

The exposure for populations of the Russian Federation due to the Chernobyl accident and main directions of further work in the coming period

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The article discusses the issues associated with the current exposure of the population of 14 regions of Russia due to the Chernobyl accident, identified tasks facing Rosпотребнадзор today. The article describes criteria and requirements for ensuring the mechanism of the transition of settlements from the conditions of a radiation accident to the public normal conditions.

Key words: Chernobyl, radiation dose to the critical group, cesium-137.

One of the most large-scale radiation accidents in the world – the accident at the Chernobyl NPP in 1986 led to radioactive contamination of significant areas of the European part of the Russian Federation and neighboring countries, covering almost 60000 km² in 14 regions of Russia. Contamination of these regions with cesium-137 is more than 1.0 Cu/km². Currently there are more than 4 thousand settlements in zones of radioactive contamination in the Russian Federation. There are live more than 1.5 million people.

Bryansk region is the most heavily contaminated: South-Western areas, there are areas with contaminated soil above 40 Cu/km². Tula, Kaluga and Orel region are suffered heavily too. In addition to these four areas in 10 regions of Russia there are settlements located in zones of radioactive contamination.

In the field work carried out since 1986 in the contaminated areas by specialists of the Research Institute of Radiation Hygiene, completed more than 250 000 measurements on the content of cesium in the bodies of inhabitants with whole-body counters (WBC), thousands of measurements of radionuclide content of iodine in the thyroid gland and measurements of individual doses external radiation (using thermoluminescence dosimetry – TLD), and tens of thousands of measurements of gamma background in different settlements and their areals, located in the zones of radioactive contamination. The obtained data allowed to estimate the actual doses of the population (as is known, the dose is the most objective measure of assessment of the actual radiation public exposure), and constantly adjust the protective actions strategy.

Already in 1986 according to results of our fields researchs and data of radiation monitoring were substantiated offers on measures of radiation protection of the affected population of the former USSR: to reduce internal exposure dose was recommended to limit the consumption of some local food products; to reduce the dose of external gamma radiation was recommended engineering decontamination of certain settlements. These measures have allowed approximately halve the accumulated dose in the population. And, especially significant dose reduction was observed in the most contaminated settlements, where protective measures, of

course, carries stricter and started earlier. The effectiveness of this activity is demonstrated in Fig. 1.

Evidently, that in the more contaminated areas where protective measures have been carried out more actively, the average dose of internal exposure of the population, normalized per unit density of soil contamination with cesium-137 is much lower than in areas with lower levels of radioactive contamination, where protection measures were rather limited.

In accordance with current Russian radiation safety Standards NRB-99/2009, in the normal conditions, the average annual dose to the critical groups of the population should not exceed 1 mSv/year.

Relating to living conditions in contaminated by the Chernobyl accident areas under the average annual effective dose to the critical group of the population AAEDcrit, in accordance with the current guidance documents should be understood average dose in 10% of the inhabitants of the settlement, with the largest (maximum) in comparison with the rest, individual doses.

It was found, that the ratio of the average dose of external exposure of the critical group to the average dose of external exposure of all the inhabitants of the settlement is 1.8. The ratio of the average dose of internal exposure of the critical group to the average dose of internal exposure of all inhabitants of the settlement is 1.8.

After the Chernobyl accident affected territories were divided into the zones of radioactive contamination. The assignment of the settlement to a particular area is determined by the level of soil contamination with cesium-137 and value AAED90 – 90% quantile of AAED, where AAED – the average annual effective dose from external and internal exposure (AAED = AAEDext + AAEDint), which could get people in the conditions of the active measures for radiation protection and self-limitations in the consumption of local food.

Table. 1 shows the distribution of settlements of various regions of the Russian Federation referred to the zones of radioactive contamination according to value of the average annual effective dose of the inhabitants (AAED90) in 2014.

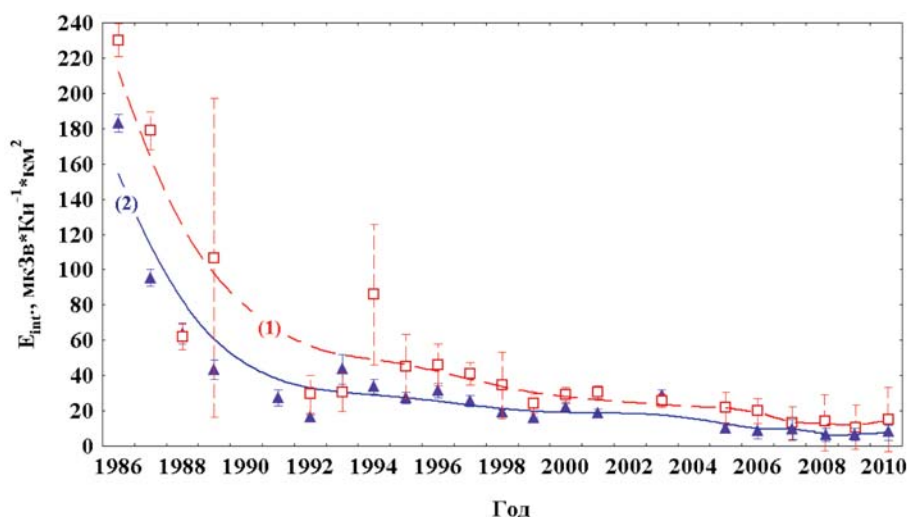


Fig. 1. The dynamics of the normalized of soil surface activity with cesium-137 (σ_{137}) of the internal exposure dose E_{int} of the population of the Bryansk region: (1) – 5–15 Cu/km²; (2) – > 15 Cu/km²

Table 1

Distribution of the settlements in different regions of Russia by the value of AAED90

Region	Quantity of the settlements	The range of doses, mSv/y				Maximum
		< 0,3	0,3–1,0	≥ 1,0	≥ 5,0	
Belgorod	79	79	–	–	–	0,091
Bryansk	978	417	285	276	8	8,0
Voronezh	79	79	–	–	–	0,11
Kaluga	353	262	91	–	–	0,91
Kursk	168	168	–	–	–	0,22
Leningrad	29	29	–	–	–	0,12
Lipetsk	75	75	–	–	–	0,13
Mordovia	16	16	–	–	–	0,16
Orel	964	952	12	–	–	0,47
Penza	35	35	–	–	–	0,13
Ryazan	320	320	–	–	–	0,22
Tambov	6	6	–	–	–	0,060
Tula	1306	1257	49	–	–	0,58
Ulyanovsk	5	5	–	–	–	0,10
TOTAL:	4413	3700	437	276	8	8,0

Unlike AAED and AAED₉₀, when evaluating AAED_{crit} used methods, thanks to which are determined the actual, not the estimated doses.

The most reliable data about the actual levels of public exposure can be obtained, first of all, when conducting a large-scale radiation-hygienic examinations of the settlements, including direct instrumental measurements (WBC, TLD, radiochemical and gamma-spectrometric analyses of food samples).

Results of the expeditionary surveys of the dozens settlements of the South-Western districts of the Bryansk region (we carried out these surveys from 2005-2014) allowed to instrumentally determine the actual average annual effective dose of internal exposure of the population

($AAED_{fact}^{int}$ and its critical groups ($AAED_{crit}^{int}$) and compare them with the results of calculations of $AAED_{int}^{int}$.

It turned out that the estimates of $AAED_{fact}^{int}$ are usually much too high compared with the actual levels of exposure of the inhabitants, as it ignores the effect of the protective measures and self-limitation in the consumption by the population of local foods on the dose.

Obviously, for a preliminary assessment of $AAED_{fact}^{int}$ and $AAED_{crit}^{int}$ (without surveys of the settlements) it is enough to multiply the calculated value of $AAED_{int}^{int}$ by a certain factor, F, which characterizes the efficiency of the countermeasures and self-limitations of the population in the consumption of local food, relative unit

The most expedient to determine the factor F as the ratio of the results of instrumental evaluation of $AAED_{fact}^{int}$ (for example, according to the WBC-measurements) to the results of the evaluation of $AAED^{int}$. As the volume of countermeasures and self-limitation of the population depend primarily on the of soil surface activity by cesium-137 (σ_{137}), the latter determines the value of F .

We were able to establish a functional connection F with σ_{137} :

$F = 0,12 + \exp(-0,0051 \sigma_{137})$, Rel. unit, if the $\sigma_{137} > 74 \text{ kBq/m}^2$ ($> 2 \text{ Cu/km}^2$);

$F = 0,8$, Rel. unit, if the $\sigma_{137} < 74 \text{ kBq/m}^2$, where $[\sigma_{137}] = \text{kBq/m}^2$.

Ultimately, it was allowed to perform appropriate calculations and to assess $AAED_{crit}$ for all 4413 settlements of the Russian Federation referred to the zones of radioactive contamination due to the Chernobyl accident.

Now, after 28 years after the accident, public dose due to the accident at the Chernobyl nuclear power plant significantly decreased.

In 13 of the 14 affected by the Chernobyl accident subjects of the Russian Federation there is no settlement, where the average radiation dose to the critical group of the population due to the accident at the Chernobyl nuclear power plant exceed 1.0 mSv/year . Only in 299 settlements of the Bryansk region the average annual dose of the critical groups of the population still exceeds $1,0 \text{ mSv/year}$. The maximum value of average annual doses to critical groups of residents ($AAED_{crit}$) is 5.9 mSv/year , and for all residents of the settlements as a whole ($AAED_{fact}$) of 3.1 mSv/year . However, the maximum dose that could get people in the absence of active measures for radiation protection and self-limitations in the consumption of local food ($AAED_{90}$) is 8.0 mSv/year .

It is interesting to compare the distribution of the settlements by the values of $AAED_{90}$, $AAED_{crit}$ и $AAED_{fact}$. As an example, in table 2 presents the results of such comparative assessments for 978 settlements of Bryansk region, located in the zones of radioactive contamination.

All the data suggests that the problem of the conditions for the normal life for inhabitants of the contaminated areas remains extremely relevant in the present time.

The main regulatory document on this issue is the Federal Law of May 15, 1991 № 1244-1 «On social protection of citizens exposed to radiation as a result of the Chernobyl disaster», extend to the territory, which, since 1991:

- average annual effective equivalent dose for the population exceeds 1 mSv (millisievert) per year (0.1 rem per year) – dose that could get the people in the absence of active radiation protection measures and self-limitation in the consumption of local foods;

- soil surface activity with caesium-137 exceeding 1 Cu/km^2 .

Exceeding of the annual dose $AAED_{90}$ 1 mSv per year at the present time there is in 276 settlements of the Bryansk region. The maximum value of the dose – 8.0 mSv/year is observed in Zaborie village of Krasnogorsk district of the Bryansk region. People in 8 settlements of the Bryansk region get dose $AAED_{90}$ more than 5.0 mSv/year at the present time.

Thus, by the dose criterion at the present time we can talk about the conservation status of the settlements of zones of radioactive contamination only in the South-Western districts of the Bryansk region.

At the same time, according to the criterion of soil contamination (greater than 1 Cu/km^2) to the zones of radioactive contamination can be attributed to the present, more than 2 thousand settlements.

As is known, the public dose is the most objective quantitative and qualitative indicator of the real assessment of radiation effects on the inhabitants of the contaminated areas.

According to scientific forecast made on the 70-year period after the Chernobyl accident (equal to the average life span of one generation) expected gradual decrease in the average annual effective dose and to the 2056 year public dose more than 1 mSv/year will remain only in 4 villages of the Bryansk region (at its maximum value – $1,4 \text{ mSv/year}$).

At the same time, growth of the accumulated exposure to the population is continuing. Calculations of average accumulated effective doses over years 1986-2010 to inhabitants of the settlements of the Russian Federation referred to the zones of radioactive contamination, showed that in 112 villages of the Bryansk region average accumulated effective dose from 1986 to 2010 of inhabitants equals or exceeds 70 mSv (with a maximum of 260 mSv). For settlements all other regions of Russia, radioactively contaminated due to Chernobyl fallout, average cumulative doses do not exceed and will not exceed 70 mSv in the future, and they will be significantly lower than this value.

By the forecast in 2056 in 126 settlements average effective dose of the inhabitants accumulated from 1986 to 2056 years will be equal to or exceed 70 mSv (at the maximum expected value – 340 mSv). These settlements are also in the Bryansk region.

Table 2

Distribution of the settlements of Bryansk region by the value of annual dose

Parameter	The range of doses, mSv/y				
	< 0,3	0,3 – 1,0	> 1,0	including, > 5,0	Maximum
$AAED_{90}$	417	285	276	8	8,0
$AAED_{crit}$	351	328	299	2	5,9
$AAED_{fact}$	654	287	37	–	3,1

The main trends for further work in the coming period:

Currently, the most important task of the Federal Service is providing of transition of the inhabitants of the contaminated areas to the conditions of the normal life. It should be recognized that the way to solve this problem at the present stage as yet insufficiently elaborated conceptually and methodologically and normative.

Significant experience of the works on liquidation of consequences of radiation accidents makes it possible at the present time to move from the principle of zoning of the settlements on the criterion of the average annual effective doses to inhabitants, calculated in the absent of the active measures for radiation protection of the population, to the principle of zoning on the criterion of doses of the critical (most exposed) groups.

It should also continue to improvement work and optimization of the radiation monitoring system, focusing surveys, primarily in heavily contaminated areas. There is no doubt that the radiation monitoring of the contaminated areas must continue to lead, not to lose control of the situation and provide accurate information to both the community and the authorities – to take adequate measures for radiation, medical and social protection of the population.

Permanent monitoring of the doses of the population makes it possible to sufficiently evaluate the current and accumulated dose modified by the protective measures and the implementation of recommendations on diet (consumption of local food). In turn, the assessments of the actual doses are the basis for epidemiological analysis of morbidity and evaluation of the association between disease and radiation exposure from radiation accidents.

Radiation accidents caused tremendous damage to the socio-economic situation of the population of the contaminated areas. Reduction of agricultural land, the temporary withdrawal of land-using of the contaminated lands, resettlement of inhabitants, the failure of markets to agricultural products from the reception area of Chernobyl led to a reduction, and in some places, and the complete elimination of agricultural production and processing in the contaminated areas. Of course, overall folding and economic situation in the country during the adjustment period affected to this process. However, poverty in rural areas of contaminated districts more noticeable than in the non-exposed.

The lack of jobs, and psychological tension caused by information gaps of the population about the actual radiation situation in their place of residence, about the nature of the effects of radiation on the human body, led to the moving of young people and the changing demographic situation in the contaminated areas.

It is obvious that the rehabilitation of contaminated territories need not only to reduce the levels of radioactive contamination of the products and public exposure. It is necessary to restore the economy, improve mental attitude of inhabitants. Availability of paid work will help people to regroup from psychology of the "victims of the radiation accident" to a confident planning of their future.

Rehabilitation of the contaminated territories of the Russian Federation, as a result of radiation accidents and incidents, depends on the solution of the whole complex of problems. The most important of these include the following:

1. Regulatory and methodological and legal support of rehabilitation of the contaminated territories of the Russian Federation.

2. Organization and providing of the radiation monitoring in the contaminated areas and assessment of public exposure.

3. Implementation of measures to reduce the exposure of people living in contaminated areas, as well as to ensure the conditions for the production of «clean» products.

4. Organization and providing of medical, social and psychological rehabilitation of the population of contaminated areas.

5. Increase in the extent of improvement of contaminated areas, creating of the normal living conditions.

6. Conducting surveys, providing rational planning and implementation of rehabilitation measures.

The solution of these tasks depends on the efficiency of the Federal Service and its agencies in the contaminated areas.

Criteria and requirements to ensure mechanism of the transition of settlements from the conditions of the radiation accident to the conditions of the normal life of the population

Currently, problem of the transition of the settlements from the conditions of the radiation accident to the conditions of the normal life of the population is very important. It is necessary to formally fix the end of the Chernobyl accident and to introduce clear criteria that define the end of the state of a radiation accident for the each settlement.

At the same time, it is impermissible what the transition to normal life was hit on the affected population and caused additional stress. The transition process should include preparatory activities, excluding the reduction in real living standards. The condition for the transition should not only be performing radiological criteria for the end of the period of a radiation accident, but the execution and preparatory measures to increase the real level of living of the population through the reconstruction and development of economic activity.

It is necessary to include radiological criteria for the transition of the settlements from the conditions of the radiation accident to normal life, as well as requirements to the mechanism for the implementation of such a transition.

Radiological criteria for the transition of the settlements from the conditions of the radiation accident to the normal life of the population

In estimating of the impact of the consequences of the Chernobyl accident on the lives of inhabitants of the contaminated areas there are three main factors:

- direct radiation effects on human health;
- disruption of the normal way of life, due to the restrictions imposed and the destruction of the usual way of agricultural production;
- psychological impact related to the accident factors on the health and quality of life.

Radiation effects on human health can be quantified by cumulative effective dose. In accordance with Radiation Safety Standards NRB-99/2009, the value of socially acceptable risk man-made exposure of the population is $5 \cdot 10^{-5}$ 1/year, which corresponds to an annual effective dose of 1 mSv/year. Therefore, this value is used as the annual dose limit for the population in conditions of normal use man-made sources of ionizing radiation. Moreover, this criterion applies for the critical (most exposed from this source) populations.

In accordance with Russian methodological documents, a critical group of the population living in the settlements, located on contaminated as a result of the Chernobyl accident areas, are 10 % of the inhabitants of this settlement, with a maximum dose of man-made radiation. At the same time for the dose to the critical group of the population is taken as the average dose from residents, members of the critical group of the population.

The criterion for restoration of conditions of radiation safety of the population living on contaminated as a result of the Chernobyl accident area is decrease in the average annual effective dose of man-made radiation exposure of the critical group of the population of this city to the level of less than 1.0 mSv/year. When this condition for residents of the settlements course will surely be performed radiation safety conditions in relation man-made radiation.

Evaluations of radiation doses to the critical group of the population should be considered only those countermeasures which action is provided for a long period of time (deactivation of territory, radical improvement of pastures). Countermeasures, whose action takes place only at the time of their application, shall not be taken into account.

When planning activities for the rehabilitation of contaminated settlements as a useful effect, it is necessary to consider not only the reduction of radiation doses to population of the settlements, which in modern conditions is very limited, but the decrease in the ^{137}Cs content in the produced goods to levels that meet the sanitary requirements. It should be kept in mind that although the effect of reducing the content of radionuclides in the manufacture of food products may not result in lower radiation doses in this population settlements, if it does not consume the product, but he always eventually leads to the reduction of radiation doses to individuals, consuming her. The decrease in specific activity of ^{137}Cs in food products, regardless of who it consumes, uniquely determines the amount of reduction of the collective dose of the population.

To reduce the internal dose of the population from natural foods (mushrooms, berries, game, fish) need to improve social infrastructure, improve the material welfare of the residents, to explain features of primary processing and technological processing of these products for cooking, which provide a significant reduction of radioactive contamination and doses to residents.

Implementation of the above two criteria for the transition to the conditions of the normal life will simultaneously be reduced to an acceptable level of social and psychological impact of the accident related factors on the health and quality of life of the population, if the procedures will not lead to new stresses.

Requirements for the mechanism of the transition of the population of contaminated areas to the conditions of the normal life:

As follows from the above, the transition of the separate settlements to the conditions of the normal life of the population must meet the following requirements:

- ensuring compliance with the requirements of generally accepted radiation safety (ensuring conditions of the safe living);
- providing opportunities of doing in the contaminated area of economic activity without the use of special measures to reduce the ^{137}Cs content in products (providing conditions of normal economic activity).

Achieving of safe living conditions is a priority, because it allows to save people from the real and imaginary dangers to their health, and an acceptable level of economic activity in this case can be achieved through special activities. But only the joint implementation of these requirements is a prerequisite for the transition of the population of settlements to the normal life. But these requirements are not sufficient. They create a possibility of transition, for the implementation of which is necessary to perform a number of additional requirements:

- On the territory should be provided the conditions for profitable economic activity of the population, provides him with decent living conditions. To do this, it is necessary to create additional incentives for the development of agricultural production, such as the establishment of tax incentives for existing businesses in these areas, compensation for increased cost of production of "pure" agricultural products by the federal and local budgets, putting the guaranteed state order for agricultural production at prices that ensuring sufficient level of profitability, etc. It is necessary to create special economic zones in the contaminated territories, to provide the arrival of investors, encourage the introduction of modern technologies of cultivation and processing of agricultural products, which give the regulatory net production in the contaminated areas. These activities should be started a few years before the expected achievement of necessary quantities of radiological criteria.

- Based on the results of ongoing radiation monitoring program should be composed of transition settlements normal activities, determining the expected date of such a transition for all settlements located in areas of radioactive contamination. According to the results of this monitoring, it must be adjusted not less than 1 time in 5 years.

- Over the 5 years before the expected transition to the normal life for each settlement should be developed a program providing a set of measures to ensure this transition without lowering of the standard of living of the population. It must be presented to the population of the settlement. Every year, the results of this program should be communicated to the inhabitants of the settlement.

- After the transfer of the settlement to normal life, it is necessary to continue radiation monitoring, to determine the annual dose of man-made radiation exposure of the population and to register persons, cumulative dose of man-made radiation which exceeded 70 mSv.

Preliminary estimations showed that at present the total number of the settlements in which the soil surface activity with cesium-137 is less than 1.0 Cu/km², the current average annual effective dose to the population AAED90 (in the absence of active radiation protection measures and self-limitation in the consumption of the local food) does not exceed 1.0 mSv/year, and the average specific activity of radionuclides in all foods of local origin does not exceed and may not exceed the permissible levels established sanitary and epidemiological rules and regulations, is 1349 in all 14 regions of Russia affected by the Chernobyl accident.

It must be emphasized, that for these calculations the assessment of the AAED90 for the component of internal exposure was performed using the numerical values of the maximum possible aggregative transfer factors of cesium-137 and strontium-90 from different groups and types of soils to foods – the 90% quantile of the frequency

distribution of numerical values of the aggregative transfer factors. Thus These requirements for possibility of production in the village of traditional agricultural products, as well as possibilities to collect "gifts of the forest", satisfying the sanitary-epidemiological rules and standards without the use of special measures to reduce the content of radionuclides was observed.

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