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TRANSFORMATION OF VULNERABILITY OF GROUNDWATER TO RADIOACTIVE POLLUTION IN THE CHERNOBYL TRACK ZONE IN THE TERRITORY OF KALUGA REGION

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We took the annual data on radiation monitoring, provided by the “Tayfun” Science and Production Association (Радиационная обстановка …, 2019), and regional state reports (Левкина и др., 2019; Доклад о состоянии …, 2019) to make a detailed analysis of the radiation situation in Russia and some of its regions. As part of the analysis we assessed the problems and prospects of nuclear energy in the country and abroad. We analyzed the monitoring of the radiation situation in the said territory by the example of the Central Federal District. It included the monitoring structure of the nuclear plants (by the example of the Kalinin, Kursk, Smolensk and Novovonezh stations) and monitoring of the radiation situation in the territories located in the radioactive trail from the Chernobyl Accident in Kaluga and Bryansk Regions.

In 2018 the impact of nuclear power plants on the radioactivity of environmental objects was low. It is under strict control and was expressed in an increased tritium content, increased regional level of ^{137}Cs volume activity, and the presence of technogenic radionuclides, such as ^{54}Mn, ^{59}Fe, ^{60}Co, ^{95}Zr, ^{95}Nb, and ^{131}I in the environment, which are absent in the global background radiation. Volumetric activities of the controlled radionuclides are significantly lower than the admissible values of the radiation standards NRB-99/2009 (СанПиН …, 2009) and do not threaten public health. However, the consequences of technogenic contamination of the environment with radionuclides after the Chernobyl Accident are still severe. It is manifested in the increased total radioactivity of surface and underground waters, soils and vegetation. And some territories require rehabilitation measures. Therefore, the monitoring researches in the area of the Chernobyl radioactive trail are relevant and necessary for a more accurate understanding of changes in groundwater radiation pollution.

The characteristics of the hydrogeological conditions showed that they are distinguished by a wide variety of aquifers, both pressure and non-pressure. Generally, the hydrogeological structure of the territory reminds a “layered cake”. The non-pressure aquifers include the waters of the Quaternary (alluvial, glacial, fluvioglacial, marsh, and proluvial horizons), Cretaceous and Jurassic sediments. All those aquifers are related and do not have sustained water confines within their stratum, or complex. The pressure groundwater aquifers of fresh groundwater include many related Carboniferous aquifers. The Upper Jurassic confining area lies between those two stratums, separating them. The aquifers of the Devonian, Proterozoic and Archean ages contain saline groundwater and brines and lie below the Carboniferous aquifers.

To assess groundwater protection and vulnerability to pollution, we used our original methodology. Its key definitions are as follows.

A protection zone separates groundwater from the surface pollution, and has a two-level structure: soils and rocks of the aeration zone.

Security is an ability of the protection zone to prevent pollution from penetrating the groundwater for a certain period of time.

Groundwater *vulnerability* to pollution is the ratio between the real technogenic load of the study area and the natural protection of groundwater. A substance is considered a pollutant if its concentrations exceed the background values. Therefore, when assessing security, we took into account the structural features of the protection zone separating groundwater from surface pollution, and the processes occurring under the influence of pollution.

When assessing security, we built a set of medium-scale maps (1:200000), for them to be the most appropriate for the possibilities of qualitative and quantitative assessments.

The map of the protection zone was obtained by combining a soil map, showing the structure of the first level of the zone, and the maps characterizing the structure of its second level (depths and lithological structure of the aeration zone). Typical sections were marked on the map, characterized by a certain structure of the first and second levels and groundwater depth. Their description is given in the map legend.

When assessing the possibility of groundwater contamination with radionuclides, the following factors were taken into account: sorption properties that ensure the retention of radionuclides by soils and rocks of the aeration zone; limitation of the traffic intensity (up to its complete retention) with an infiltration flow to groundwater; migratory properties of soils and rocks of the aeration zone, depending on the physicomechanical, water-physical and filtration properties and their mineralogical composition, and characterizing the movement intensity of the polluted infiltrating waters front deeper into the aeration zone right to groundwater; filtration (infiltration) path, i.e. the power of the aeration zone or groundwater depth; half-life of radionuclides.

Groundwater protection from any pollutant depends on the time the contaminated infiltration water front needs to reach the aquifer. The time it took for the radionuclides to dissolve in the soil and rocks of the aeration zone to fill their sorption capacity and then reach the groundwater, was determined by the proposed mathematical expression.

Essentially, the allocation of categories according to the proposed time for the pollutant to move through the protection zone, is an approximate predictive estimate of the process of groundwater pollution by radionuclides.

The maps of groundwater protection from ^{90}Sr and ^{137}Cs were based on the map of the protection zone. A comparison of the maps shows that ^{90}Sr is most dangerous for groundwater, since it can cover large areas of the aquifer in a short period (less than 5 years).

The map of groundwater protection from ^{90}Sr shows that about 50% of the territory is not protected from it, 20% is poorly protected, another 20% is conditionally protected, mainly in the north, and 5% is protected and moderately protected groundwater.

It is a completely different situation with ^{137}Cs contamination. The unprotected groundwater can be found only along the narrow strip along the riverbeds, poorly protected – in the valleys of several small rivers in the northwest, moderately protected – in the high river terraces, conditionally protected adjust to the watersheds, protected and conditionally protected are prevailing.

Thus, an estimation of the time that radionuclides need to travel through the protection zone allows us to make an approximate prediction of the process of groundwater contamination with that extremely dangerous pollutant.

The map of groundwater vulnerability to ^{137}Cs is based on the ^{137}Cs technogenic load map (^{137}Cs surface distribution) and the ^{137}Cs groundwater protection map. We assessed and mapped the groundwater vulnerability to ^{137}Cs contamination as it was at the time of the Chernobyl Accident, then 30 years after, as well as 60 and 90 years after.

According to the step-by-step assessment of soil vulnerability to pollution, a general tendency is observed in the changes of the technogenic load in the territory of the radioactive trail. It can be concluded that in the interval of 100-120 years the activity of the initial ^{137}Cs surface deposition will decrease to the values below the limits, but will still exceed the background values, and will completely disappear 300 years after the accident.

Within the 100-120 years after the Chernobyl Accident, the areas with ^{137}Cs groundwater pollution exceeding the background concentrations can still be detected in the radioactive trail zone.
Keywords: radiation situation, monitoring, radionuclides, groundwater protection and vulnerability, pollution sources, technogenic load.
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