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EVALUATION OF THE POTENTIAL HAZARD OF SECONDARY RADIOACTIVE CONTAMINATION OF UNDERGROUND WATER BY SEWAGE WORKS

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The time dependence of the distribution of the volume activity of radionuclides over ground layers is calculated under chemically equilibrium and hydraulically stationary conditions and under conditions of continuous operation of radioactively hazardous units of sewage works. As initial information, a set of data on the hydrogeological characteristics and physicochemical properties of the sewage-water sediments (SWSs) found at the sewage works of Chechersk and Slavgorod is used. The results of the calculations performed are analyzed, and the data on the egress of radiocesium from the SWSs found in the sludge areas and filtration fields with different bases into underground water are presented.

A radioenvironmental inspection of sewage works in the towns of the Republic of Belarus, carried out under the state program of elimination of the consequences of the accident at the Chernobyl nuclear power plant, has shown that in the contaminated regions the transfer of radionuclides by domestic and industrial sewage waters has led to the concentration of radioactive contaminations in sewage-water sediments (SWSs).

Analysis of the technological layouts of the sewage works and of the results of examining specific installations has shown that, radioenvironmentally, the most hazardous units of such works are sludge areas, filtration fields, and biological ponds [1], where more than 90% of the activity is accumulated. In these technological units of the sewage works, the level of radoactive contamination of dewatered SWSs can correspond in the specific activity of ^{137}Cs to the level of radioactive contamination of conditionally radioactive wastes (CRAW) and radioactive wastes (RAW). Therefore, the above-indicated units accumulate radionuclides and are a potential hazard of radioactive contamination of underground water because of the migration of radionuclides into the bedrocks of the filtration fields and of the bioponds and into the bases of the sludge areas.

To evaluate the degree of radioenvironmental hazard of the units of sewage works which accumulate radioactive SWSs, it is necessary to investigate how the distribution of the radionuclide concentration in the volume of natural and artificial protection barriers and in the underground water zone varies with time. Taking into account the long duration of the process of migration of radionuclides in natural geological media, we can evaluate the degree of radioenvironmental hazard only by calculation based on models that allow for physical and hydrogeological processes occurring both in accumulating radionuclides and their leaching from the contamination source and in their subsequent transfer to the underground-water zone.

The rate of transfer of radionuclides in their vertical migration from the local contamination source (region of accumulation of SWSs) to the underground-water zone was calculated with the use of the mathematical model developed by us. Its block diagram represents a set of interconnected chambers positioned in tandem – control volumes described by the system of differential equations with lumped parameters.

The problem was formulated with the use of the following basic assumptions:

(a) only the most mobile forms of radioisotopes migrate in geological media; they are carried by soil and infiltration moisture;

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(b) the transfer of each dissolved radionuclide is performed independently;

(c) in the considered volume, migration occurs in an isotropic porous medium;

(d) the processes of interaction of radionuclides in the system ground-water are equilibrium in character and obey the equation of the Henry linear adsorption isotherm [2];

(e) the migration process is considered under hydraulically stationary conditions and under the conditions of continuous operation of individual units of sewage works.

The mathematical model describing the migration of radionuclides from bioponds and filtration fields allows for the process of accumulation of radionuclides, the process of washing of them out of the bottom layer of the activated sludge by a pressure water flow [3], the process of radioactive decay, and the process of convective mass transfer through layers of different thicknesses and different sorption characteristics. In the case where radionuclides migrate from the activated sludge layer in sludge areas, we took into account the amount of radionuclides carried by sludge water to the surface of the natural or artificial base of the sludge area [4].

The system of equations describing these processes for individual control volumes in the migration of radionuclides from the units of sewage works where the SWSs are accumulated to the water-bearing horizon is represented by one-type differential equations for n chambers:

$$V_i \frac{dC_i}{dt} = G_{i-1} C_{wi-1} - G_i C_{wi} - \lambda_d V_i C_i \,, \tag{1}$$

$$C_i = \theta_i n_{ai} C_{wi} + \rho_{si} (1 - n_{ai}) \, C_{si} \,, \tag{2}$$

$$C_{wi} = C_{si} / K_{di} \,. \tag{3}$$

When radionuclides migrate from the activated sludge in filtration fields and bioponds, the flow-rate characteristic is determined by the conditions of the hydraulic bond between the top volume and the underground water [3]. In the case where radionuclides migrate from the activated sludge in sludge areas, this characteristic depends on the type and properties of SWSs and on their moisture content and resistivity and is determined experimentally [4].

The system of equations (1)-(3) is solved analytically for n chambers. The general form of the solution can be represented as follows:

$$C_{wi}(t) = C_0 \sum_{j=1}^{i} A_j \exp - (\lambda_j + \lambda_d) \, t \,, \tag{4}$$

$$\lambda_i = \frac{G_i}{V_i \, \theta_i R_i \, n_{ai}} \,, \tag{5}$$

$$R_i = 1 + \rho_{si} K_{di} \frac{1 - n_{ai}}{n_{ai} \, \theta_i} \,. \tag{6}$$

For the above-described models of migration, we calculated the time dependence of the distribution of the volume activity of ^{137}Cs over the ground levels down to the water-bearing horizon in the case of continuous operation of radioactively hazardous units of sewage works. As initial information, we used a set of data on the hydrogeological characteristics and physicochemical properties of the SWSs at the sewage works in Chechersk and Slavgorod.

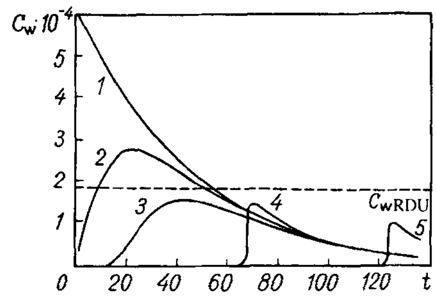

Fig. 1. Time dependence of the volume activity of ^{137}Cs (C_w, Bq/m^3) at the outlet from the chambers of a sludge area with an artificial base in Chechersk: 1) egress of cesium from the SWS into the first drainage blanket; 2) egress of cesium from the SWS into the second drainage blanket (coarse sand); 3) egress of cesium to the artificial base of the area; 4) egress of cesium to the aeration zone; 5) egress of cesium to the underground water. *t*, years.

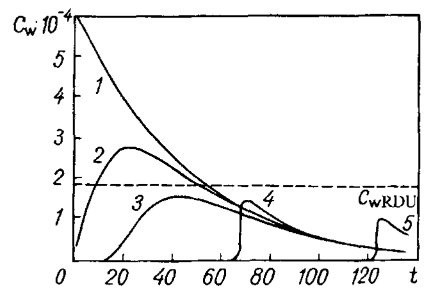

Fig. 2. Time dependence of the volume activity of ^{137}Cs (C_w, Bq/m^3) at the outlet from the chambers of filtration fields in Slavgorod: 1) egress of cesium from the near-bottom layer of activated sludge; 2) egress of cesium from the bottom layer of the ground; 3) egress of cesium to underground water.

Because of the fact that the service conditions of the radioactively hazardous units of the chosen sewage works were not clearly understood and information on the characteristics and features of the media in which migration processes occur was absent, our calculations were based not on the actual conditions of transfer of radionuclides in natural media but on the assumed conditions, which are very uncertain and can be varied in wide limits. In the case under consideration, we performed conservative evaluations of a potential hazard of contamination of underground water by radionuclides as a result of secondary migration processes.

Analysis of the results of the calculations performed has shown that in the case where sludge areas with a natural sand base were used for dewatering of radioactive SWSs, within 8 years after the accident the content of radiocesium in the underground water exceeded the Republic's allowable levels (RDU-96) prescribed for water $\{C_{w,RDU}(^{137}Cs)\} = 18{,}500$ Bq/m^3. In the case where a natural sandy-loam base or a complex artificial base are used, ^{137}Cs can enter the water-bearing horizon, but its volume activity will be lower than the RDU-96 limits (Fig. 1). For the model variant of the continuously operating filtration fields of sewage works with a sand base (Slavgorod), it was established that the egress of ^{137}Cs from them into underground water can be expected to take place within 6 years; the content of ^{137}Cs will reach its limiting value within 13 years, and its output volume activity will increase further (Fig. 2). Calculations of the model variants of biological ponds in Chechersk have shown that at a thickness (H) of the natural protection barrier (the basic ground is a sand loam) of 4 m, the underground water can be contaminated with radiocesium, the volume activity of which exceeds the RDU-96 limits, within 25 years.

A complex inspection of the sewage works in the zone with a density of surface contamination with ^{137}Cs of more than 1 Cu/km^2 has shown that more than 18,000 m^3 of SWSs are accumulated annually in the contaminated territory. From the preceding, it may be concluded that, to decrease the hazard of secondary radioactive contamination of the environment by sewage works in the contaminated territories, it is necessary to modernize the units of sewage works, develop methods of removal of radioactive contaminants from sewage water, and decrease the mobility of radionuclides in the regions where radioactive SWSs are accumulated. In the latter case, the local mineral carbonate-containing raw material that, as investigations show, practically irreversibly sorbs up to 90–95% of ^{137}Cs can be used. For ^{137}Cs, the sorption ability of this mineral is 0.6–1.0 mg-equiv./g, and the leaching of radioisotopes is no more than 5%. It should be noted that the above-indicated mineral also sorbs radiostrontium.

NOTATION

i, chamber number, $i = 1 - n$; V_i, volume of the ith chamber; C_i, average volume activity of radionuclides in the ith chamber; C_s, specific activity of radionuclides sorbed by the ground; C_w, volume activity of radionuclides in dissolved form; K_d, effective coefficient of distribution in the system ground-water; n_a, active porosity of the ground; θ, degree of moisture content of the ground; G, flow rate of water flow through the ground layer; C_0, average volume activity of radionuclides in dissolved form in the activated sludge at the initial moment of time; λ_d, radioactive-decay constant; λ_i, convective-transfer constant; R_i, retarding factor; A_j, coefficients determined by integrating the differential equations; t, time. Subscripts: s, ground; w, water; d, decay; a, activity.

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