Evaluation of the effect of the Ryazan' Electric Power Plant on the environment and human health

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1 Introduction

Based on the ecological models and using the program means developed at the Institute of Radiation Physics and Chemistry Problems (IRPCP) of the Belarus Academy of Sciences and the Nuclear Safety Institute (NSI) of the Russian Academy of Sciences, an extensive work was carried out on the example of the REPP to evaluate the effect of the operation of a large thermal electric station on human health and contamination of the environment with heavy metals.

Brief description of the REPP-basic performance specification
Installed power - 2720 MW. Quantity and power of sets - 4 x 300 MW (coal);
2 x 800 MW (fuel oil, gas).
Fuel - gas, fuel oil, coal.
Year of commissioning - 1981.
REPP is one of the most efficient ones. The specific equivalent fuel consumption of 800-MW sets is 335.5 g/kWh.

2 Calculation of the ground-level concentrations and precipitation of hazardous substances as a result of the operation of the REPP

Below a procedure is described for calculating the ground level concentrations and fallouts averaged over a long-term period of ejection of hazardous substances into the atmosphere in standard operation of the REPP. The procedure is based on the use of the Lagrangian stochastic model of transfer in the atmosphere that makes it possible to more accurately take into account (as against standard Gaussian procedures) the entire variety of meteorological conditions and also the polydispersity of the source of emission.

On the first stage, simulation and numerical calculation of the emission of hazardous impurities in a gaseous and solid phases were made. These calculations were carried out on the basis of the program module "SMOG" developed at the Institute of Radiation Physics and Chemistry Problems (IRPCP) of the Belarus Academy of Sciences that makes it possible to calculate the total emission of the main dangerous impurities with consideration of the technical characteristics of the thermal plant and of the presence of harmful substances in the fuel used. The data on the total yearly emission in 1996 of heavy metals at the REPP, calculated with the aid of the "SMOG" module, are presented in Table 1.

Table 1 Total emission of heavy metals at the REPP (kg/yr) [1].

Metal	Cr	Ni	Cu	Zn	As	Pb	Hg	Se	Cd
Mi_z	236,4	2959	437,5	18505	294	2351	192,5	60	1152

On the second stage, on the basis of the data of the regional meteorological station for 1996, simulation of the transfer of gaseous and aerosol emissions was made and also calculation of the ground level concentrations and fallouts using the “NOSTRADAMUS-ZONE” program complex. The calculations were made for the territory of the sanitary restriction zone of the REPP with rather a realistic simulation of the size distribution function of aerosols and eight-point averaging of the wind rose.

3 Lagrangian stochastic procedure of the propagation of contaminants in the atmosphere

A stochastic trajectory model of impurity propagation in a nonuniform velocity field. The transfer and diffusion equation that describes the propagation of impurity in the atmosphere has the form [2]:

$$\frac{\partial c}{\partial t}+\frac{\partial Uc}{\partial x}+\frac{\partial Vc}{\partial y}+\frac{\partial Wc}{\partial z}=\frac{\partial}{\partial x}\left(K_x\frac{\partial c}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y\frac{\partial c}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z\frac{\partial c}{\partial z}\right)+Q+S \qquad (1)$$

In this equation c is the volumetric concentration; U and V are the horizontal components of the wind velocity; $W = W - W_g$; W is the vertical component of the wind velocity; W_g is the rate of gravitational precipitation; K_x and K_y are the coefficients of horizontal diffusion; K_z is the coefficient of vertical diffusion; Q is the emission source power; S is the term taking into account precipitative washout; chemical conversions.

The calculation of the concentration of the impurity propagating in a complex field of the wind velocity is based on Boughton, Delauentis and Dunn’s system of stochastic equations for the coordinates of the particles:

$$\frac{dX}{dt}=U+U^1;\frac{dV}{dt}=V+V^1;\frac{dZ}{dt}=W+W^1 \qquad (2)$$

U^1, V^1, and, W^1 are the components of the wind velocity fluctuation; these are random quantities. The system of stochastic eqn. (2) can be written in the form

$$dX=Udt+\sigma_X a_X;\ dY=Vdt+\sigma_y a_y;\ dZ=\left(W+\partial K_Z/\partial Z\right)dt+\sigma_Z a_Z \qquad (3)$$

where a_x, a_y, and a_z are the random quantities with the Gaussian probability distribution, with a single variance and zero expectation value. If $\sigma_X=\sqrt{2K_X dt}$; $\sigma_y=\sqrt{2K_y dt}$; $\sigma_Z=\sqrt{2K_Z dt}$, the system of stochastic eqn. (3) is reduced to the following equation:

$$\frac{\partial c}{\partial t}+\frac{\partial\left(U-\partial K_x/\partial x\right)c}{\partial x}+\frac{\partial\left(V-\partial K_y/\partial y\right)c}{\partial y}+\frac{\partial\left(W-\partial K_z/\partial z\right)c}{\partial z},$$

$$=\frac{\partial}{\partial x}\left(K_x\frac{\partial c}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_v\frac{\partial c}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z\frac{\partial c}{\partial z}\right).$$

As a rule, the derivatives of the coefficients of horizontal turbulent exchange can be ignored in comparison with the horizontal wind velocity. In this case the system of stochastic eqn. (3) is reduced to eqn. (1). In many models of this kind the term $(\partial K_z/\partial z)dt$ in the last equation of system (3) was not taken into account.

As shown in [3], this leads to a nonrealistic distribution of impurity over the height, to its accumulation near the surface, and overestimated fallouts. Since the coefficient of the vertical diffusion in the lower layers of the atmosphere rapidly increases with height, this gives rise to the effective mean (against the background of turbulent fluctuations) vertical velocity.

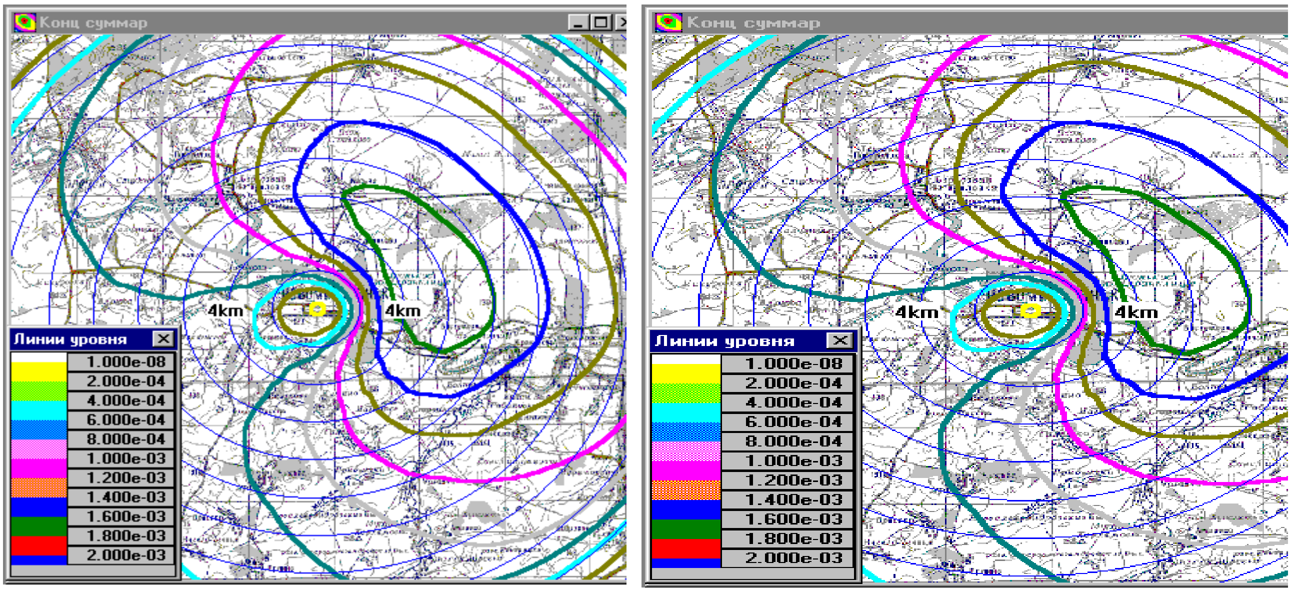
Detail description of the model is presented in [3].
The procedure developed was used to model a fallout as a result of emission at the REPP. The following data on the sources of emission were used (Table 2.).

Table 2 Gaseous emission at the REPP.

Ordinal no	Name of the parameter	Source 1	Source 2
6	Temperature of flue gases, °C	180	145
5	Velocity of outflow of flue gases from a chimney, m/sec	22.06	9.59
3	Mouth diameter, m	9.6	14
2	Height, m	320	320
1	Load factor	1	1

The characteristics of the lognormal distribution of the emission of fly ash are: $\sigma = 2$, $d_{50} = 10$ μm. These data are used to determine the group composition of the source.

Figure 1 presents final annual average ground-level concentrations.



(a) **(b)**

Fig. 1 The final annual average ground-level concentrations for source 1 (a) and for source 2(b).

4 Risk assessment for the residents of the sanitary restriction zone of the REPP

To assess the risk of carcinogenesis from exposure to the substances contained in the air of the sanitary restriction zone of the REPP (the value of the ground-level concentrations of heavy metals was assessed with the aid of "NOSTRADAMUS-ZONE" and "SMOG" program complexes), the well-known procedure was used developed by EPA in the USA and implemented at IRPCP of the Belarus Academy of Sciences in the form of the program module “Studio Risk”. On the basis of the generalized results of epidemiological investigations and experimental data the EPA calculates the normalized risk caused by inhalation of a substance and defined as the upper boundary of the limiting risk of carcinogenesis for lifetime with a long-term effect of an agent that has the concentration in air equal to 1 mkg/m^3. To evaluate the risk of cancer diseases the exposure is averaged by the weight of a body and lifetime. In the general case the equation for calculating inhalation exposure has the form:

$$LAIE=(IR*CCA*ED)/(BW*LT),$$

where LAIE is the lifetime-averaged inhalation exposure; IR is the inhalation rate; CCA is the contaminant concentration in air; ED is the exposure duration; BW the body weight; LT the lifetime.

Thus, the effect of a contaminating impurity contained in the atmospheric air depends not only on its concentration, but also on the inhalation rate, and exposure duration. Inhalation rate depends substantially on sex, age, kind of human activity, and on some other factors. The United States Environmental Protection Agency has carried out extensive investigations of the available literature data and recommended inhalation rates for different sex-age groups with different levels of activity.

To carry out calculations, it is necessary to have data on the mean weight of a body, mean length of life, and mean inhalation rate for men and women. It is possible to take the mean weight of a body to be equal to 78.1 kg for men and 65.4 kg for women; the mean inhalation rate to be 23 m^3/day for men and 21 m^3/day for women. The mean length of life for the population of CIS can be determined from statistical data. It is equal to 63.5 years for men and 74.3 for women.

An important stage in assessing risk from exposure to one or another chemical agent is the development of an exposure scenario that would take into account the actual duration of exposure to a substance with a certain concentration, the duration of different kinds of activity of a human for a representative time interval, the specific features of these kinds of activity for different sex-age groups, and the corresponding differences in the inhalation rates. The calculations carried out with allowance for these data make it possible to range risk levels for different groups of exposed humans.

To carry out sampling risk assessment of carcinogenesis, two exposure scenarios were developed for two categories of population.

1st scenario. Grown-up men and women who do a hard physical work and are permanent residents of the sanitary restriction zone of the REPP.

2nd scenario. Grown-up men and women who belong to the category of brain-workers and are permanent residents of the sanitary restriction zone of the REPP.

These exposure scenarios were considered separately for men and women. The representative interval of time was selected to be 1 year. In the U.S. EPA investigations were carried out that made it possible to determine the time spent on different kinds of activity by different groups of people depending on sex, age, and profession. These data were taken as the basis and were corrected to allow for the specific features of our mode of life. It is assumed that a working day lasts 8 hours and a vacation 24 days.

Table 3 contains the calculated carcinogenesis risk data obtained for sampling populated areas located on the territory of the sanitary restriction zone of the REPP that burnt fuels of different deposits. As seen from the data given, the risk of carcinogenesis for the lifetime due to inhalation of heavy metals contained in the atmospheric air varies within 10^{-9}-10^{-6}. The greatest hazard comes from exposure to arsenic the incurred risk from which in some localities attains the value 10^{-6}. The change in exposure for all the heavy metals occurring when burning coal of different deposits may attain an order of magnitude.

It should be noted that in the present work the risk of carcinogenesis was assessed only for the inhalation route of exposure. Long term deposition of heavy metals may lead to their notable accumulation in the upper layer of the soil. Subsequent migration of heavy metals through the root system of plants leads to substantial contamination of agricultural products and especially those grown in the limits of the sanitary restriction zone of the REPP. The quantitative risk assessment of carcinogenesis in the case of oral exposure requires the development of the models of migration of heavy metals over food chains.

Table 3 Individual risk of carcinogenesis for lifetime in sampling populated areas of the sanitary restriction zone of the REPP. Exposure to a number of heavy metals contained in the atmospheric air as aerosols for the case of burning Kuznetsk coals and black oils of various deposits (averaged data, men, I scenario).

Populated area	Risk for Cr-6	Risk for Ni	Risk for As	Risk for Cd	Risk for Pb
Baklakovo	3,4 10^{-8}	8,1 10^{-9}	4,0 10^{-8}	2,5 10^{-8}	3,4 10^{-10}
Bulychevo	8,3 10^{-8}	2,0 10^{-8}	9,9 10^{-8}	5,8 10^{-8}	8,3 10^{-10}
Denisovo	3,0 10^{-8}	6,9 10^{-8}	3,7 10^{-7}	2,0 10^{-7}	3,0 10^{-10}
Drokovo	1,3 10^{-6}	3,2 10^{-8}	1,5 10^{-7}	9,3 10^{-8}	1,3 10^{-8}
Dubovoe	8,6 10^{-8}	2,1 10^{-8}	1,1 10^{-7}	5,9 10^{-8}	8,6 10^{-10}
Kulino	2,6 10^{-7}	5,9 10^{-8}	3,0 10^{-6}	1,8 10^{-7}	2,6 10^{-9}
Moklakovo	2,1 10^{-7}	5,1 10^{-8}	2,5 10^{-7}	1,5 10^{-7}	2,1 10^{-9}
Nikolo-Skopin	1,0 10^{-7}	2,6 10^{-7}	1,2 10^{-7}	7,5 10^{-8}	1,0 10^{-9}
Pankino	3,3 10^{-8}	8,1 10^{-8}	4,0 10^{-7}	2,4 10^{-8}	3,3 10^{-10}
Pronsk	1,3 10^{-7}	3,2 10^{-8}	1,5 10^{-7}	9,3 10^{-8}	1,3 10^{-9}
Chizhov	1,6 10^{-7}	3,9 10^{-8}	1,9 10^{-7}	1,1 10^{-7}	1,6 10^{-9}
Yumashevo	1,2 10^{-7}	2,9 10^{-8}	1,4 10^{-7}	8,0 10^{-8}	1,2 10^{-9}
Yurakovo	2,1 10^{-7}	5,5 10^{-8}	2,7 10^{-7}	1,5 10^{-7}	2,1 10^{-9}

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