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RADIOACTIVE CONTAMINATION OF THE ENVIRONMENT AS A RESULT OF THE CHERNOBYL DISASTER

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Summary. The Chernobyl disaster was a catastrophic nuclear accident. The activity of radionuclides emitted into the environment as the result of Chernobyl accident has significantly decreased and transuranium elements ^{137}Cs and ^{90}Sr are of the main radiological danger. For years after the disaster a radiation situation in Ukraine have changed, in particular, short-lived and medium-lived radionuclides have decomposed, and the quantity of major dose-forming radionuclides now have decreased almost twice times.

Key words: *Chernobyl disaster, Exclusion zone, radionuclide, exposure dose of radiation, contamination, monitoring.*

Problem setting. As a result of the Chernobyl accident in Ukraine, more than 3 million Ukrainian citizens have suffered, and 2293 settlements are located on contaminated territories. For the time passed after the accident at the Chernobyl Nuclear Power Plant, the radiation condition of the territories affected by radioactive contamination has improved. It was contributed by natural processes and measures taken to prevent the release of radionuclides outside the Exclusion zone, overcoming the consequences of the accident in agricultural and forestry production and realization of decontamination works. At that time the population of Ukraine during 30 years after the accident received exposure doses that exceeds 80% of the lifetime dose during life (70 years), which can be formed because-of Chernobyl radionuclides.

Analysis of studies and publications. A large contribution to the development of practical and theoretical materials on liquidation the consequences of radiation accidents, in particular Chernobyl catastrophe R.M. Aleksakhin, D.M. Grodzinsky, B.S. Prister, V.A. Shevchenko, G.M. Kozubov, A.I. Taskaev, V.O. Kashparov, I.M. Gudkov, O.O. Orlov, G.P. Perepelyatnikov, S.O. Gerashkin and others have made.

The environmental consequences of the Chernobyl disaster are determined by irradiation of natural objects and their radioactive contamination. External irradiation is caused by the radiation of all

radionuclides from the cloud of emissions, settled on the soil, vegetation and water surface, skin coverings of people and animals. Internal radiation is connected with radionuclides that can be absorbed by organisms. Today there are more than 40 settlements in Ukraine where the radioactivity in milk constantly exceeds permissible levels 100 Bq/l in 5-10 times [1]. The main objects of the environment that cause the entry of radionuclides to human organism are agricultural products, forest gifts and water.

The purpose of the article is to study the level of environmental contamination by Chernobyl radionuclides, which irradiation nowadays cause chronic exposure to biological objects with constant dose rate.

The main material. The average annual concentration of ^{137}Cs and ^{90}Sr in the surface layer of the atmosphere on the territory of the country in 1984 - 1985 reached $0.21 \cdot 10^{-5} \text{ Bq/m}^3$ and $0.12 \cdot 10^{-5} \text{ Bq/m}^3$ respectively. Levels of soil contamination were in the range of 0.8 ... 4.0 k Bq/m² (at a practically constant ratio of Cs/Sr about 1.6) [1, 2]. Contamination of plutonium isotopes varied within 10...60 Bq/m². The gamma background comprised was equal to 10 ... 20 $\mu\text{R/h}$. Contamination of Sr in surface and sea water ranged from 12 to 33 Bq/m³. An additional radiation dose of population due to nuclear tests over the five-year period before the accident was near 1 mSv.

The Chernobyl disaster significantly changed the radiation situation in Ukraine and other European countries. As a result of the explosion of the nuclear reactor of the Chernobyl Nuclear Power Plant and the destruction of its protective membranes, a powerful release of radioactive substances into the troposphere occurred. The total activity at the time of the accident in the active zone of the reactor exceeded $210 \cdot 10^{18}$ Bq. According to various authors, the environment was polluted by $13 \cdot 10^{18}$ Bq of radionuclides. About 200 radioactive isotopes of elements were transported in the atmosphere in complex trajectories for thousands of kilometers from the Chernobyl Nuclear Power Plant and in 1986 they were observed in all countries of the Northern hemisphere and in the waters of the Pacific, Atlantic and Arctic oceans. The most notable among the radionuclides were ^{131}I and ^{137}Cs . Over time, the activity of radionuclides emitted into the environment has significantly decreased and transuranium elements ^{137}Cs and ^{90}Sr are of the main radiological danger.

Chernobyl emissions are characterized by the presence of a wide spectrum of forms and composition of substances containing radionuclides: gas and steam-aerosol mixtures, fuel particles, mineral particles, organic compounds, etc. Their composition varies from monoelementary noble gases, atomic iodine, ruthenium to polymeric compounds, graphite, silicate and other particles with different ratios between radionuclides [3, 4].

More than 90% of the isotopes of Pu, ^{90}Sr , $^{141,144}\text{Ce}$, ^{241}Am was emitted into the atmosphere in the form of fuel particles of 10 microns or less. The distribution of ^{137}Cs within the exclusion zone is almost 75 % due to fuel particles [5]. Condensation particles, which are smaller in size than fuels are peculiar for the territories remote from Chernobyl Nuclear Power Plant not less than 30 ... 40 km [6]. The largest distance from Chernobyl Nuclear Power Plant was passed by steam-aerosol and gas mixtures, particles of sub-micron size of such elements as $^{103,106}\text{Ru}$, $^{131,133}\text{I}$, ^{132}Te , $^{134,137}\text{Cs}$. It resulted in the formation of quite large areas of radioactive spots on the territory of most European countries. On the territory of the Exclusion zone ^{90}Sr has gained mobility and over the years is becoming more and more bioavailable, while $^{134,137}\text{Cs}$ stays in place, binding into sedentary forms with clay minerals of the soil [7].

In connection with the rains in the Zhytomyr, Cherkasy and Kyiv regions, in Podillia and Prykarpattia with increased pollution density of

$^{134,137}\text{Cs}$ were formed. More than 80 % of Ukraine's forest area suffered significant contamination of ^{137}Cs and ^{90}Sr [8]. The natural processes of decay of radionuclides for the years following the Chernobyl disaster have made significant adjustments to the structure of the distribution of radionuclides. The area where the levels of contamination of ^{137}Cs are comparable to the pre-accidental ones had increased two times and the area of territories where the level of contamination of ^{90}Sr exceeded the pre-accidental had decreased nearly two times [9]. The level and the scale of Pu contamination Pu practically did not change. Activity of ^{214}Am is gradually increasing due to the collapse of ^{241}Pu . To peculiarities of pollution of urbanized areas belong the presence of point and line concentrations of contaminations along roads, between borders, under separate trees, along dams, in roof coverings, and so on.

Over time radionuclides migrate from the surface to deeper layers, and a significant amount of them moves in space with surface water. The rivers are still the main transport systems for the transfer of radioactive contamination. For example, over the years after the accident, the waters of the Pripjat River removed more than $12 \cdot 10^{12}$ Bq ^{137}Cs and $148 \cdot 10^{12}$ Bq ^{90}Sr . About $19.6 \cdot 10^{15}$ Bq ^{137}Cs and $2.3 \cdot 10^{15}$ Bq ^{90}Sr [10] are concentrated in the Dnipro and Pripjat basins. The processes of flushing the radioactivity in the river with the surface runoff at the catchments have become the dominant factor in the spread of pollution to significant areas outside the Exclusion zone. The annual decrease in the amount of radionuclides due to natural flushing from the surface of contaminated soils is negligible and the processes of natural snowmaking and raining for years after the accident did not significantly reduce the total amount of radionuclides in the catchment areas.

The radiation level of the Pripjat River in Chernobyl today corresponds to the following indicators: the specific activity of radionuclides ^{137}Cs and ^{90}Sr in water is 28-29 Bq/m³ (the activity of ^{90}Sr outside the Exclusion zone since the beginning of 2017 is $0.68 \cdot 10^{12}$ Bq).

The water reservoirs of the Dnipro cascade were polluted by radioactive aerosols that settled on the water surface and through supplies with river inflows. In the process of transportation with the Dnieper waters radionuclides from the river runoff were partially redistributed as a result of their sedimentation in the bottom sediments. Nowadays the dominant radionuclides in the water masses of

the reservoir are ^{90}Sr and the ^{137}Cs [10, 11]. Due to the active sedimentation processes, only a small part of the radionuclides enters the reservoirs of the lower reaches of the Dnieper, and the levels of pollution, in particular the Kakhovka reservoir, have practically returned to the levels observed before the Chernobyl accident.

The total amount of ^{137}Cs in atmospheric fall-outs on the Black Sea and the Sea of Azov was estimated at about $2.8 \cdot 10^{15}$ Bq [12, 13]. According to monitoring studies in the layers of 0.8 ... 1.0 cm of soil there is a peak of Chernobyl pollutions. In the years after the accident, the additional introduction of radionuclides with river waters was negligible compared to initial pollution due to precipitation with atmospheric fall-outs [11].

Determination of the exposure dose of gamma radiation on the territory of Ukraine is carried out daily at the stations of the radiometric network of the Hydrometeorological Service. The gamma background for most of the territory of Ukraine is within the range of 5...22 mR/h, which is close to natural levels. Modern value of the exposure dose of gamma radiation in Chernobyl account is 19.8...24 mR/h, on the Chernobyl Nuclear Power Plant industrial site is 45.9...51.2 mR/h, at the Dytatki KDP is 8.4...12.6 mR/h [14].

The main source of the occurrence of technogenic radionuclides into the atmosphere air is the secondary wind rise of radioactive elements

from the earth's surface. According to observations, the total beta-activity of atmospheric aerosols in most of the territory of Ukraine is in the range of $0.075...0.175 \cdot 10^{-3}$ Bq/m³. The concentration of ^{90}Sr in recent years was in the range of $0.0001...0.0012 \cdot 10^{-3}$ Bq/m³, which basically corresponds to the pre-accidental level (the average annual concentration of ^{90}Sr in 1985 was $0.0008 \cdot 10^{-3}$ Bq/m³). The average activity of cesium in the surface layer of the atmosphere of Chernobyl is $7.2 \cdot 10^{-6}$ Bq/m³, at the Chernobyl Nuclear Power Plant industrial site is $1.2 \cdot 10^{-4}$ Bq/m³, at the Dytatki KDP is $3.2 \cdot 10^{-6}$ Bq/m³ [14].

Conclusions. The radiation background has decreased by hundreds of times compared to 1986. The preventive measures and self-cleaning processes led to a decrease of the content of radionuclides in the objects of the environment and in agricultural products, which in turn led resulted in decrease of internal exposure of the population. After the 30 years from the accident the main sources of long-lived technogenic radionuclides (^{137}Cs , ^{90}Sr) which form the dose of internal radiation for human body are food and drinking water. About 93% of the Chernobyl dose [15] has already been implemented, and it has been established that the most significant sources of radioactive load all over the country will be technogenic-reinforced sources of natural origin (mostly radon).

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