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Numerical investigation of the modeling of transportation and deposition of the radioactive pollution in the Caucasian Region in case of the hypothetical accident on the Armenian Nuclear Power Plant

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Abstract

By means of regional model of development of atmospheric processes in the Caucasian Region and the equation of a substance transfer the spatial distributions of the radioactive pollution (^{131}I) and zones of radioactive deposition are investigated. In the model the radioactive decay and aerosols deposition processes are taken into account. The distribution of radioactive pollution is simulated in cases of the South, South West and South East background winds. The distribution of only one radionuclide aerosol ^{131}I with diameter 10 μm is considered.

It is shown, that the relief of the Caucasus significantly influences on the trajectory of the pollution distribution. The North West orientation of the Main Caucasian Range resists air motion to the north, constrains the radioactive pollution in the boundary layer to flow around the Main Caucasian Range from the west or east sides. It is obtained that the 48 hours are necessary for the radioactive cloud to overflow the South Caucasus and distribute over the territory of the North Caucasus. The radioactive pollution is falling out mainly in the central, southeast and northwest parts of the South Caucasus. The zone of the radioactive deposition is extended along the background wind and deformed by the influence of the relief. The maximum length of the zone of significant deposition of radioactive substance equals approximately 750 km in case of the background South East wind and 350 km in other cases. The maximum width of the zone approximately equals 150 km. It is obtained that the surface density of the deposited radioactive nuclide in the zone of significant radioactivity decreases from 360 a.u./m^2 down to 1 a.u./m^2 when the concentration of 10 μm aerosol ^{131}I in emission plume during 6 hours are equal to 100 a.u./m^3.

1. Introduction

The accidents of the Chernobyl, Fukushima and other power plants show that the nuclear reactors carry the great potential hazards for population and environment especially when plants are located in the seismic hazardous regions [1, 3].

The Armenian Nuclear Power Plant (ANPP) is one of such objects. It lies in the South Caucasus in Metsamor 20 km from the capital of Armenia Yerevan on one of the Earth's most earthquake-prone terrain. ANPP, as a very dangerous object, was closed after earthquake in Armenia in 1988 but was reopened in 1995. ANPP has one of just a few remaining Soviet nuclear power reactors that were built without the primary containment structures. Consequently, the hazard of the radioactive pollution of the environment in the Caucasus becomes highly probable event. The neighbouring countries, Turkey and Azerbaijan, protest the operation renewal of ANPP, and Azerbaijan has called on the UN Security Council to suspend the operation of the nuclear power plant in Metsamor [4-6].

The radioactive aerosols, emitted in the atmosphere from the nuclear reactors, can be transferred on the large distance and produce a radioactive contamination of the underlying territory [3, 7]. Therefore, a preliminary determination of the possible trajectories of the radioactive pollution cloud and nuclear deposition in the various meteorological situations has a practical importance for the environmental safety services.

A prediction of the dispersion of the radioactive pollution is possible by means of numerical simulation of the radioactive substances transfer. The accident of the Chernobyl nuclear plant shows necessity of development of the hemispheric, long- and meso-scale transport models for radioactive substances. The existing numerical dispersion models of pollution were developed as well as some new models of transfer of radioactive pollutions were elaborated (ApSimon et al., 1987; Lange et al., 1988; Alberger at al., 1988; Hass at al., 1990; Ishikawa, 1991, 1995; Ishikawa and Chino, 1991; Brandt at al., 2002; Khatib, 2008; Winiarek and etc. [8 -17]).

The tasks of the article are the numerical simulation of the possible trajectories of the movement of the radioactive clouds hypothetically emitted from ANPP and determination of the possible zones of nuclear fallout in the Caucasus. G. Lazriev considered some issues of this problem [18].

In the present article G. Lazriev's approach is continued to be investigated on the basis of the use of the regional model of the atmospheric processes over Caucasus region elaborated at the M. Nodia Institute of Geophysics; it allows calculate the spatial distribution of the meteorological fields over the complex relief of the Caucasus [19]. We have simulated the dispersion of the radioactive pollution by using of the momentum equation.

2. Formulation of the problem

2.1. Basic equations

The main equations of the model describing variations of the meteorological fields are

(a) for the troposphere

$$\frac{du}{dt} = -\frac{\bar{P}}{\rho}\frac{\partial \phi}{\partial x} + l\,v + g\,(1+0.61q)\,\vartheta\frac{\partial z}{\partial x} + \mu\,\Delta u + \frac{1}{\rho h^2}\frac{\partial}{\partial \zeta}\rho\,\nu\frac{\partial u}{\partial \zeta} ,$$

$$\frac{dv}{dt} = -\frac{\bar{P}}{\rho}\frac{\partial \phi}{\partial y} - l\,u + g\,(1+0.61q)\,\vartheta\frac{\partial z}{\partial y} + \mu\,\Delta v + \frac{1}{\rho h^2}\frac{\partial}{\partial \zeta}\rho\,\nu\frac{\partial v}{\partial \zeta} ,$$

$$\frac{\partial \phi}{\partial \zeta} = \frac{g}{R\bar{\bar{T}}}(1+0.61q)\,\vartheta h , \qquad \frac{\partial h}{\partial t} + \frac{\partial uh}{\partial x} + \frac{\partial vh}{\partial y} + \frac{\partial \tilde{w}h}{\partial \zeta} + \frac{1}{\rho}\frac{d\rho}{dz}wh = 0 ,$$

$$\frac{\partial \vartheta'}{\partial t} + u\frac{\partial \vartheta}{\partial x} + v\frac{\partial \vartheta}{\partial y} + \tilde{w}\frac{\partial \vartheta}{\partial \zeta} + S\,w = \mu\,\Delta\vartheta + \frac{1}{\rho h^2}\frac{\partial}{\partial \zeta}\rho\,\nu\frac{\partial \vartheta}{\partial \zeta} + \frac{L}{\rho C_p}\varphi_{con} - \frac{\partial \theta}{\partial t} ,$$

$$\frac{\partial q'}{\partial t} + u\frac{\partial q}{\partial x} + v\frac{\partial q}{\partial y} + \tilde{w}\frac{\partial q}{\partial \zeta} = \mu\,\Delta q + \frac{1}{\rho}\frac{\partial}{\partial \zeta}\rho\,\nu\frac{\partial q}{\partial \zeta} - \varphi_{con} - \frac{\partial Q}{\partial t} ,$$

$$\frac{\partial m'}{\partial t} + u\frac{\partial m}{\partial x} + v\frac{\partial m}{\partial y} + \tilde{w}\frac{\partial m}{\partial \zeta} = \mu\,\Delta m + \frac{\partial}{\partial \zeta}\nu\frac{\partial m}{\partial \zeta} + \varphi_{con} - \frac{\partial N}{\partial t} , \qquad (1)$$

$$w = \frac{\partial z}{\partial t} + u\frac{\partial z}{\partial x} + v\frac{\partial z}{\partial y} + \tilde{w}h , \quad \mathrm{z} = \zeta\,\mathrm{h} + \delta ,$$

$$\frac{d}{dt}=\frac{\partial}{\partial t}+u\frac{\partial}{\partial x}+v\frac{\partial}{\partial y}+\tilde{w}\frac{\partial}{\partial \zeta}, \qquad \Delta=\frac{\partial}{\partial x^2}+\frac{\partial}{\partial y^2};$$

b) for the active layer of soil

$$\frac{\partial C}{\partial t}=\frac{\partial}{\partial z}D(C)\frac{\partial C}{\partial z}-\frac{\partial E(C)}{\partial z}, \qquad \frac{\partial T_{soil}}{\partial t}=K_{soil}\frac{\partial^2 T_{soil}}{\partial z^2} \quad \text{at} \quad \delta_0 > z > Z_{soil}; \qquad (2)$$

c) for the layer of sea water

$$\frac{\partial T_{sea}}{\partial t}=K_{sea}\frac{\partial^2 T_{sea}}{\partial z^2}+\frac{1}{C_{sea}\,\rho_{sea}}\frac{\partial I}{\partial z}, \quad \text{at} \quad \delta_0 > z > Z_{sea}, \qquad (3)$$

where t is time; x, y, and z are the axes of the Cartesian coordinate directed to the east, north and vertically upwards, respectively; $\zeta=(z-\delta)/h$ is the dimensionless vertical coordinate; $\delta=\delta_0(x,y)+50\,\mathrm{m}$ is the surface layer height; δ_0 is the height of the relief; $H(t,x,y)$ is the height of the tropopause; $h=H-\delta$; u, v, w, and $\tilde{w}$ are the wind velocity components along the axes x, y, z, and ζ, respectively; $\vartheta=T'/\overline{T}$, and $\phi=P'/\overline{P}(z)$ are the analogues of temperature and pressure, respectively; $\overline{T}=300K$; T' and P' are the devotions of temperature and pressure from the standard vertical distributions

$T'(t,x,y,z)=T(t,x,y,z)-\overline{T}+\gamma\, z-\overline{\overline{T}}(t,x,y,z)$, $\mathrm{P}'(\mathrm{t,x,y,z})=\mathrm{P}(\mathrm{t,x,y,z})-\overline{\mathrm{P}}(\mathrm{z})-\overline{\overline{\mathrm{P}}}(\mathrm{t,x,y,z})$;

T and P are the temperature and pressure of the atmosphere, respectively: $\overline{T}-\gamma\, z$ and $\overline{P}(z)$ are the standard vertical distributions of the temperature and pressure, respectively; γ is the standard vertical temperature gradient; $\overline{\overline{T}}$ and $\overline{\overline{P}}$ are the background deviations of the temperature and pressure from standard vertical distributions; ϑ and θ are the mesoscale and background components of the analogue of temperature, respectively; $\vartheta'=\vartheta-\theta$; q and Q are the mass fraction of water vapour and the background mass fraction of water vapour, respectively; $q'=q-Q$; m and M are the mass fraction of cloud water and the background mass of cloud water, respectively; $m'=m-M$; T_{soil} and T_{sea} are the temperatures of soil and seawater, respectively; C is the volume content of soil water; $\rho(z)$ and ρ_{sea} are the standard vertical distributions of the densities of dry air and seawater, respectively; $\sigma=-\rho^{-1}\,dp/dz$; g is the gravitational acceleration; R is the universal gas constant for dry air; C_p and C_{sea} are the specific heat capacities of dry air at constant pressure and seawater, respectively; S is the thermal stability parameter; L is the latent heat of condensation; ϕ_{con} is the condensation rate; $\partial N/\partial t$ is the intensity of prescription;

$\partial N/\partial t=(m-m_{cr})/\delta t$ *when* $m>m_{cr}$ *and* $=0$ *when* $m\le m_{cr}$; $\mathrm{m_{cr}}$ is the critical magnitude of the mass fraction of a cloud water; δ t is the time of setting out of a surplus cloud water; D is the diffusion coefficient of water in soil; E is the filtration coefficient of water in a soil; I_{sea} is the total solar radiation flux in sea water; K_{soil} and K_{sea} are the thermal diffusivity coefficients of soil and sea water, respectively; μ and ν are the horizontal and vertical turbulent diffusion coefficients.

The equation of transport of the radioactive nuclide is

$$\frac{\partial Con,i}{\partial t}+u\frac{\partial Con,i}{\partial x}+v\frac{\partial Con,i}{\partial y}+(\tilde{w}-\frac{W_{sed}}{h})\frac{\partial Con,i}{\partial \varsigma}=\mu\Delta Con,i+\frac{\partial}{\partial \varsigma}\nu\frac{\partial Con,i}{\partial \varsigma}-\alpha\, Con,i \quad (4)$$

where, Con,i is the concentration of radioactive nuclide *i*; the index $\alpha=\ln 2/T_{rad}$ is the radioactive-decay constant; T_{rad} is a decay period; W_{sed} is an aerosol deposition velocity. The equation (4) shows that any functions that equal to $Con,i\,(\mathrm{t,x,y},\zeta)\times const$ also obey the equation (4). Therefore we will consider $Con,i\,(\mathrm{t,x,y},\zeta)$ as unit value and then in order to obtain the real magnitude of concentration we are to multiply the calculated field of Con,i by $const$. The set of equations (1) and (2)-(4) are solved in the coordinate systems *(t, x, y,* ζ*)* and *(t, x, y, z)*, respectively.The initial and boundary conditions, the values of background fields, and methods of parameterization of the separate meteorological processes are selected in accordance with specific objectives of modeling.

2.2. Initial and boundary conditions, main parameters of the regional problem The initial and boundary conditions for the set of equations (1) - (4) are

The initial conditions at $t=0$ we have

a) for the system (1)

$$\vartheta'=q'=m'=0\,,\ u=\bar{\bar{u}}\,(0,\ x,\ y,\zeta),\ \ v=\bar{\bar{v}}\,(0,\ x,\ y,\zeta)\,;\,,h=\bar{\bar{h}}\,(0,\ x,\ y)=9000-\delta\left(x,y\right)$$

b) for equations (2) and (3)

$$C=C_0(x,\ y,\ z),\quad T_{sea}=T_{0,sea}(\ x,\ y,\ z)\,,\ T_{soil}=T_{0,soil}(\ x,\ y,\ z)\,, \quad (5)$$

c) for equation (4)

$$Con,i=\begin{cases}Con,i^0\,(x,y,\zeta) & \text{if}\quad (\mathrm{x,y},\zeta)\in\Omega\\ 0 & \text{if}\quad (\mathrm{x,y},\zeta)\notin\Omega\end{cases}.$$

The vertical boundary conditions

d) for the system (1)

$$\frac{\partial\psi}{\partial\zeta}=0,\ \tilde{w}=0,\ \varphi=\varphi_1(t,x,y)+(g/R\overline{T})\Delta\theta(h(t,x,y)-h(0,x,y))\quad ,\ \text{at}\ \zeta=1,$$

$$\left.\begin{aligned}&\nu\frac{\partial \mathrm{u}}{\partial\zeta}=\mathrm{A}|\mathrm{V}|\mathrm{uh}/\Delta\zeta_0, && \nu\frac{\partial \mathrm{v}}{\partial\zeta}=\mathrm{A}|\mathrm{V}|\mathrm{vh}/\Delta\zeta_0,\\ &\nu\frac{\partial\vartheta'}{\partial\zeta}=\mathrm{A}|\mathrm{V}|(\vartheta'-\vartheta'_0)\mathrm{h}/\Delta\zeta_0, && \nu\frac{\partial \mathrm{m}'}{\partial\zeta}=\mathrm{A}|\mathrm{V}|\mathrm{m}'\mathrm{h}/\Delta\zeta_0\\ &\nu\frac{\partial \mathrm{q}'}{\partial\zeta}=\mathrm{A}|\mathrm{V}|(\mathrm{q}'-\mathrm{q}'_0)\mathrm{h}/\Delta\zeta_0, && \tilde{\mathrm{w}}=0\ ,\end{aligned}\right\}\ \text{at}\ \ \zeta=0,\quad (6)$$

e) for equations (2) and (3)

$$\rho_e C_e K_e \frac{\partial T_e}{\partial z} - \rho C_p A|V|(T - T_e)/\Delta\zeta_0 - \rho L_q A|V|(q - q_e)/\Delta\zeta_0 = I_e$$

$$\begin{cases} C = C_{por}\ , & \text{at} \int_0^1 \partial N/\partial t\, d\zeta > 0 \\ D\dfrac{\partial C}{\partial z} = \dfrac{\rho_w}{\rho} A|V|(q - q_e), & \text{at} \int_0^1 \partial N/\partial t\, d\zeta \le 0 \end{cases}, \qquad \text{at } z = \delta_0 \qquad (7)$$

$$\frac{\partial T_e}{\partial z} = \frac{\partial C}{\partial z} = 0\ , \qquad \text{at } z = \delta_0 - 2\,\text{m};$$

f) for the equation (4) the concentration of radioactive pollution In the area of emission during an interval of time 0 – t is given by the formulae

$$Con,i = \begin{cases} Con,i^0 & \text{if } (x,y,\zeta) \in \Omega \quad \text{and} \quad t \le t^0 \\ \dfrac{\partial Con,i}{\partial \zeta} = 0 & \text{if } (x,y,\zeta) \notin \Omega,\ \zeta = 0 \quad \text{and} \quad t \le t^0 \\ \dfrac{\partial Con,i}{\partial \zeta} = 0 & \text{if } \zeta = 0 \quad \text{and} \quad t > t^0 \end{cases}, \qquad (8)$$

$$\frac{\partial Con,i}{\partial \zeta} = 0 \quad \text{if} \quad \zeta = 1.$$

The lateral boundary conditions

$$u = \bar{\bar{u}}(t,x,y,\zeta),\ v = \bar{\bar{v}}(t,x,y,\zeta),\ h = \bar{\bar{h}}(t,x,y),\ \vartheta' = q' = m' = 0,$$

$$\partial\psi/\partial n = \partial h/\partial n = \partial Con,i/\partial n = 0, \text{ if } x = 0, X;\ y = 0, Y,$$

$$\begin{aligned} &\frac{\partial Con,i}{\partial n} = 0, \text{ if } x = 0, X;\ y = 0, Y \text{ and } v_n \text{ directed inward of the domain} \\ &Con,i = 0, \text{ if } x = 0, X;\ y = 0, Y, \text{ and } v_n \text{ directed outward of the domain} \end{aligned}, \qquad (9)$$

where $|V| = (u^2 + v^2)^{1/2}$; ϕ_1 is given function of time and coordinate and shows the magnitude of the pressure in the tropopause; $\Delta\zeta_0$ is non-dimensional thickness of the atmospheric surface layer; X and Y are the coordinates of lateral boundaries; n is a unit normal vector; $\psi = (u, v, \vartheta', q', m')$; index „0" indicates the value of the function at the level $z = \delta_0$; $q'_0 = q_0 - q_{sat}$ on the sea surface and $q'_0 = (q_0 - q_{sat})C/C_{por}$ on the soil surface; C_{por} is the porosity of the soil, index „e" indicates either „sea" or „soil" for the sea and soil surfaces; Ω is a rectangular prism area in vicinity of the lower boundary; Con,i^0 is a known initial magnitude of emitted radioactive ingredient; t_0 is duration of a radioactive emission; C_{soil} and ρ_{soil} are the specific heat capacity and soil density, respectively; C_0, $T_{0,sea}$ and $T_{0,soil}$ are average monthly values for the June of functions C, T_{sea} and T_{soil}, respectively; A and $\Delta\zeta_0$ are constant parameters; $\bar{\bar{u}}, \bar{\bar{v}}$, and $\bar{\bar{h}}$ are the background values of the wind velocity components and atmosphere thickness, respectively; $\bar{\bar{u}}$ and $\bar{\bar{v}}$ are calculated by means of geostrophic wind and quasi-static equations using the known background values of temperature and pressure at the tropopause level $\bar{\bar{\theta}}(t,x,y,\zeta)$ and $\phi_1(t,x,y,1)$, respectively. By vary $\bar{\bar{h}}$, $\bar{\bar{\theta}}$ and ϕ_1 it is possible to obtain the necessary background winds.

Coefficient of vertical turbulence is decreasing in the vertical direction from the value at the surface layer from $5\,\mathrm{m}^2\cdot\mathrm{s}^{-1}$ up to 0.001 $\mathrm{m}^2\cdot\mathrm{s}^{-1}$ at a height of 3-4 km above the Earth's surface. At more high altitudes it equals to 0.001 $\mathrm{m}^2\cdot\mathrm{s}^{-1}$. Coefficient of the horizontal turbulence is equal to $5000\,\mathrm{m}^2\cdot\mathrm{s}^{-1}$. Background value of the relative humidity is equal to 40%, the background value of the water content mass concentration equals to zero.

Other meteorological parameters are the well known values characterizing middle latitudes.

3. Analyze of results

Numerical integration of equations (1) and (2)-(4) with the initial and boundary conditions (5)-(9) are carried out using both the explicit and implicit schemes. In the modelling domain the rectangular finite-difference grid is used with $108\times90\times17$ points having 10 km horizontal steps and the non-dimensional vertical step equalling 1/17. In the soil and sea the number of levels is equal 20, the vertical step equals 10 cm. The temporal step equals 4 min.

The background fields of temperature and pressure are selected in such a manner that they form the South, South-East and South-West background stationary geostrophic winds.

Since we limited ourselves by the Caucasus Region, the calculations were performed for a period up of 48 h. The transfer of the radioactive nuclide ^{131}I was modeled which during 6 h was being emitted in the atmosphere into rectangular prism area Ω (10 km$\times$10 km$\times$1.5km) in vicinity of ANPP (Fig.1). The initial concentration $Ccon,i^0$ =100 arbitrary units (a.u.). The radius of the particles equals 10 μm and corresponding fall-out velocity calculated by Stokes formula is equal to W_{sed} = 1cm/s [21], the decay period T_{rad} =8,02 day.

Figures 2, 3 and 4 show the distribution of the concentration of I^{131} and the wind field obtained in case of the background south wind on the surface level $z = delta = \delta(x, y) + 100$ m and on the altitudes z = 1, 2, 4, 6, 8 km at the moment of the time t = 6, 24 and 48 h, respectively. In Fig. 2 we can note that during 6 h the radioactive emission forms the radioactive cloud over ANPP that by wind and atmosphere turbulence is stretched to the north along the direction of the background wind. The radioactive cloud is located into ellipsoid columns area with maximum horizontal sizes 100 km and

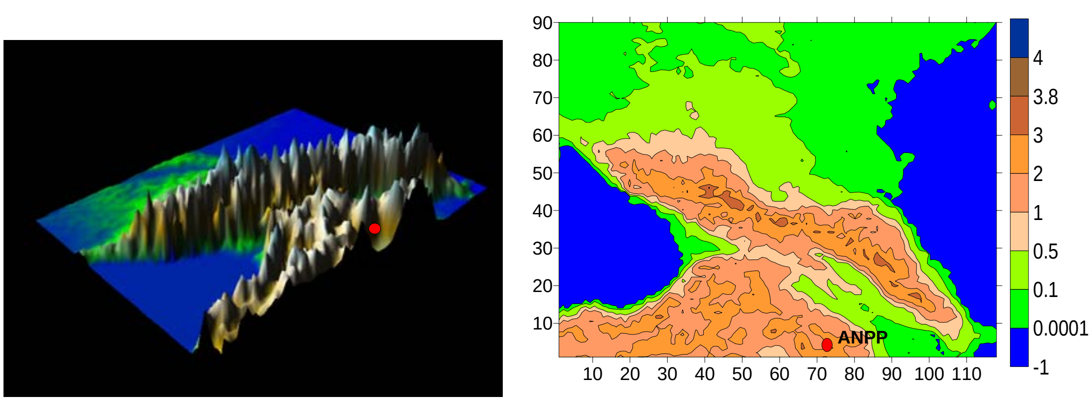

Fig. 1. The Caucasus Region relief and topography (heights in km) and the location of the ANPP (the red circle)

170 km along x and y coordinates, respectively, and with vertical width approximately equal 9 km. The magnitude of the concentration is equal to 100 a. u. into the emission plume in the 4 km layer and exponentially decreases on the periphery of this area.

After six hours the radioactive cloud increases step-by-step in size because of the movement along the wind and atmospheric turbulence; simultaneously the concentration of the pollutant substance decreases in result of the processes of dispersion, deposition, and radioactive-decay. The radioactive cloud in the surface layer at t = 24 h is obtained over the central part of the South Caucasus mainly up of the territory of the north part of the Armenia and the east part of Georgia. Over this surface layer the size of the polluted atmosphere volume gradually increases up to 6 km; the zone of the higher concentration is displaced from the South Caucasus to the North Caucasus (from the East Georgia to the Stavropol Kray). The magnitude of maximal concentration during the 24 hours is decreased down to 0.48 a. u. In the upper troposphere z > 6 km, the size of the polluted area and concentration of radioactive pollution is decreased, and the zone of pollution is wholly located over the North Caucasus.

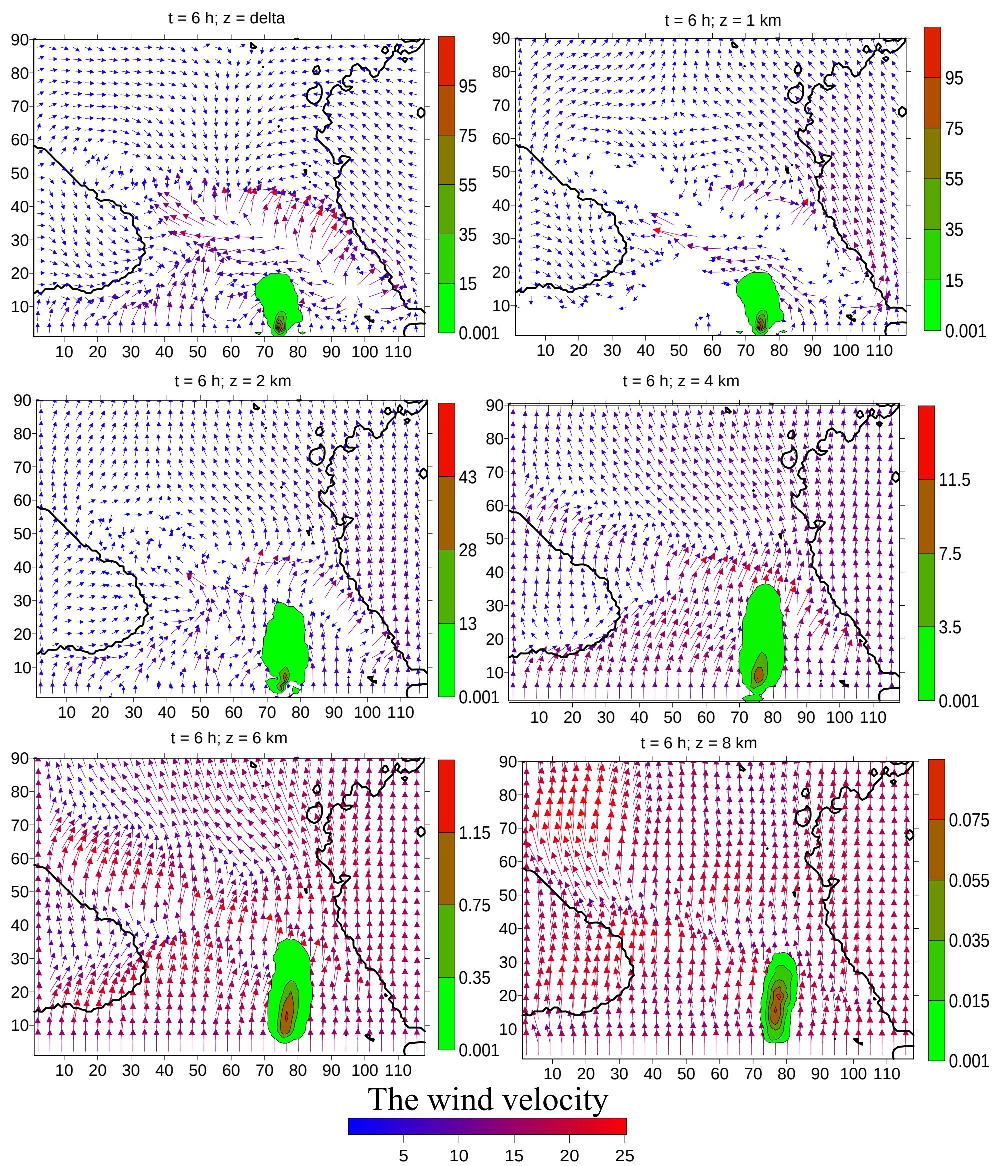

Fig. 2. The spatial distribution of the concentration *Con,i* and wind fields at *t* = 6h.

During two days (Fig. 4) the radioactive cloud mainly moves over territory of the North Caucasus and localizes over the Stavropol Kray. In the South Caucasus the radioactive cloud is obtained over a small territory of the central part of Georgia. The concentration there is small varying between 0.001 - 0.006 a.u. The maximal value of concentration in the plume of pollution caused by the processes of dispersion, deposition, and radioactive-decay is decreased about 2000 times from 100 a. u. to 0.05a.u. The spatial distribution of the radioactive deposition on the earth surface is shown in Fig. 5. As it is shown here, the main part of the radioactive dust falls on the territory of Armenia and Georgia into the stripe of 100 km in width and about 400 km in length. The radioactive ingredient up to 12 h falls out only on the territory of the South Caucasus. After this time the process of fallout begins also on the territory of the North Caucasus. After 20 h from the beginning of emission the radioactive fallout happens mainly on the territory of the North Caucasus and at t = 48 h the surface density of ^{131}I on the territory of the north slope of the Main Caucasus Range reaches 10 a.u. on 1 m^2. The radioactive deposition on the territory of the South Caucasus ends after 30 h.

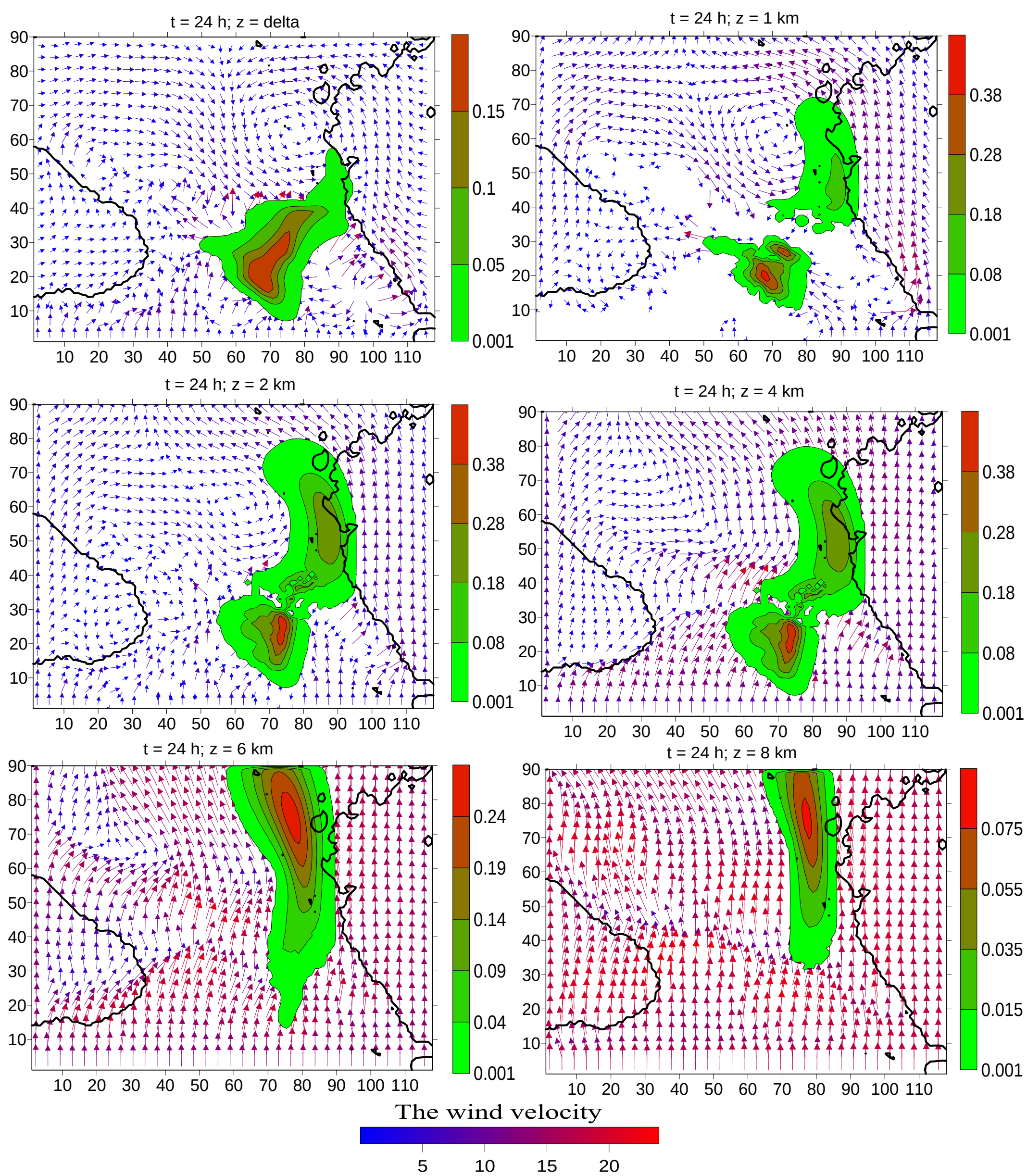

Fig. 3. The spatial distribution of the concentration *Con,i* and wind fields at t = 24 h.

The results of the numerical modeling of the radioactive diffusion when the background south-east wind is considered are shown in Fig. 6. The calculation shows that the radioactive pollution moves to the north firstly on the territory of Armenia and then over the central and north-west parts of the Caucasus Region. At t = 24 h the main part of atmosphere over Georgia is polluted by radioactive ingredient. Further the radioactive cloud falls over the Main Caucasus Range, splits in two parts and at t = 48 h we obtain two zones of the radioactive pollution. One of these zones is located over the Black Sea and another over the north slope of the Main Caucasus Range. The radioactive deposition obtained at t =0, 24 h and 48 h are also shown in Fig. 6. We see that in 48 h the radioactive fallout mainly happens on the territory of the north part of Armenia, the south, central, and north-west parts of Georgia. The small amounts of the radioactivity are also deposited on the territories of Turkey and Russian.

The maximal magnitude of he surface density at t = 48 h is equal to 360 a.u./m^2 and is obtained in vicinity of source of emission.

When the background south-west wind blows, the radioactive pollution diffuses in the atmosphere over the north-east part of Armenia, whole territory of Azerbaijan, Republic, Dagestan, and the Caspian Sea (Fig. 7). The atmosphere in vicinity of east border of the Georgia will be polluted also.

4. Discussion

This article is our first investigation about of the possible radioactive pollution of the Caucasus territory in case of the accident takes place in ANPP. In this article, the problem of distribution of the radioactive element ^{131}I with diameter 10 μm is discussed. Such modeling can be made for other radioactive radionuclides.

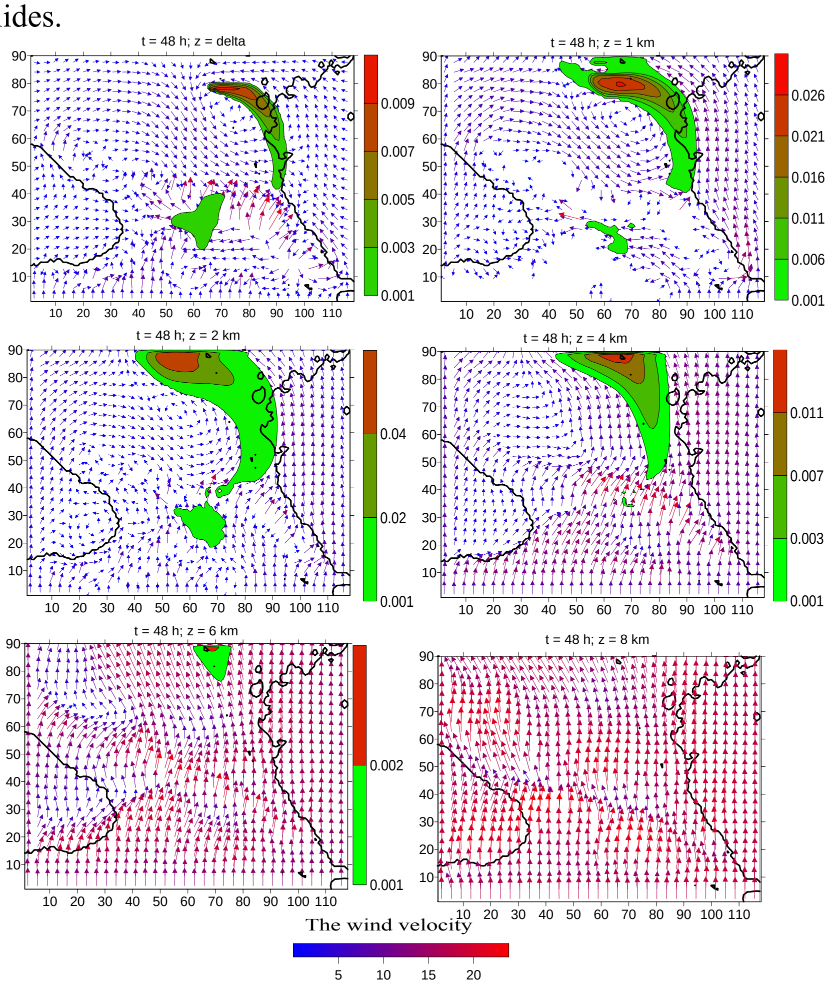

Fig. 4. The spatial distribution of the concentration *Con,i* and wind fields at *t* = 48 h.

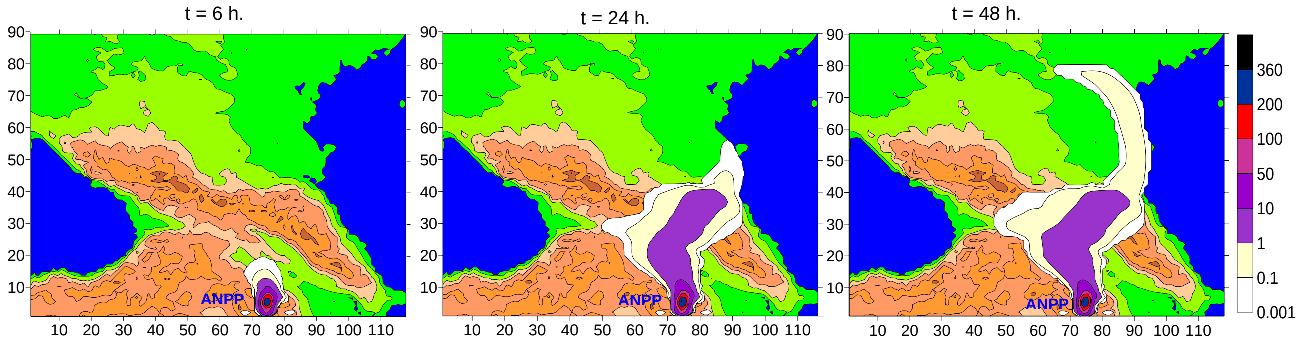

Fig. 5. Distribution of the surface density of the radioactive deposition at t = 6, 24 and 48 h

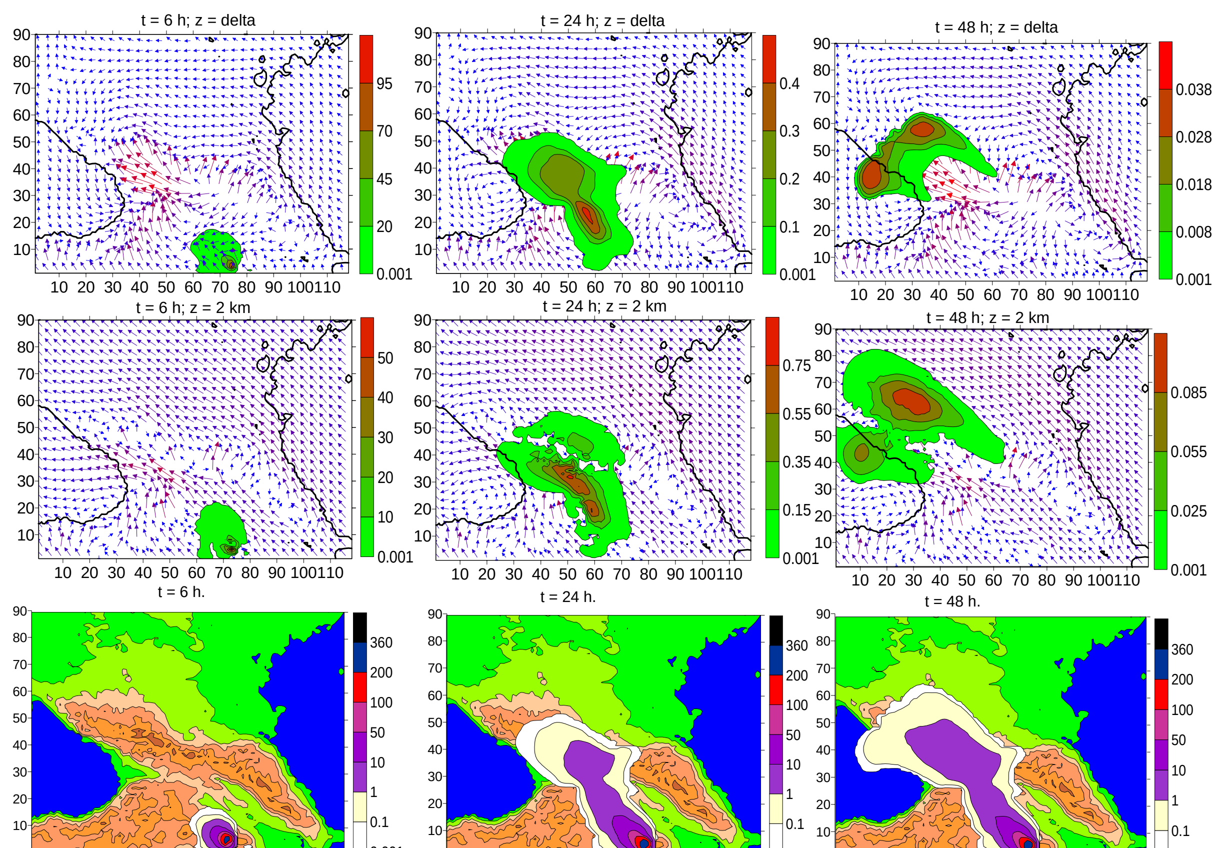

Fig. 6. Concentration of the radioactive substance in the atmosphere (upper six figures) and surface density of the radioactive deposition of ^{131}I (lower three figures) in case of the south-east background wind.

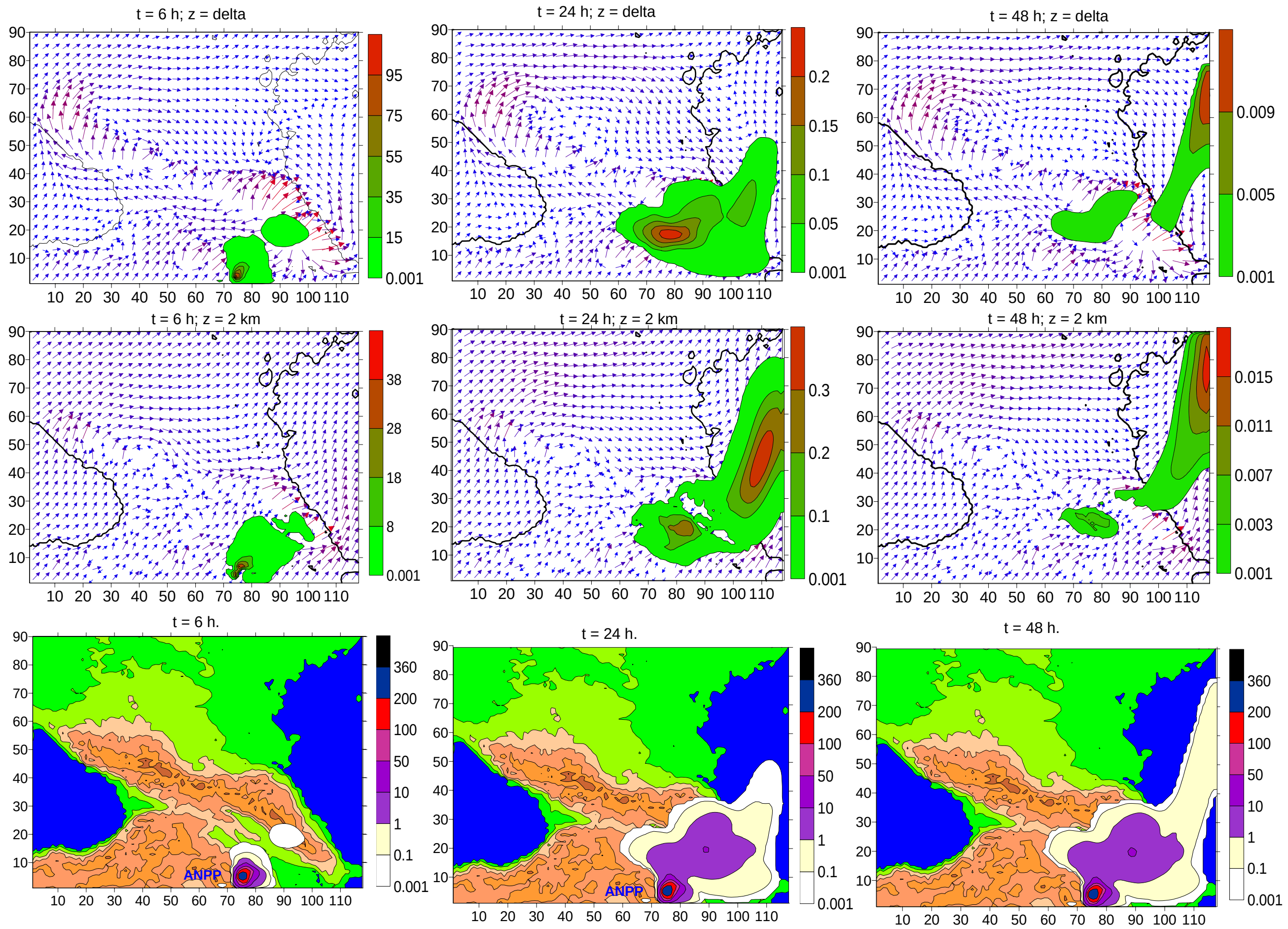

Fig. 7. Concentration of the radioactive substance in the atmosphere (upper six figures) and a surface density of radioactive deposition of ^{131}I (lower three figures) in case of the south-west background wind

It is evident, that the sum of obtained concentrations and radioactivities will give us the main picture of the possible radioactive contamination.

The radioactive pollution falls out mainly on the central, southeast, and northwest parts of the South Caucasus. The zone of radioactive deposition is extended along the background wind and deformed by influence of the relief. In case of the background southeast wind the maximal length of the zone of significant deposition of radioactive substance is approximately equal 750 km and – 350 km in other cases. The maximal width of this zone equals approximately 150 km. The concentration of deposited radioactive element in the zone of radioactive fall-out decreases from 360 a.u./m^2 down to 1 a.u./m^2.

For the reason of the absence of the observation data it isn't possible to estimate a quantitative reality of the obtained results. But, having compared the trajectory and shape of the radioactive cloud obtained in this article and in other works [1, 10, 15-17], it may be concluded that the obtained results properly describe the main features of the radioactive dispersion process in the Caucasus. Therefore, the model and results obtained here can be considered as first approximation for the further investigation and practical use. In addition, in our opinion, the spatial grid step 10 km is rather large for adequate description of studied process over complex terrain of Caucasus. We intended simulating the diffusion processes of radioactive pollution with the horizontal step approximately equal to 1-5 km in the atmosphere of the Caucasus.

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Численное исследование модельного распространения и осаждения радиоактивного загрязнения (^{131}I) в случае гипотетической аварии на Армянской атомной электростанции

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Резюме

С помощью региональной модели развития атмосферных процессов в Кавказском регионе и уравнения переноса примеси исследовано пространственное распределение радиоактивного загрязнения (^{131}I) в атмосфере в случае возможной гипотетической аварии на Армянской атомной электростанции. В модели учтены процессы радиоактивного распада и осаждения на подстилающую поверхность. Распространение радиоактивного загрязнения смоделировано для случаев южного, юго-западного и юго-восточного ветров и радоактиного аэрозоля с диаметром 10 мкм.

Показано, что рельеф Кавказа в приземном слое атмосферы существенно влияет на траекторию распространения радиоактивной примеси. Ориенторованный на северо-запад Большой кавказский хребет, препятствуя перемещению воздуха на север, заставляет основную часть загрязнения обтекать препятствие с северо-взападной или с северо-восточной стороны, и далее распространиться над территорией Северного кавказа. Получено, что радиоактивному облаку необходимо проблизительно 48 часов для перетекания через Южный кавказ. Основная часть радиоактивного загрязнения выпадает над центральной, северо-западной и юго-восточной частями Южного кавказа. Зоны радиоактивного осаждения вытянуты вдоль фоновых ветров и частично деформированы под влиянием рельефа территории. Максимальная длина зоны значительного выпадения радиоактивного вещества приблизительно равна 750 км в случае фонового юго-восточного ветра и - 350 км для других направлений фоновых ветров. Получено, что когда в течение первых 6 часов концентрация частиц с диаметром 10 мкм равна 100 п.е./м^3 (произвольная единица/м^3), тогда поверхностная плотность выпавшего радиоактивного вещества в зоне максимального загрязнения уменьшается от максимального значения 360 п. е./м^2 до 1 п. е./м^2.

რადიაქტიური დაბინძურების (^{131}I) გავრცელების და დალექვის რიცხვითი გამოკვლევა სომხეთის ატომური ელექტროსადგურის ჰიპოთეტური ავარიის შემთხვევაში

ა. სურმავა

რეზიუმე

კავკასიაში ატმოსფერული პროცესების განვითარების რეგიონალური რიცხვითი მოდელისა და მინარევის გავრცელების განტოლების გამოყენებით შესწავლილია სომხეთის ატომური ელექტროსადგურიდან ატმოსფეროში ჰიპოთეტური შესაძლო ავარიის შედეგად ამოფრქვეული რადიოაქტიური ელემენტის ^{131}I-ის გავრცელება ფონური სამხრეთის, სამხრეთ-დასავლეთის და სამხრეთ-აღმოსავლეთის ქარების შემთხვევაში. გათვალისწინებულია რადიოაქტიური დაშლისა და აეროზოლის დალექვის პროცესები. განხილულია მხოლოდ 10 მკმ დიამეტრის რადიოაქტიური ნუკლიდის გავრცელება.

ნაჩვენებია, რომ კავკასიის რეგიონის რელიეფი ძლიერად მოქმედებს მინარევების გავრცელებაზე. პარალელის გასწვრივ ორიენტირებული კავკასიონის ქედი, ეწინააღმდეგება რა ჰაერის ჩრდილოეთით მოძრაობას, აიძულებს რადიოაქტიური ნივთიერების ძირითად ნაწილს, გარსშემოედინოს მთავარ კავკასიონის ქედს დასავლეთის ან აღმოსავლეთის მხრიდან და შემდგომ გავრცელდეს ჩრდილოეთ კავკასიაში. გამოთვლებით ნაჩვენებია, რომ დაახლოებით 48 საათია საჭირო იმისათვის, რომ რადიოაქტიური ღრუბელი გადაევლოს სამხრეთ კავკასიას და გავრცელდეს ჩრდილოეთ კავკასიაში. რადიოაქთიური ნივთიერება ძირითადად ილექება სამხრეთ კავკასიის ჩრდილო-დასავლეთ, ცენტრალურ და ჩრდილო-აღმოსავლეთ ნაწილებში ფონური სამხრეთ-აღმოსავლეთის, სამხრეთის და სამხრეთ-დასავლეთის ქარების შემთხვევებში, შესაბამისად. დიდი რაოდენობით დალექვის ზონის სიგრძე დაახლოებით 750 კმ-ის ტოლია სამხრეთ აღმოსავლეთის ფონური ქარის დროს, და – 350 კმ-ის სხვა შემთხვევებში. ამ ზონის სიგანე დაახლოებით 150 კმ-ს უდრის. მიღებულია, რომ როდესაც 10 მკმ ზომის აეროზოლის ამონაფრქვევის კონცენტრაცია ამონაფრქვევ ჭავლში 6 სთ-ის განმავლობაში 100 პ.ე./მ^3–ის (პირობითი ერთეული/მ^3) ტოლია, მაშინ დალექილი რადიაქტიური ნივთიერების ზედაპირული სიმკვრივე მაქსიმალური დალექვის ზონაში მცირდება 360 პ.ე./მ$^{2-}$დან 1 პ.ე./მ^2-მდე.