14. Официальные данные по оценки численности населения на 1 января 2013 года. База данных показателей муниципальных образований. Официальный сайт Федеральной службы государственной статистики Брянской области. – http://www.gks.ru/dbscripts/munst/munst15/DBInet.cgi, дата обращения 28.05.2014

15. Атлас Брянской области. Главное управления геодезии и картографии при совете министров СССР, 1976. 32 с.

16. Оценка средних годовых эффективных доз облучения критических групп жителей населенных пунктов Российской Федерации, подвергшихся радиоактивному загрязнению вследствие аварии на Чернобыльской АЭС: Методические указания (МУ 2.6.1.2003-05). – М.: Минздрав России, 2005. / Оценка доз облучения населения Российской Федерации вследствие аварии на Чернобыльской АЭС: Сб. офиц. метод. документов. Издание третье.– СПб. – 2011. – 20 с.

17. Единые санитарно-эпидемиологические и гигиенические требования к товарам, подлежащим санитарно-эпидемиологическому надзору (контролю). – 2-е изд., спр. – М.: Федеральный центр гигиены и эпидемиологии Роспотребнадзора, 2010. – Приложение 3. – С. 175.

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Поступила: 19.11.2014 г.

Analysis of the dynamics of aggregative transfer factors of cesium-137 to mushrooms after the chernobyl accident as a basis for construction predictive models

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In the present paper shows the analysis of the available data on levels of concentrations and aggregative transfer factors (TFag) of ^{137}Cs from soil to different species of mushrooms growing in the contaminated areas of the Bryansk region, which is used to improve predictive models for estimation the expected levels and the expected values of TFag and planning of further research.

Keywords: *Bryansk region, radioactive contamination, food products of forest origin, ^{137}Cs, aggregative transfer factor(TFag), the half-period, internal exposure dose, GIS technology.*

In spite of the fact that nearly 28 years passed after the Chernobyl accident, decreasing of the soil surface activity levels occurs very slowly. For today total square of the territory of Bryank region contaminated over 37 kBq/m^2 (1 Cu/km^2) is more than 6682 km^2 (square kilometers). [1]. Due to the high level of residual radioactive contamination of large areas of Russia after the Chernobyl accident a long-term forecast of radioactive contamination of forest food products, contributing to the internal dose of the population living in these areas, is an topical task. In forest ecosystems mushrooms are the main dose-forming components in the food chain [2-4] (especially for critical groups such as inhabitants of contaminated areas, forestry workers, hunters and their families).

Currently, the main contribution to the dose (up to 80%) began to give natural foodstuffs, mainly mushrooms, which are traditional food of rural residents of contaminated areas [5-8].

For long-term forecast of the behavior of radionuclides in forest ecosystems, it is necessary to have a reliable mathematical model of the dynamics of the aggregative transfer factors (TFag), depending on the time and other factors that may effect on the TFag. The main parameters effecting on the TFag from soil to mushrooms are: – soil surface activity; – physical-chemical properties of the soil (exchangeable potassium content, pH, concentration of exchangeable potassium (K_2O), concentration of the organic substance (C), the sum of exchange bases(S), cation exchange capacity (CEC), the contents of alphitite and soil moisture); – Mushroom species specificity [9,10].

Because mushrooms are largely determined the dose of internal exposure of human and serve as indicators of the bioavailability of ^{137}Cs, it is necessary to clarify the parameters describing the rate of change of accumulation of ^{137}Cs depending on the time passed since the accident. This model will help to predict the expected average levels of contamination of mushrooms, the range of most probable values for the individual species of mushrooms, to identify areas where pollution levels mushrooms will be located within established standards, to give a more precise assessment of the contribution of mushrooms in individual and collective doses.

The objective of this article is to analyze the existing data to refine the parameters of the predictive model of estimates of the expected levels of ^{137}Cs in different species of mushrooms and the expected values of the TFag, as well as de-

velop a plan for further survey.

In accordance with the objective of the research was solved the following tasks:

1. To conduct a statistical analysis of the available data, to identify common patterns and to group the data for development of the schema for planning of survey;

2. To develop a base map for spatial data analysis.

3. To develop a plan for field studies for verification of the forecast model and the specification of its parameters.

The object of the study is concentration of 137Cs in mushrooms collected in the territories of the Bryansk region with elevated levels of radioactive contamination after the Chernobyl accident, the radionuclide accumulation patterns and changes in the levels of accumulation over time.

The main part of data that formed the basis of this work is the data obtained in the Institute of radiation hygiene for the period from 1987 to 2007 (courtesy of the laboratory of radiochemistry), as well as our own data obtained in 2008 and 2009 [11, 12].

As the main study area was chosen Bryansk region, its south-western regions, the most affected by the Chernobyl accident in 1986.

Statistical processing (evaluation sample mean, standard deviation) and a graphical representation of dynamic dependencies, the frequency distribution is carried out by means of MS Excel, and in some cases using Mathlab 2008b.

Cartographic representation of the data was carried out using mapping package Mapinfo 7.0, which were built by separate map layers – the boundaries of administrative units; – The location of settlements; – Landscape features; – Soil types; – Levels of radioactive contamination of the soil; – Isolines expected levels of 137Cs in mushrooms.

The subsequent combination of separate map layers allowed us to estimate the possible impact on the results of studies of individual factors, such as soil type, the level of contamination, distance fromsettlements to forests and other.

Isoline contouring of the levels possible concentration of ^{137}Cs in mushrooms was carried out by Mathlab 2008b in specially developed in the laboratory of ecology of NIIRG computer program.

The level of radioactive contamination of 137Cs is the key parameter that depends on the concentration of radionuclide in vegetation, agricultural food products, and, of course, mushrooms. Data on the soil surface activity in the affected regions of Russia annually transferred to the Institute of radiation hygiene by Rosgidromet.

Figure 1 shows maps of radioactive contamination of the Bryansk region in different periods of time [13].

Figure 2 selection areas of radioactive contamination, constructed according to Rosgidromet for 2014 through specially designed programs developed in the laboratory of ecology and transferred to MapInfo within the boundaries of the administrative map of the Bryansk region.

MapInfo means were calculated areas of radioactive contamination in selected on the map ranges of soil surface activity. The results of calculation for 2014 showed that the total area of the Bryansk region contaminated by more than 1 Cu/km2 is 6682 km2. Despite the fact that since the accident at the Chernobyl nuclear power plant was almost a half-life (137Cs – 30 years), reduced levels of surface contamination of soil is very slow. Forecast calculations in levels of soil surface activity in South-Westernpart of the Bryansk region, between now and 2056 are shown in Table 1.

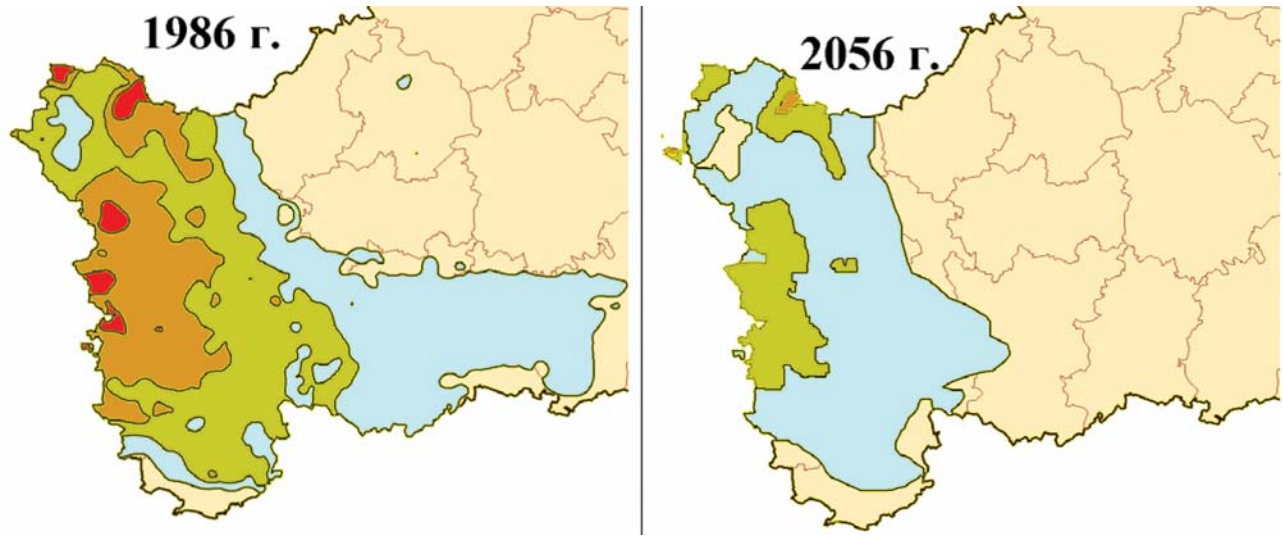

Figure 1. The soil surface activity with ^{137}Cs in the South-Western part of the Bryansk region in 1986 and 2056, Legend: red – >40 Ku/km^2; orange – 15-40 Ku/km^2; green – 5-15 Ku/km^2; blue – 1-5 Ku/km^2.

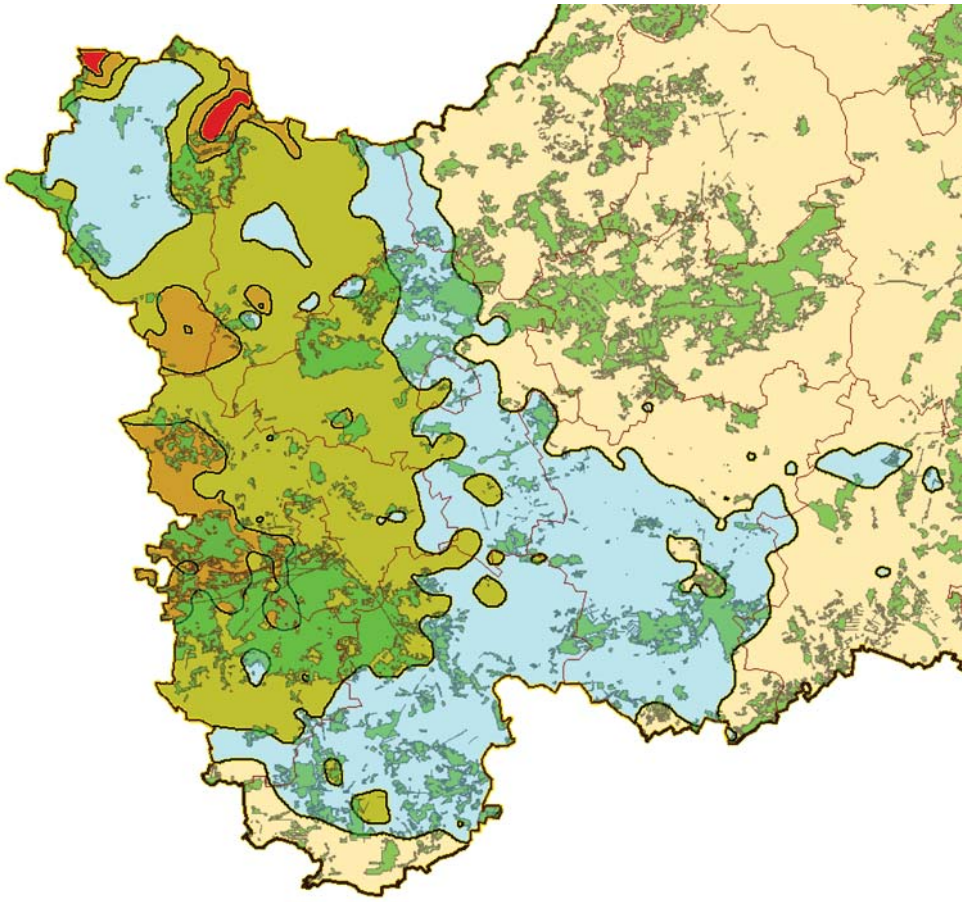

Figure 2. Characteristics of radioactive contamination in the Bryansk region ^{137}Cs in 2014
Legend: Red -> 40 Ku/km^2; Orange – 15-40 Ku/km^2; Green – 5-15 Ku/km^2; Blue – 1-5 Ku/km^2.

Table 1

Soil surface activity investigated areas of the Bryansk region in 2014 and 2056 years soil surface activity ^{137}Cs,

Cu/km^2(kBq/м^2)	areas of contamination, 2014, km^2	areas of contamination, 2056, km^2
1-5 (37-185)	3090	4651
5-15 (185 – 555)	2936	872
15-40 (555-1480)	615	42
>40 (>1480)	41	0
Total:	6682	5565

It should be noted that, according to forecasts of radioactive contamination of the investigated areas of the Bryansk region in 2056, there will be lower levels of surface contamination, but the area of contamination will continue to be extensive- 5565 km^2. In the area of radioactive contamination will still get large forest areas, therefore, the problem of high concentration of 137Cs in mushrooms will be relevant in 2056. Due to the fact that the mushrooms are traditionalfood stuff, the population until 2056 will receive additional internal exposure dose on their consumption.

The mostly affected due to the Chernobyl accident are South-Eastern arrears of the Bryansk region: Krosnogorky, Gordeevsky, Klintzovsky, Novozybkovsky Zlinkovsky and Klimovsky. 306 027 inhabitants live in this territory, 167 685 from them are urban inhabitants and 306 027– rural (table 2).

Table 2

The population of the South-Western districts of the Bryansk region on January 1, 2013 [14]

District	Population		Total
	Urban	Rural	
Krosnogorky	5 610	6 862	12 472
Gordeevsky	3 077 (г. Гордеевка)	11 223	11 223
Klintzovsky	69 593 (г. Клинцы)	19 539	19 539
Новозыбковский	40 773 (г. Новозыбков)	11 784	11 784
Zlinkovsky	8 067	4 230	12 297
Klimovsky	13 444	15 533	28 997
Total:	167 685	138 342	306 027

One of the factors that affect the TFag of 137Cs from soil to mushrooms is a type of soils. For the analysis of soil types was used raster soil map of the Bryansk region at a scale of 1:1500 000 [15]. Using a set of tools MapInfo were built a separate layers of map of the soil types of studied districts of the Bryansk region (figure 3).

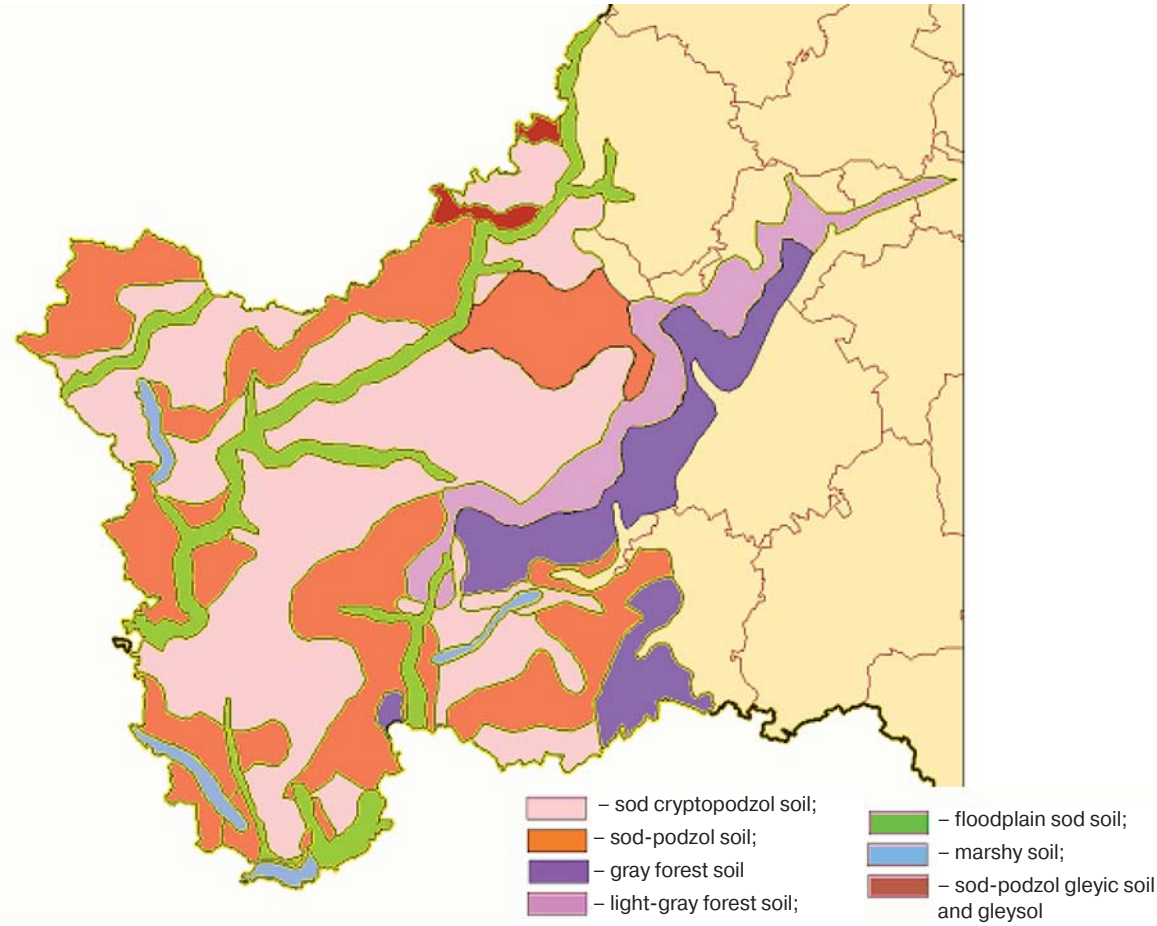

Figure 3 Distribution of types of the studied soils in South-Western districts of the Bryansk region

Figure 3 shows that among all the soil types characteristic for the Bryansk region on its contaminated areas the most prevalent types are sod podzol soil (light and medium podzolic) and a small amount of floodplain sod soil located in the floodplains, where, as a rule, mushrooms practically does not grow. Sod-podzol soils are characterized by low content of physico-chemical properties (concentration of exchangeable potassium (K2O), concentration of the organic substance (C), the sum of exchange bases(S), cation exchange capacity (CEC), the contents of alphitite (Clay) and soil moisture) that contributes to the increase of TFag of 137Cs from soil to mushrooms, consequently, the increase of the contribution to the dose of internal exposure of the population through the consumption of mushrooms growing on these soils.

The intensity of mushroom collecting is often related to the distance from the forest, so it is important to understand the extent to which residents have the opportunity to plan visits to forests. It is clear that the more distance to the forest, the harder it is to schedule a visit. On the other hand, in the nearest woods, even on highly contaminated areas the temptation of mushroom collecting is significant. From figure 3 it can be seen that part of the settlements surrounded by forests, and the number of the settlements are removed from the forests.

Extensive radioactive contamination after the Chernobyl accident by 137Cs led to a significant increase of its concentration in natural food products, in particular, mushrooms. We have to take into account that collection and harvesting of mushrooms is traditional both for urban and rural population of Russia. [16]. Studying of the long-term dynamics of TFag 137Cs in different species of mushrooms showed that the decrease in the rate of accumulation is very slow (period of semi-purification is tens of years), with minor variations over the years, this is due to the accumulation of 137Cs in the mycelium of mushrooms, which can hold up to 40 % of 137Cs migrating deeper into the soil profile throughout his life (10-20 years). [2-3]. Thus, the mushrooms in the long-term perspective will play a significant role in the formation of internal exposure dose as an additional source of human exposure [6-8, 11-12].

Figure 5 presents the data on the TFag 137Cs to mushrooms collected in the Bryansk region after the Chernobyl accident from 1986 to 2009 and shows a trend of decreasing of TFag depending on the time elapsed after the accident Noteworthy is wide variation of TFag, which is unlikely due to the type of soil as prevalent mainly sod-podzol soils.

Noteworthy is wide variation of TFag, which is unlikely due to the type of soil as prevalent mainly sod-podzol soils.

The rate of drawdown of TFag for the entire data, obtained in the period from 1986 to 2008 is characterized, without taking into account radioactive decay, a period of 17 years.

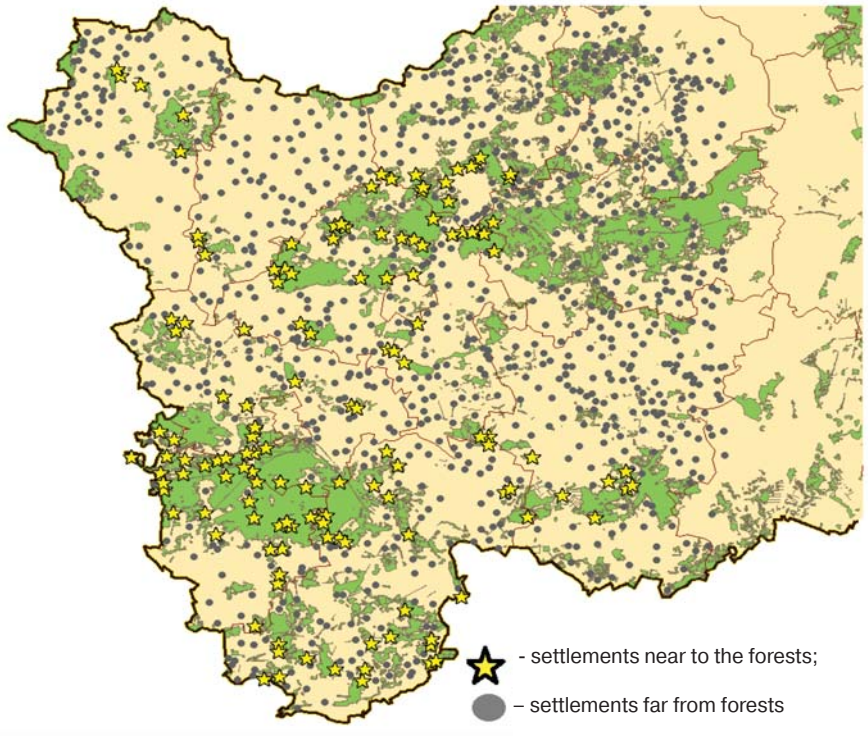

Figure 4. Base map of the settlements of the South-Western districts of the Bryansk region, located at different distances from forest

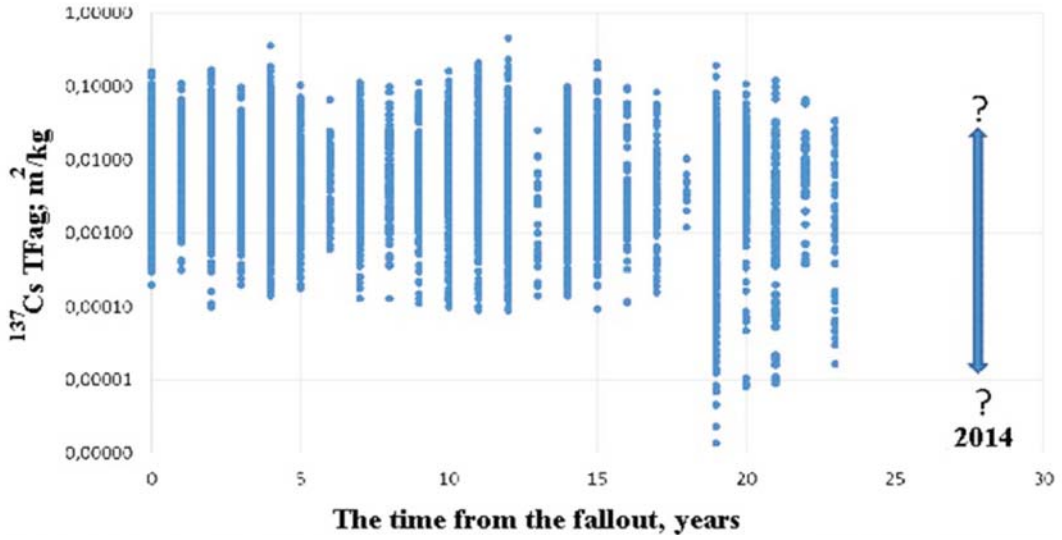

Figure 5. Characteristic of the data on ^{137}Cs aggregated transfer factors from soil to mushrooms, in Bryansk region beginning with 1986

Analysis of the frequency distributions of logarithms of 137Cs aggregative transfer factors from soil to mushrooms according to data obtained in the period from 1987 to 2009 demonstrates that TFag for mushrooms with tubular hymenophore (lilac columns) (№3), for mushrooms with lamellar hymenophore (red columns) (№2) and for mushrooms as a whole (№1) lay in a very wide diapason (figure 6).

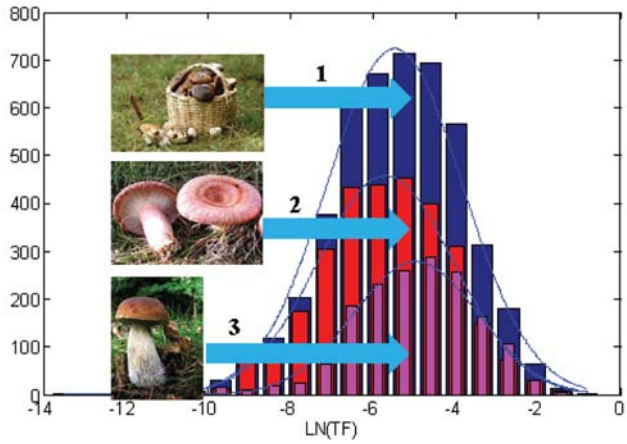

Figure 6. Frequency distribution of the logarithm of the TFag ^{137}Cs in different species of mushrooms according to NIIRG and own data for the period from 1987 to 2009
Remark: 1 –mushrooms with tubular hymenophore and lamellar hymenophore; 2 – mushrooms with lamellar hymenophore; 3 – mushrooms with tubular hymenophore.

The average values of TFag for mushrooms with tubular hymenophore (purple columns), higher than with lamellarhymenophore (red columns). This is mainly due to the fact that the mycorrhiza (mycelium) of the mushrooms with tubular hymenophore (all Boletus: Xerocomus, Boletus badius, Suillusbovinus,Suillusluteus) is located in the deeper mineral soil horizons, where ^{137}Cs with the time elapsed after the accident, partly moved through vertical migration. In addition, some kinds of mushrooms prefer moist growing conditions, which also contributes to increased transfer of ^{137}Cs from soil to plants, with which they form a symbiotic relationship.

The rate of decline of TFag separately for mushrooms with tubular and lamellar hymenophore is shown in Figure 7. The figure shows that the rate of decline of TFagfor mushrooms with a tubular hymenophore is 15 years and more, while for mushrooms with lamellar hymenophore more than 100 years. If you select all of the analyzed species of mushrooms with lamellar and tubular hymenophore only mushrooms belonging to the group highly accumulated such as Xerocomus chrysenteron, Boletus badius, Suillusbovinus, Suillusluteus, Lactariusnecator, Lactariusrufus, Lactariustorminosus, the TFag for this group will be 2 times higher in comparison with the mushrooms with lamella hymenophore and 3 times higher – mushrooms with tubular hymenophore.

Due to the fact that mushrooms are not only a product of personal consumption, but also spread through trade networks (canned, frozen) for mushrooms are establish certain standards. According to the standards of the joint sanitary-epidemiological and hygienic requirements to goods and products subject to sanitary and epidemiological supervision [17] the tolerance levels of ^{137}Cs in mushrooms should not exceed 500 Bq/kg in fresh and 2500 Bq/kg in dried mushrooms.

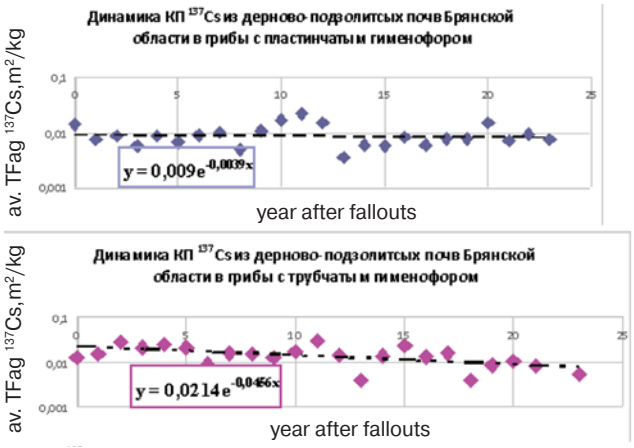

Figure 7. Dynamics TFag ^{137}Cs sod-podzol soils of the Bryansk region in mushrooms with lamellar and tubular hymenophore

Knowing the approximate average values of TFag for different species of mushrooms can be evaluated at any level of soil surface activity content of the radionuclide in the mushrooms will comply with the standard or exceed it in a certain number of times. Using information about the levels of soil surface activity in the settlements by 2014, it is possible to estimate the possible level of cesium in the mushrooms. An extensive data of Rosgidromet on soil surface activity with ^{137}Cs was allowed to construct the isolines of levels of exceeding the standard of radionuclide concentration in contaminated areas. These isolines were constructed for the conservative values of the TFag, taken equal to 0.01 m^2/kg for all species of mushrooms (figure 8).

Isolines in Figure 8 shows the areas of exceeding of the allowable level of ^{137}Cs in mushrooms with different types of hymenophore collected in forest areas characterized by different levels of soil surface activity.

The levels of possible contamination of mushrooms can also be evaluated by the expected levels of internal exposure dose due to the consumption of mushrooms.

Based on the data about the lev ls of soil surface activity and the expected values of the TFag it is possible to calculate predicted dose of internal exposure of the population living in areas with different levels of soil surface activity due to the consumption of mushrooms.

The model parameters estimation of effective doses of internal exposure due to intake of radionuclides by mushrooms, include the volume activity of radionuclides in them, diets, dose coefficients linking the intake of radionuclides into the body and effective dose of internal exposure [16].

According to the statistical data of a population survey on the effective annual consumption of wild mushrooms older residents of the midland of the European part of Russia, the average consumption of mushrooms by population living in villages, towns and cities with a population less than 100 thousand people is from 8 to 10 kg/year [16].

The average annual committed internal dose (D) due to the consumption of mushrooms is calculated by the formula (1) in accordance with the Guideline [16]:

$$D = m\ (kg/year) * \sigma\ (Bk/m^2) * TFag\ (m^2/kg) * dk\ (mSv/Bk) \quad (1)$$

where: D – committed dose of internal exposure due to the consumption of mushrooms, mSv;

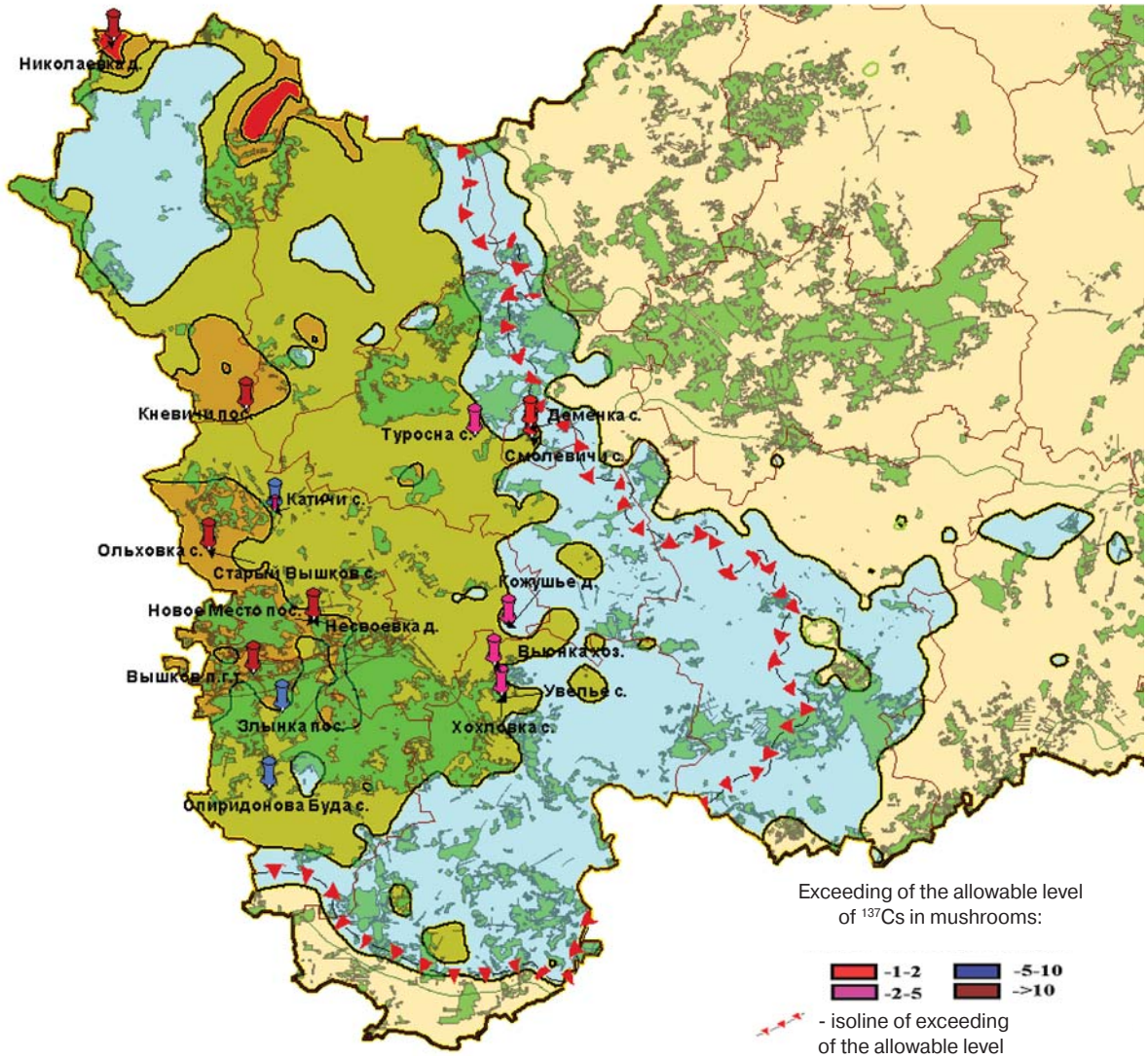

Figure 8. Isoline of exceeding of the allowable level of ^{137}Cs in mushrooms Note: the change in the soil surface activity is indicated by the following gradation color: red – >40 Cu/km^2; orange – 15-40 Cu/km^2; green – 5-15 Cu/km^2; blue – 1-5 Cu/km^2. Symbols of different colors mark forest areas, within which grow mushrooms exceeding of the concentration of ^{137}Cs in number of times.

m – annual effective consumption of mushrooms taken equal to 10 kg/year;

σ – soil surface activity of study area, Bq/m^2;

TFag – aggregative transfer factors of ^{137}Cs from soil to mushrooms, taken equal to 0.01 m^2/kg;

dk – dose coefficient for the food ways of ^{137}Cs in the human body; for adult men and women made an average value of dk=1,3*10-5 mSv/Bq.

The results of the estimates are presented in table 3, which shows that when the average consumption of 10 kg of mushrooms per year, collected in the areas with soil surface activity c in the places of residence of the population from 15 to more than 40 (555-1480) Cu/km^2 (kBq/m^2) – dose of internal exposure due to the consumption of mushrooms can reach 0.75 and more than 2 mSv per year.

Table 3

The results of the estimates of committed dose due to the consumption of mushrooms

soil surface activity ^{137}Cs, Cu/km^2 (kBk/m^2)	Dose, mSv/year
1-5 (37-185)	0,05-0,25
5-15 (185 – 555)	0,25-0,75
15-40 (555-1480)	0,75-2
>40 (>1480)	> 2

As a result of this work was carried out statistical analysis of the available data on aggregative transfer factors of ^{137}Cs from soil to different species of mushrooms and revealed the following regularities: aggregative transfer factor to mush-

rooms with tubular hymenophore, mushrooms with lamellar hymenophore and in all the mushrooms are in a very wide range. The slowdown in accumulation occurs in all the mushrooms very slowly, with the half-period for all mushrooms – 17 years without taking into account radioactive decay; The rate of reduction aggregative transfer factor to mushrooms with tubular hymenophore higher than for mushrooms with lamellar hymenophore, because of the depth of the mycelium; the analysis conducted to assess potential internal dose of the population from the consumption of mushrooms growing in areas with different levels of soil surface activity shows that the average consumption of 10 kg of mushrooms per year, collected in the territories of residence internal dose due to mushrooms can reach more than 2 mSv per year.

Were developed multi-layered geographic information basis for planning of the field studies including the administrative boundaries of districts, settlements, levels of soil surface activity, types of soils, forests, areas with exceeding of the permissible levels of ^{137}Cs in lamellar and tubular mushrooms collected in forests characterized by different levels of soil surface activity;

With the use of spatial data representation was developed plan of field studies on verification of the predictive model and the specification of its parameters. It is planned to explore the 22 forest sites of the 7 South-Western districts of the Bryansk region, located on sod-podzol soil t with different levels of soil surface activity of ^{137}Cs (from 0.3 to 60.8 Cu/km^2).

Preliminary work, including cartographic analysis of data on the soil surface activity, soil types, aggregative transfer factors of 137Cs from soil to different species of mushrooms allows to draw some conclusions concerning the problem of building a predictive model on the basis of which it is possible to predict over what period and on what areas the levels of contaminations of mushrooms will not exceed established standards.

1. To build a predictive model it is necessary to conduct additional field studies to clarify the reduction level of aggregative transfer factors of Cs to different species of mushrooms, because reliability of presented in the article estimates is low by the significant scatter of the data. The preferred region for this study is the Bryansk region.

2. In the upcoming field studies need to compare the expected levels of accumulation of Cs in mushrooms at different levels of soil surface activity with the actual that will help to assess the reliability with which to work the predict model.

3. It is necessary to clarify what extent the soil type and other factors can affect on aggregative transfer factors and research the possibility of building of models, providing more reliable data.

List of references

1. Data of Gidromet for 2013.
2. A.I. Shcheglov, O.B. Tsvetnova. Mushrooms-bioindicators of industrial contamination // Monthly scientific journal of the Russian Academy of Sciences "Priroda", 2002. No. 11. p. 39-46.
3. Tsvetnova O.B. Long-term dynamics of accumulation of 137Cs and 90Sr by higher mushrooms / O.B. Tsvetnova, A.I. Shcheglov, N.D. Kuchma // Soil Science: Bulletin Of Moscow University, 2004. Series 17, No. 3. – p. 43 – 48.
4. Zarubina N.E. Radionuclide contamination of higher mushrooms as a result of the accident at the Chernobyl NPP / N.E. Zarubina, V.V. Trishin // Radioactivity after nuclear explosions and accidents: Proceedings of the international conference, Moscow, 5-6 December 2005, Volume 3.
5. Impact of contamination on human and agricultural ecosystems. The dose of the population due to contamination from nuclear explosions and accidents. Strategies and countermeasures. Under the editorship of academician Y.A. Izrael. p. 19-24.
6. Shutov V.N. The role of mushrooms and berries in the formation of the internal dose of the population of Russia after the Chernobyl accident / V.N. Shutov, G.J. Bruk, M. V. Kaduka, [and other] // ZNiSO, 1998. No. 2. – M.: FZGSEN Ministry of health of Russia. p. 19-23.
7. Shutov V.N. Dynamics of radioactive contamination of natural food products after the accident at the Chernobyl NPP / V. N. Shutov, M. V. Kaduka, G. J. Bruk [and other] // ZNiSO 2003 – No. 4. – M.: FCGSEN Ministry of health of Russia. p. 9-12.
8. Kadoka M.V. The role of mushrooms in the formation of the internal dose of the population after the Chernobyl accident. Radioactivity after nuclear explosions and accidents / M.V. Kaduka, V.N. Shutov, G.J. Bruk [and other] // Proceedings of the international conference (Moscow, 5-6 December 2005). St. Petersburg: Gidrometeoizdat, 2006, V. 3. – p. 230-239.
9. Ipatiev V.A., Baginsky V.F., Bulavik I.M. and other. Woods. Chernobyl. People. Forest ecosystems after the Chernobyl disaster: status, prognosis, behavior of the population, ways of rehabilitation. Gomel, 1999.
10. Perevolotsky A.N. Predicting assessment of 137Cs in forest mushrooms and berries in the area of the regular fallouts of the Belarusian NPP / A.N. Perevolotsky, T.V. Perevolotskaya // Radiation and risk, 2013. Vol. 22, No. 2. p. 61-66.
11. Shilova K.V. Radioactive contamination of food in distance period after the Chernobyl accident / K.V. Shilova, M.V. Kaduka, V.N. Shutov // abstracts of the international scientific – practical conference, September 15-17, S.-Petersburg. "Hygienic aspects of radiation safety of the population in areas with high levels of radiation", 2009. p. 73-74.
12. Shilova K.V. Contamination of 137Cs and 90Sr of the forest foodstuffs in the Bryansk region // Scientific journal "Radiation Hygiene" V. 3 No. 2, 2010. p. 55-61.
13. The Atlas of current and predict effects of the accident at the Chernobyl nuclear power plant in affected territories of Russia and Belarus (ASPA Russia-Belarus) / Ed. by Y. A. Izrael, I.M. Bogdzewicz. Moscow.-: Fund "InfoSphere" – NIA – Nature; Minsk: Belkartografia, 2009. – 140 p.
14. Official data on the estimated population on 1 January 2013. The database of indicators of municipalities. Official site of the Federal service of state statistics of the Bryansk region. Source address: http://www.gks.ru/dbscripts/munst/munst15/DBInet.cgi date 28.05.2014
15. Atlas of the Bryansk region. The main office of geodesy and cartography under the Council of Ministers of the USSR, 1976. 32 p.
16. Assessment of average annual effective doses to the critical groups of the population of the settlements of the Russian Federation exposed to radioactive contamination due to the accident at the Chernobyl NPP: MU 2.6.1.2003-05. – M.: Russian Ministry of Health, 2005. / Assessment of doses to the population of the Russian Federation due to the accident at the Chernobyl NPP: Book of offic. method. documents. Third edition.- SPb. – 2011. – 20 p.
17. The uniform sanitary and epidemiological and hygienic requirements for goods subject to sanitary-epidemiological supervision (control).- 2nd ed.. – M.: Federal center of hygiene and epidemiology, 2010.- Annex 3. – p. 175.