ASSESSMENT OF AIR POLLUTION DISTRIBUTION FROM RADIOACTIVE SOURCES AND ITS IMPACT ON HUMAN HEALTH

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Abstract: The paper assesses the concentration of gas aerosols produced as a result of radioactive sources emission. A Gaussian diffusion model is used for calculation of the particle concentration, and the Cs_{137} isotope is taken as an example of the particles. The determination of the dispersion parameters used in the Gaussian model will be carried out using the Pasquill-Gifford and Briggs' method. Based on calculated concentrations of radionuclides, their impact on human health will be analyzed.

Keywords: radioactivity, Gaussian model, Air pollution

INTRODUCTION

The aim of the paper is to analyze the distribution of radioactive admixture from a point source and to point out to its impact on human health. This is especially significant in light of the fact that our country was exposed to the uranium depleted missiles, which is the source of radioactive radiation, in the armed action of the NATO Pact in 1999.

Discharging hazardous substances into the atmosphere, whether accidentally (due to human negligence, plant failures, natural disasters, mistakes in the transport of dangerous goods) or deliberately (in terrorist attacks) pose a great danger to the population and infrastructure.

The problem of air pollution is a global problem as it affects practically all countries in the world, i.e. all their regions, settlements, socioeconomic and age groups. Air pollution is the biggest threat to environmental protection and is responsible for one in nine deaths per year, which is about 3 million people each year (Neira, 2016). It can be said that air quality represents a marker for the sustainable development of the society. It is therefore necessary to get to know the basic characteristics of the atmosphere and the elements that reach it.

The atmosphere surrounds our planet and extends practically infinitely. In a layer of 5 km there is about 50% of all air, and about 90% of the total air in the layer up to 20 km. The atmosphere is exposed to the influence of thermal solar radiation and, therefore the air tempera-

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ture in the atmosphere is inhomogeneously distributed. According to the temperature change with height, the atmosphere is divided into 5 characteristic layers. From the standpoint of atmospheric diffusion of the admixture, the most significant layer is up to a height of 11 km, which is called a troposphere.

The temperature drops in that layer as it moves away from the earth's surface, by approximately 0.65 ° C for every 100 m. If it is assumed that the temperature is 15 ° C (288 ° K) at sea level, then the temperature at the outer limit of the troposphere is -56 ° C (217 ° K). Above this layer at a height of up to 40 km there is a stratosphere in which the temperature does not change with height. About 75% of the total air volume of the atmosphere is located in the troposphere. Thermal, hydrodynamic, chemical, photochemical, electromagnetic and other processes continuously flow in the atmospheric air thus determining the temperature, pressure, speed of movement, and chemical composition of the air masses.

The basic amount of admixtures in the atmosphere is, by their composition, divided into gaseous, solid and liquid substances. Thereby, gaseous substances (carbon dioxide, sulfur dioxide, hydrocarbons, nitrogen oxides, organic compounds) make up about 90% of the total. The amount of solid substances (dust, heavy metals, radionuclides, mineral and organic compounds) accounts for about 10% of the total. Mass of liquid substances, such as, for example sulfuric acid is negligible in the first two categories. The lifetime of the most important gaseous substances (types of nitrogen oxides and sulfur dioxide, as well as the products of their reactions, e.g. SO_4, NO_3...) is from several hours to several weeks. During the time when these admixtures move from the source to the moment they settle down on the surface of the earth, they cross the distances from ten to several hundred meters. The deposition of the admixture can be dry or damp.

Aerosols or solid admixtures are divided according to their radius into: microscopic ($r < 0.1$ μm), medium ($r = 0.1$-1μm) and large ($r > 1$μm).

RADIOACTIVE ADMIXTURES

The paper will consider the impact of radioactive substances on the atmosphere and their impact on human health in particular. The basic difference between the impact on the living world of radioactive substances and chemical substances is that chemicals act directly and proportionally to the amount of substance in the body, while radioactive substances have additional effect due to the radiation of ionizing radiation both directly and remotely.

There is a natural radioactivity in our environment. It occurs with spontaneous disintegration of radioactive nuclei-radioactive nuclei-transformation into other nuclei with accompanying ionizing radiation. In most cases, the decay is accompanied by the emergence of the so-called radioactive series. The disintegration ultimately ends with the formation of stable nuclei. Depending on the core decomposition scheme, there are simple (linear) series and complex series (scheduling). The percentage of the transformation of the parent radionuclide into the nucleus of the daughter is defined by the branching coefficient. All known radioactive nuclei are combined with an isobaric sequence with a mass number A = 166. The constant of radioactive decay is $\lambda = 0,693T_{1/2}$ where $T_{1/2}$ is the period of half-life. The law of radioactive decay in the function of time is given as (Marinkov, 1976)

$$N(t) = N(0)\exp(-\lambda t)$$

where $N(0)$ is the number of atoms at the initial moment. Equation of the equilibrium of nuclei in a radioactive nuclear series is a system of ordinary differential equations (Marinkov, 1976)

$$\frac{dN_i(t)}{dt} = -\lambda_i N_i(t) + \lambda_{i-1} N_{i-1}(t),$$

where N_1 is the number of the parent nuclei, and - the number of nuclei of the daughter nucleus. The activity of the source is. The SI unit of activity is Bekerel (Bq), which represents one decay in one second. The volume activity has a unit (Bq/m^3). Radioactive transformations are achieved by α decay, β- and β + decay, electron interaction and radiation of γ radiation. The largest number of radionuclides decomposes with β-decay especially radionuclides from the mass number $A = 72$ to the mass number $A = 166$.

Generally, radioactive admixtures get into the atmosphere from three basic sources:

1. from radioactive elements of the Earth's crust and their decay products (natural radioactivity)
2. from cosmos through the reaction of air with cosmic radiation
3. due to nuclear tests, a nuclear reactor

The main sources of radioactive admixtures are nuclear power plants, nuclear explosions trial, nuclear reactors, depleted uranium used in military missiles. The most dangerous to human health are radioactive substances with large periods of half-life. The most characteristic are ^{90}Sr and ^{137}Cs. Thanks to the clarity, ^{90}Sr is deposited in bone tissue, and ^{137}Cs are deposited in muscle tissue, replacing K.

The composition of radionuclides depends on the characteristics of the source (reactor) and the radiation characteristics of the products of fission and actinide. Inertial radioactive gases and isotopes of iodine play a major role in the formation of radiation regimes in some areas. As a rule, 18 isotopes of Krypton, 15 isotope of Xenon, 20 isotopes of iodine enter the composition of radionuclides formed as fragments of the reaction (Marinkov, 1976). Many of them have a small half-life period ($T_{1/2} < 1$ min) or enter a negligible small fraction into the total activity of the radionuclide of the given group. A group of long-lived fission products consists of ^{89}Sr, ^{90}Sr, ^{134}Cs, ^{137}Cs radionuclides, and also ^{95}Zr, ^{95}Nb, ^{141}Ce, ^{144}Pr.

Analyzing the effect of radioactivity on living organisms, it should be emphasized that radioactive radiation:

1. weakens the organism, reducing its immunity and slowing down its growth
2. reduces the reproductive ability of an organism, leading to temporary or permanent sterility
3. damages genes that occur in the second or third generation

The paper will particularly analyze isotope^{137}Cs and isotope ^{131}I. Nuclear waste consists of cesium 137. Its concentration of activity in the northern Earth hemisphere, especially in Europe, increased significantly after the Chernobyl disaster in 1986. It is known that ^{137}Cs is an artificial radionuclide which is formed by fission. It did not exist in nature before the start of nuclear tests and accidents at nuclear plants. According to some studies, the genetic risk of ^{137}Cs is the highest, so it is of particular importance to examine its migration and change the concentration of activity. Especially because the half-life of the other elements is from a few days to ten years, and all except the ^{137}Cs have generally disintegrated.

^{131}I is an isotope of radioactive iodine with a half-life of 8 days, with energy of 364 keV. It has accompanying negative β radiation emissions. The iodine- I^{131} isotope can in a short time, $T_{1/2} = 8.04$ days cause damage to the thyroid gland, and cesium ^{137}Cs affects genetic changes.

Meteorological factors play a major role in the processes of atmospheric pollution and the precipitation of radioactive pollutants. The degree of danger in a particular case of radioactive

pollutants emission depends on the meteorological situation at a given moment, while the potential danger of continuous radioactive substances being emitted into the atmosphere depends on the mean meteorological conditions of the given region and is estimated on the basis of the calculation of transport processes and the diffusion of radioactive substances in the given, concrete climatic conditions taking into account the thermal state of the atmosphere.

MODELLING OF AIR POLLUTION PROCESSES

Pollution concentration measurements provide important quantitative information on the state of air quality at specific locations at a particular point in time. They cannot point out the reasons leadingto air quality problems. For the measurement of the concentration of harmful gases a variety of physical, chemical, physic-chemical and electrochemical methods can be used. The limit values for concentration of hazardous gases at the site of the accident are determined by regulations. The measurement results can be presented in the form of a weight ratio of the dangerous substance and a gas volume unit, e.g. $\mu g/m^3$ or as a flow (mass of the dangerous component in the unit of time: mg/h, g/h and the like). To measure the emission of hazardous gases, continuous methods are used (continuous measurement over a longer period of time) and discontinuous (measuring the concentration of gases in a shorter time interval). Measurement is of great importance for determining the effect of concentration of hazardous gases on the health of the population and the environment (Nikezić, 2017).

The modeling of air pollution gives a complete deterministic description of the occurrence of the problem of air pollution, including the analysis of cause-and-effect relationships between different parameters (the number and spatial distribution of pollutant emissions sources, terrain topography around the source, meteorological conditions, such as wind direction and wind speed, stability of the atmosphere and temperature gradients, physicochemical changes of pollutants, etc.), as well as some guidelines on the application of pollution mitigation measures. The results of the applied model can help us assess the appropriate locations for measuring stations, for various legal, research or forensic applications.

Starting from the method of mathematical description of the substance dispersion process, three classes of the model for the analysis of air pollution can be distinguished: Lagrange, Euler and Gaussian. Lagrange and Euler methods belong to the class of deterministic models by which the concentrations of dangerous gases can be calculated by different methods of solving the equation of turbulent diffusion (Daly, 2007). Most software applications for assessing air pollution expansion, which are now used in practice, are based on the application of the Gaussian method, which belongs to the class of statistical models. Therefore, only the Gaussian model (Lazaridis, 2011) is presented in the paper.

GAUSSIAN MODEL

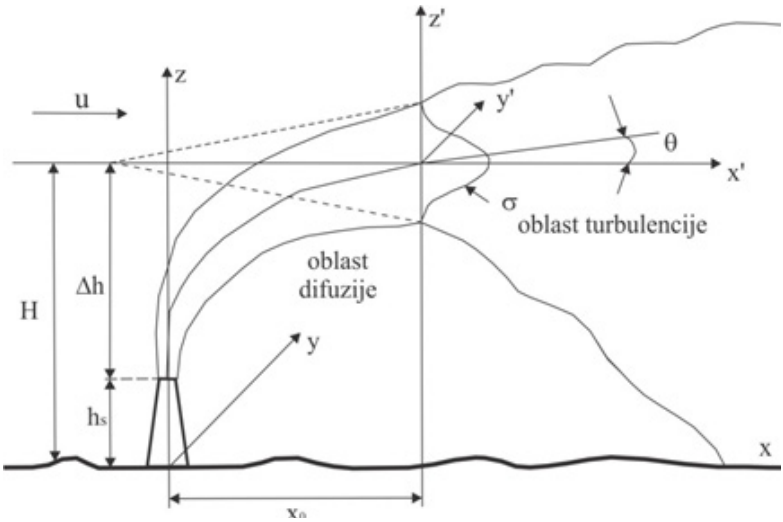
This paper discusses a point source that continuously emits radioactive substances in the atmosphere. According to Gaussian model, the concentration of an admixture at an arbitrary point of space for this case can be calculated as (Hanna, 1982):

$$C(x,y,z)=\frac{Q}{2\pi\sigma_y\sigma_z u}\exp(-\frac{\lambda x}{u})\left[\exp\left(\int_0^x\frac{dx}{\sigma_z\exp\left(\frac{H^2}{2\sigma_z^2}\right)}\right)\right]^{-\frac{\sqrt{2/\pi}}{v_d/u}}\times$$

$$\times\exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left[\exp\left(-\frac{(z-H)}{2\sigma_z^2}\right)+\left(-\frac{(z+H)}{2\sigma_z^2}\right)\right]$$

Figure 1 Principal scheme of radioactive admixture scattering in the atmosphere

where the $C(x,y,z)$ is mean volume concentration of radioactive pollutants at point (x,y,z) in $\mathrm{Bq/m^3}$. Here, Q is the power of the source of pollutants in Bq, $u(\mathrm{m/s})$ is the wind speed, $\sigma_i(i=x,z,y)$ are the dispersion ratios of the pollutants in the appropriate directions, $\exp(-\lambda x/u)$ is the radioactive decay of the corresponding nucleotide, $v_d(\mathrm{m/s})$ the deposition rate of the given nucleotide, $H=(h_s+\Delta h)\,(\mathrm{m})$ the effective height of the source h_s (the height of the source, Δh the medium height of the flue gas perch). This relation applies in the case of a point continuous source,



when a dry deposition of radioactive pollutants is carried out, where a part of the pollutants are deposited on the surface of the earth, and the part reflects and returns to the atmosphere. Due to circulation of air masses, radioactive dust and aerosols spread to large areas and fall to the surface of the earth.

For a practical calculation of the ground-level concentration of the substance, it is necessary to determine the values of the coefficient of dispersion $\sigma_y(x)$ and $\sigma_z(x)$ as a function of the distance from the source along the wind direction, i.e. from x as well as from the condition of the atmosphere stability. There are several ways to determine them, but there is no universal method. As a rule, the method determines the target of the calculation. Most of the physics experts in the boundary layer of the atmosphere use the Pasquill-Gifford method. Another method which will be used in the work is the Brigs method. The formulas used for the

dispersion coefficients are applicable up to a distance of 10 km from the source, a 3 cm field relief for rural areas and 1 m for urban environments and a time of 1 hour from the emission of an admixture from the source. There are other methods, such as Irvin's, which will not be considered in this paper (Builtjes, 2010).

Pasquill-Gifford method

Analytic expressions for the dispersion coefficient based on the Pasquill-Gifford curve are (Lazaridis, 2016; Hanna, 1982):

$$\sigma_y = \frac{r\,x}{\left(1+\frac{x}{a}\right)^p}; \quad \sigma_y = \frac{s\,x}{\left(1+\frac{x}{a}\right)^q}$$

where the parameters r, s, p, q depend on the atmospheric stability class and are given in Table 1.

Table 1. Analytical expressions for dispersion coefficients according to Pasquill-Gifford

Stability class	A	B	C	D	E	F
r(m/km)	250	202	134	78.7	65.6	37
s(m/km)	102	96.2	72.2	47.5	33.5	2
a(km)	0.927	0.370	0.283	0.707	1.07	1.17
P	0.189	0.162	0.134	0.135	0.137	0.134
q	-1.918	-0.101	0.102	0.465	0.624	0.70

Briggs' model

According to the Briggs' model, the parameters of the dispersion coefficients are determined on the basis of Table 2.

Table 2. Analytical expressions for dispersion coefficients according to Briggs

Stabilit y class	A	B	C	D	E	F
$\sigma_y(x)$	$\frac{0,32x}{\sqrt{1+0,0004x}}$	$\frac{0,32x}{\sqrt{1+0,0004x}}$	$\frac{0,32x}{\sqrt{1+0,0004x}}$	$\frac{0,16x}{\sqrt{1+0,0004x}}$	$\frac{0,11x}{\sqrt{1+0,0004x}}$	$\frac{0,11x}{\sqrt{1+0,0004x}}$
$\sigma_z(x)$	$\frac{0,24x}{\sqrt{1+0,001x}}$	$0,24x$	$0,20x$	$\frac{0,14x}{\sqrt{1+0,0003x}}$	$\frac{0,08x}{\sqrt{1+0,00015x}}$	$\frac{0,08x}{\sqrt{1+0,00015x}}$

RESULTS OF THE EXPERIMENTAL EXAMPLE

For the analysis and the graph display of the reduced concentration of admixtures ($C_r = C / Q$) depending on the distance from the source along the wind direction (x), the following values of the parameters were adopted: $H = 21{,}5$ m , $u = 1{,}5$ m/s , $v_d = 0{,}35$ m/s and the atmospheric stability class D (neutral) was taken to determine the dispersion coefficients. The radioactivity constant ^{137}Cs is $\lambda = 7{,}32 \cdot 10^{-10}$ s^{-1}, and the iodine radioactivity constant is ^{131}I (Essa, 2005).

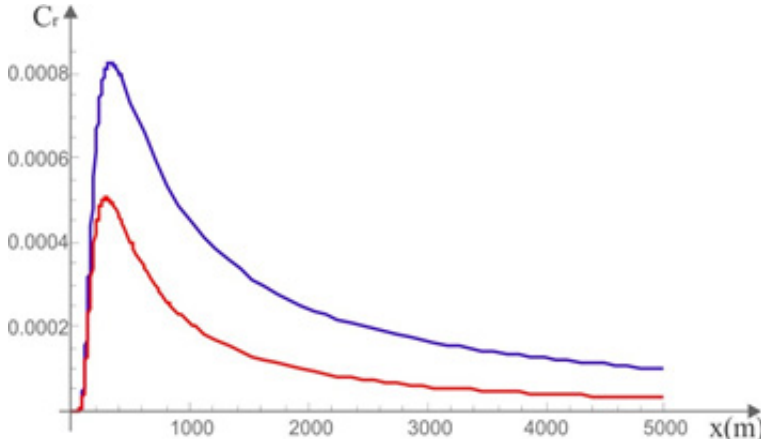


Figure 2 . Relative concentration for ^{137}Cs at different heights from the ground. The values z = 0 m corresponds to the red line, z = 50 m blue line, and z = 100 m corresponds to the black line

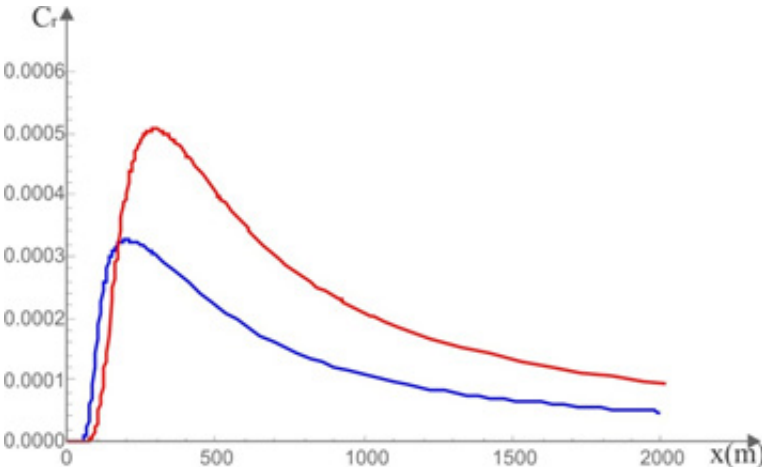


Figure 3. Relative concentration ^{131}I (blue line) and ^{137}Cs (red line) into the function of distance from the source

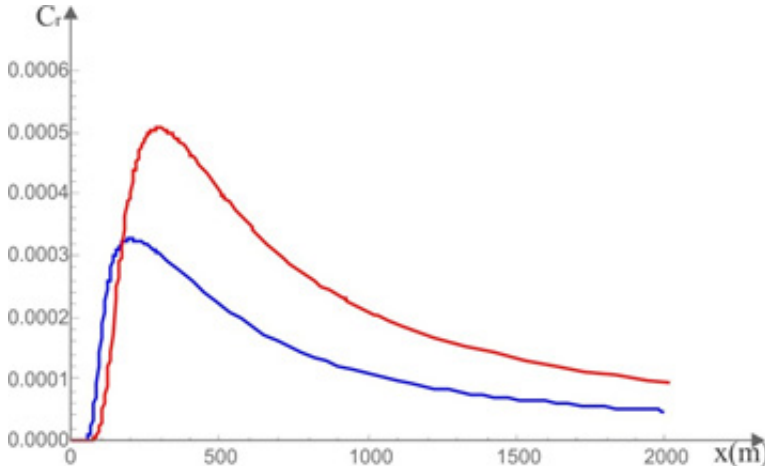


Figure 4. Relative concentration in the function of x-distance in case of the choice of dispersion coefficients by the Pasquill-Gifford method (red line) and the Brigs method (blue line) for ^{137}Cs

CONCLUSION

From the calculations and the attached graphics, it is clear that the concentration of radioactive admixture grows in the vicinity of the source of the emission, it reaches the maximum value at a certain distance and with the increase in distance it decreases.

Likewise, the ground concentration (z = 0 m) has a higher value than the concentration at the same distance at a height of 50 m, which again is higher than the concentration at a height of 100 m from the ground at the same distance (Figure 2).

Furthermore, it can be noticed (Figure 3) that the isotope concentration of iodine ^{131}I is greater than the ^{137}Cs concentration at the same distances from the source. This arises probably from the fact that the isotope ^{131}I has a shorter life time than the isotope^{137}Cs, which means that more particles disintegrate in the unit of time, i.e. have more activity.

If for the choice of dispersion coefficients for the same class of stability Pasquill-Gifford method is used, higher values of the relative concentrations of radioactive nuclei are obtained than in the case of using the Briggs' method.

All admixtures that pollute the air, in one way or another, have a negative effect on human health. These substances come into the body primarily through respiratory organs or food intake. Breathing organs are directly harmed as about 50% of the particles with a radius of 0.01-0.1 μm penetrate into the lungs and stay in them. Considering that light radioactive admixtures are maintained for about 2 years in the stratosphere, 1-4 months in the upper parts of the troposphere and 6-10 days in the lower troposphere and that the mean wind speed is 30-35m / s, it is clear that these admixtures cross large distances from their source. For human health, the most dangerous are radioactive substances with a large period of half-life. The most characteristic are ^{90}Sr and ^{137}Cs. Thanks to similarity to Ca, ^{90}Sr is found in bone tissue, and ^{137}Cs are deposited in muscle tissue, replacing K. Additionally, iodine ^{131}I due to a short

period of half-life is very dangerous for human health because it can damage the thyroid gland very quickly.

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