cultivated soils is described by the depth value L, from which the radionuclide is unirormly distributed.

Coefficients for the dose-rate estimation in concidering a ^{137}Cs depth distribution were calculate using the method of numerical integration. Dose-rate values, formed by ^{137}Cs gamma-irradiation come from the fine soil layers on the variable depth, were integrated based on the exponential or uniform model of ^{137}Cs depth distribution. Dose-rate value for each thick layer of soil was calculated using functions (1) and (2). Calculation of dose-rate over the soil surface of 1 m was carried out for the exponential distribution with the index from 5,0 to 0,03 cm^2/g and for the uniform distribution of ^{137}Cs inventory in the soil layer from 0-0,2 to 0-20 cm. The calculation data, corresponded to the ^{137}Cs inventory of 37 kBq/m^2, are presented in the table 1. The errors of dose-rate calculation are < 10 %.

Let us note, that the roughness of soil surface influences considerably on the value of dose-rate near the soil surface. The decrease of dose-rate due to the roughness of soil is comparative to the decrease due to the Caesium vertical migration in soils. So, basing on the our experience for estimation the dose rate over the agricultural lands of plains it is need to take a value of the disturbed layer greater to 1-3 cm than in the real situation.

Table 1. Dose-rate of gamma-irradiation of ^{137}Cs on the height 1 m over the soil, when the ^{137}Cs inventory is 1 Ci/km^2 (37 kBq/m^2) and the vertical distribution of this inventory in the soil in exponential

Index of vertical distribution cm^2/g	Dose-rate of gamma-irradiation of ^{137}Cs on the height 1 m over the soil 10^{-6}R/hour	
	(1)	(2)
5,000	9,869	8,870
2,000	8,946	7,909
1,000	8,029	6,992
0,667	7,410	6,390
0,500	6,935	5,939
0,400	6,548	5,578
0,333	6,220	5,276
0,250	5,683	4,789
0,200	5,253	4,406
0,143	4,590	3,826
0,100	3,883	3,220
0,067	3,105	2,565
0,050	2,592	2,137
0,040	2,226	1,834

0,033	1,951	1,606

Table 2. Dose-rate of gamma-irradiation of ^{137}Cs on the height 1 m over the cultivated soil, when the ^{137}Cs inventory is 1 Ci/km^2 (37 kBq/m^2) and the vertical distribution of this inventory in the soil in uniform

Cultivated layer cm	Dose-rate of gamma-irradiation of ^{137}Cs on the height 1 m over the soil 10^{-6} R/hour	
	(1)	(2)
0,2	10,742	9,712
0,5	9,908	8,820
1,0	9,031	7,919
1,5	8,424	7,314
2,0	7,955	6,855
2,5	7,570	6,484
3,0	7,242	6,172
4,0	6,701	5,666
5,0	6,262	5,262
7,0	5,570	4,641
10,0	4,805	3,072
15,0	3,914	3,213
20,0	3,287	2,692
25,0	2,818	2,306
30,0	2,454	2,009

The rules of calculative mapping of dose-rate of ^{137}Cs gamma-irradiation on 1 m over the soil surface based on the use of a big massive of data on the soil ^{137}Cs contamination, received by the airborn-γ-spectrum survey, are followings.

1. Initial ^{137}Cs map must be compiled as a raster.

2. All soil samples "layer by layer" from the territory of mapping must be grouped on the value of the exponential index β. We propose to choose the 3 groups of landscapes with the different type of ^{137}Cs vertical distribution in soils: with $\beta<1$ cm^2/g (a high vertical migration); $1\leq\beta\leq2$ cm^2/g (a middle and the more widespread type of vertical migration); $\beta>2$ cm^2/g (a small vertical migration).The regionment of the different conditions of the vertical migration must be made based on the landscape map. A new geo-informative coverage of landscapes region boundaries and of the vertical migration index β must be created.

3. The geo-informative coverage of land-use must be created (the data on the depth of the cultivated layer, if this information is accessible, must be include in the data-base.

4. A spatial grading of ^{137}Cs inventory values with some types of depth distribution must be made:

- Data on the natural landscapes with a high ^{137}Cs vertical migration in soils;
- Data on the natural landscapes with a middle ^{137}Cs vertical migration in soils;
- Data on the natural landscapes with a small ^{137}Cs vertical migration in soils;
- Data on the cultivated lands (additional groups of data must be formed, if the different depth of soil cultivation is known).

5. Calculation of values of dose-rates on the base of ^{137}Cs data in concidering a kind of depth distribution of this radionuclide must be carried out using the matrix algebra rules. The coverage named "dose-rate of ^{137}Cs gamma-irradiation" must be compiled as a raster.

6. Map of dose-rate of ^{137}Cs gamma-irradiation in isolines must be compiled using one of interpolation methods.

Map of ^{137}Cs contamination of the European part of the former USSR permits to compile, using ^{137}Cs geo-infromative coverage, a map of dose-rate of ^{137}Cs gamma-irradiation [1]. This map was compiled using the described rules. This map shows, that ^{137}Cs forms the dose-rate <1 x 10^{-6} R/hour on the widespread territories; ^{137}Cs forms a dose-rate 3-30 x 10^{-6} R/hour within the contamination spots with ^{137}Cs levels 1-5 Ci/km^2 (the dose-rate levels are in connection with the depth distribution of ^{137}Cs in soils), but these dose-rate levels, as a rule, cannot bring to the external dose of man >0,1 R/year.

Calculative maps of dose-rate of ^{137}Cs gamma-irradiation on the height of 1 m are present in the Atlas [1] for each of 19 more contaminated district of Russia. The picture of isolines of the dose-rate repeat not the isolines of ^{137}Cs spatial distribution. Maps of dose-rate are more intricate, that the ^{137}Cs maps, because they are based on the landscape and landuse structure of territory. On some maps you can see, that the dose-rate isolines outline the river valleys or the forests on the inter-rivers.

Maps of dose-rate of ^{137}Cs gamma-irradiation on the height of 1 m are present as an example on the figures 1 a and b for the Penza region of Russian plain for the two dates: 1986, May and 2000 (fig.1 a – Penza Caesium spot on the Middle Volga High plain, 1986, May; fig.1 b - – Penza Caesium spot on the Middle Volga High plain, 2000). The population, leaving on these territories, were shocked by journalists used the radiation monitoring data after the Chernobyl accident in their articles without explanation the radiobiological and ecological mean of these data. Figures show, that the ^{137}Cs dose-rate levels are lows at the modern time, as at the period immediately after the Chernobyl accident. The natural radionuclides of soil (U, Th, ^{40}K) form the dose-rate about 5 x 10^{-6} R/h in the Penza region. A cosmic radiation gives an addition about 3 x 10^{-6} R/h. So, the figures show, that the contribution of the natural radioactivity to the integral dose-rate on the majority of the investigated territories give more than 50 %.

References

1. Atlas of radioactive contamination of the European part of Russia, of Belarus and Ukraine. /Ed. By Yu.A.Izrael, - Moscow: State Service of Geodesy and Cartography, 1998.

2. Kogan R.M., Nazarov I.M., Fridman Sh.D. Principles of γ-spectrometry of the environment. Moscow: Atomizdat, 1972.

3. Kimel' L.R., Mashkovich V.P. Protection against the ionizing irradiations. Moscow: Atomizdat, 1972.

4. Boltneva L.I., Brendakov V.F., Malakhov S.G., Nazarov I.M., Chirkov V.P. Depth distribution of ^{137}Cs in the some kinds of soils of the USSR in 1967 and a dose-rate of gamma-irradiation. Radiobiology, Vol.13, 1971.

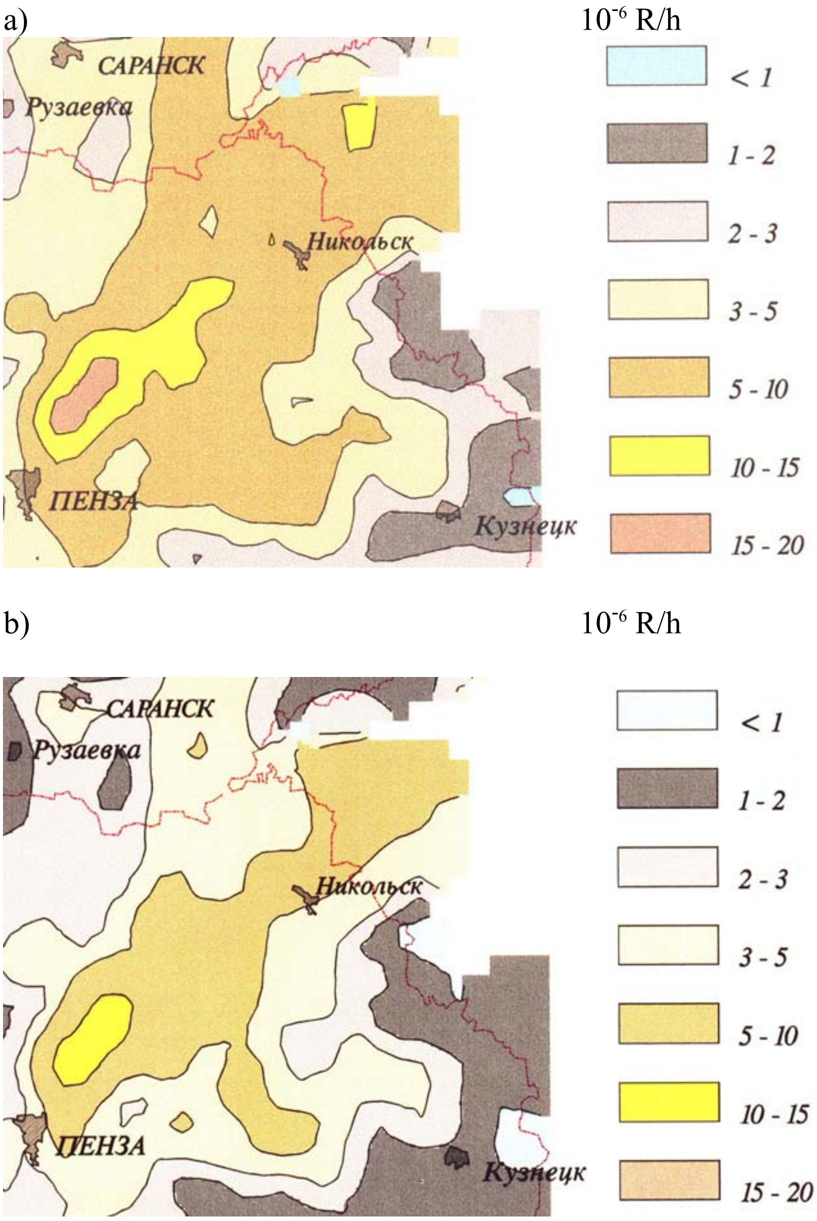

Fig.1. Change of the gamma-irradiation dose-rate field from a) May of 1986 to b) May of 2001 (15 years after the Chernobyl accident) for Penza Caesium spot (Middle-Volga High Plain)