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THE USE OF ENVIRONMENTAL DECISION SUPPORT SYSTEMS FOR MODELING OF ATMOSPHERIC POLLUTION FOLLOWING THE CHEMICAL ACCIDENTS

I.V. KOVALETS, V.P. BESPALOV, S.Ya. MAISTRENKO, O.I. UDOVENKO

Abstract. We studied the possibility of the combined application of screening models to assess the characteristics of sources in accidents at storage facilities for hazardous substances with complex models of atmospheric transport as part of modern decision support systems to calculate air pollution in a wide range of spatial and temporal scales. The evaporation time following an emergency spill, estimated by screening models, is used to set the emission intensity and calculate the atmospheric transport by the RODOS nuclear emergency response system. For the accident in Chernihiv on March 23, 2022, it was estimated that the maximum permissible concentration of ammonia 0.2 mg/m3 was exceeded at distances up to 75 km from the source. The dependence of the calculated maximum concentrations on time is close to asymptote $c_{\max} \sim t^{-4.5}$ up to 15 h after emission, which is consistent with the asymptote $\sigma \sim t^{2/3}$ for the time dependence of the sizes of puffs following turbulent dispersion of instantaneous releases.

Keywords: atmospheric dispersion, RODOS system, hazardous substances, ammonia, LASAT, DIPCOT, “Povitrya” system.

INTRODUCTION

The military aggression of Russia has led, in particular, to numerous cases of man-made accidents in Ukraine with the emission of potentially hazardous substances (HS) into the atmosphere. In many cases, hazardous chemicals such as ammonia, chlorine, and others are stored in liquefied form. As a result of damage to a tank or pipeline, a rapid release of the gaseous phase into the atmosphere (primary cloud) and a spill of the liquid phase of the corresponding chemicals onto the underlying surface with subsequent evaporation (secondary cloud) can occur simultaneously. Operational forecasting of damage zones as a result of the spread of clouds formed after the spill of HS in the world and in Ukraine is carried out according to simplified methods, which are called “screening models” [1]. Such models describe both the formation of an emission source through the spread and evaporation of a spill and the spread of a cloud of HS. Examples of such screening models are works [1–4]. In many cases, the initial results of screening models are only the integral characteristics of the cloud of HS, such as the radius of the affected area. When propagating at a distance of more than 10–20 km, it is necessary to take into account the influence of spatially and temporally variable meteorological conditions on the formation of pollution concentration fields, which is possible by using state-of-art atmospheric transport models (ATMs) that simulate cloud propagation based on data from numerical weather forecast models and are able to calculate atmospheric transport at distances from

~0.1 to ~1000 km. Examples of modern ATMs are the LASAT [5] and DIPCOT [6] models as part of the EU nuclear emergency response system RODOS [7], the WRF-CHEM and CMAQ Euler models [8], the FLEXPART Lagrangian model, and the CALPUFF Lagrangian-Eulerian model [9] and others. All of the above models are widely used in the world both for forecasting pollution in real-time and for analyzing environmental risks associated with possible emissions of pollutants into the atmosphere. In a number of cases, intermediate results of screening model calculations can be used to set the source characteristics in atmospheric transport models for further modeling the distribution of a cloud of HS. The purpose of this work is to study the possibility of combined use of screening models for assessing the characteristics of emission sources during accidents at hazardous chemicals storage and transportation facilities with the state-of-art atmospheric transport models for calculating atmospheric pollution over a wide range of spatial and temporal scales.

METHODS

In this work, we use the atmospheric transport model of the RODOS system of the European Union for nuclear emergency response [7]. It was recently implemented in Ukraine to predict the consequences of radiation accidents and analyze the risks associated with possible accidents [10, 11]. The RODOS system uses several atmospheric transport models. In this work, we used the LASAT model of Lagrangian particles [5], which is the most resource-demanding, but at the same time the most suitable for application in the case of emissions near the Earth's surface. In the LASAT model, particles are considered idealized material points, which are not assigned a spatial size. Other atmospheric models of the RODOS system use so-called "puffs" — instantaneous emissions that represent long-term emission. Each puff is assigned a Gaussian distribution of matter in space, and the vertical and horizontal size of the puff is determined by the dispersions of this distribution in the horizontal and vertical planes σ_h^2, σ_v^2. The distribution dispersions increase with time, but when propagating in flows with a large velocity shift, for example, near the Earth's surface, the symmetry of the distribution in real clouds is violated, which may be not well described by the corresponding models.

The input meteorological data of the RODOS system in Ukraine are the results of numerical weather forecasting of the WRF–Ukraine system, which operates at the Ukrainian Hydrometeorological Center and uses the modern WRF meteorological model for calculations [12]. The weather prediction data of the WRF–Ukraine system have been repeatedly verified on the basis of hydrometeorological measurements in Ukraine [13].

The source parameters were calculated using the "Povitrya" system [14], which is in the public domain [15]. The system "Povitrya" implements screening models for predicting damage zones during HS emissions [3, 4], the intermediate results of which are the mass of the primary cloud (m_1) and the evaporation time (τ) of the secondary cloud. The mass of the primary cloud depends, in particular, on the boiling point of the given substance, the heat of boiling, the specific heat of the substance, and the air temperature. Since the total mass of matter in the container m_0 is set by the user, the emission intensity q_s during the formation of a secondary cloud by evaporation can obviously be calculated by the formula:

$$q_x = \frac{m_2}{\tau} = \frac{m_0 - m_1}{\tau}. \quad (1)$$

Here m_2 is the mass of the secondary cloud. For most substances in the model [3], the mass of the primary cloud is neglected, and then $m_2 = m_0$. In [16], examples of the application of Ukrainian and foreign models for calculating the evaporation rate q_s and the mass of the primary cloud and their comparison are given. It is shown that Ukrainian [3, 4] and foreign [2] models give comparable results.

Fig. 1 presents a flowchart for the calculation of air pollution based on the combined use of screening models to assess the characteristics of sources of emissions of hazardous chemicals with state-of-art models of atmospheric transport. For the calculations of the screening model, it is necessary to set a relatively small number of input parameters: the volume of the spill, the conditions of the spill (was there a spill containment pallet or not), the storage conditions of the substance (under pressure or not), the type of terrain (for example, "flat terrain"), the type of vegetation (for example "grassland"), meteorological conditions at the time of the spill (wind speed and direction, surface air temperature, soil temperature if available, atmospheric stability). The masses of primary and secondary clouds calculated on the basis of the screening model, as well as the evaporation time, are used to set the emission intensity in the atmospheric transport model according to the formula (1). The mass of the primary cloud is accounted for as an instantaneous or short-term emission. The calculated characteristics of the source are transferred to the ATM, which calculates the spread of atmospheric pollutants taking into account meteorological conditions changing in time and space. In this work, the transfer of the estimated characteristics of the emission source to the ATM was performed manually. The result of the ATM calculation is the field of near-surface concentration of the pollutant distributed in time and space.

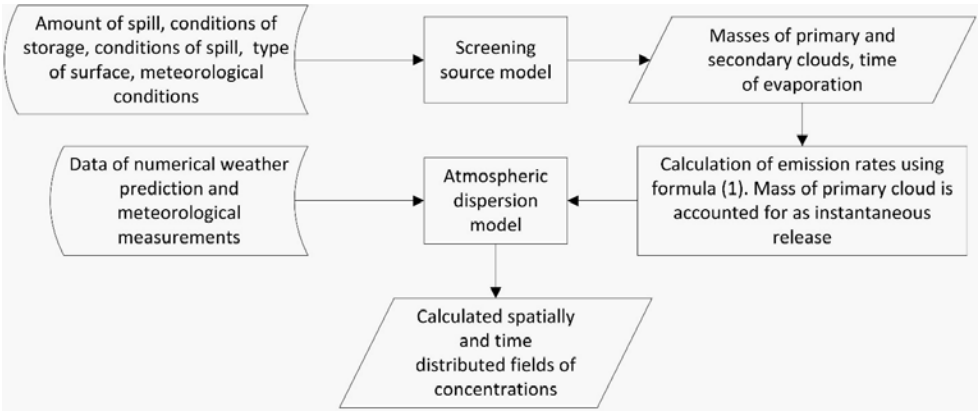

Fig. 1. Flowchart of calculation of air pollution based on the combined application of screening models to assess the characteristics of sources of emissions of hazardous chemicals with state-of-art models of atmospheric transport

MODEL VERIFICATION

Let us compare the results of modeling the depth of propagation of a chlorine cloud after a rapid spill of 67 tons of this substance, performed by the "Povitrya"

system, with calculations of international atmospheric transport models [17], specially designed to calculate the propagation of heavy gases, such as chlorine. The meteorological conditions of the modeling scenario [17] were as follows: wind speed of 3 m/s, stability category 'F' (very stable atmosphere), and air temperature of 25 °C. When modeling such an event by the "Povitrya" system according to the method [3], the depth of the cloud propagation zone is 20 km, and the evaporation time is 90 min.

The range of concentrations calculated by eight models [17] at different distances from the source is shown in Fig. 2. As can be seen from the presented data, the range of concentrations calculated by the models in [17] for a distance of 25 km is from 2 to 30 ppm. According to the American Industrial Hygiene Association (AIHA), this range includes the maximum concentration that does not cause irreversible health effects when exposed for one hour ERPG2=3 ppm, and the maximum concentration of chlorine that does not threaten life ERPG3 = 20 ppm, [18]. Therefore, according to the calculations of the models in [17], at a distance of 25 km, it is necessary to take countermeasures for the event under consideration, which is consistent with the cloud propagation depth of 20 km according to the results of the "Povitrya" system.

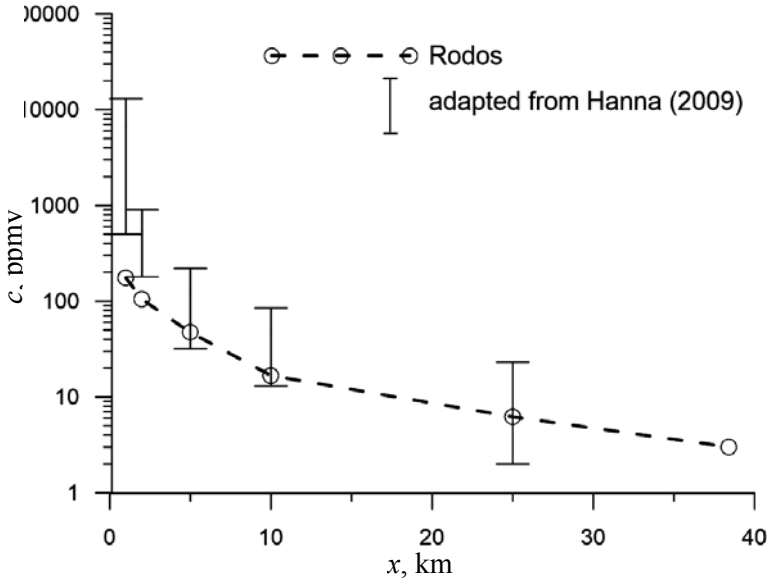

Fig. 2. Maximum concentrations of chlorine in the air calculated by the RODOS system on the cloud symmetry axis for the conditions of the computational experiment according to [17] and the duration of the source calculated by the "Povitrya" system; concentration ranges according to the calculations of 8 models in [17] are shown by vertical lines

Fig. 2 also shows the results of calculating the maximum chlorine concentrations by the RODOS system at the same distances as the models in [17]. The emission source in the RODOS system was set according to the formula (1), where τ=90 min according to the calculation of the "Povitrya" system, and the mass of the primary cloud was neglected. The emission height was assumed to be 10 m since the emission height in the RODOS system cannot be less than 10 m. As can be seen from the data presented in the figure, the concentrations calculated by RODOS are underestimated compared to other models according to [17] and are outside the ranges concentrations of these models up to a distance of 5 km.

This difference is most likely due to buoyancy effects that affect meteorological fields in the vicinity of the cloud when the density of the cloud is significantly different from the density of the surrounding air [19]. These effects may be important for modeling the propagation of chlorine at high concentrations since the latter is a heavy gas whose density at atmospheric pressure is about 2.2 times that of air. Buoyancy effects are taken into account by models [17], which are specially designed for calculating heavy gases and are ignored by both the RODOS system and almost all ATMs used to calculate atmospheric transport at a distance of more than 30 km since taking into account buoyancy effects requires separate approaches to modeling.

Let us evaluate the significance of buoyancy effects for this problem. In [19], a parameter was introduced that characterizes the significance of such effects depending on the emission conditions and meteorological conditions. According to [19], buoyancy effects can be neglected if the following condition is satisfied:

$$\Pi = \frac{(g_0' q_0 / D)^{1/3}}{U} < 0.15 . \qquad (2)$$

Here U is the wind speed, D is the source diameter, q_0 is the volumetric gas flow rates in the source (m^3/s), $g_0' = g(\rho_g - \rho_a)/\rho_a$ is buoyancy, g is the gravitational acceleration, ρ_g is the gas density at atmospheric pressure, ρ_a is the air density. To use formula (2), we estimate the parameters: $g_0' = 12\ m/s^2$, $q_0 \approx 4.5\ m^3/s$ (the estimate of the evaporation time according to the data of the "Povitrya" system was used), $U = 3\ m/s$. To estimate the source diameter, we use the approach [3], in which it is assumed that during a spill on the real surface of the Earth, the spill diameter ceases to increase at a spill basin height of less than 0.05 m due to the impact of minor surface irregularities. Using this estimate, it is possible to obtain an estimate of the spill diameter $D = 33\ m$. Substituting these data into formula (2), we obtain $\Pi = 0.4$, so the effects of buoyancy are important for this problem. When estimating pollution levels near the source the buoyancy effects could be properly accounted for by using specialized models of the heavy gas dispersion, such as those used in [17].

As can be seen from Fig. 2, at distances greater than 5 km, the results calculated by RODOS fall within the range of model calculations [17]. If at a distance of 5 km the results of RODOS are at the lower limit of the calculation range of other models, then at a distance of 25 km they are already inside the range. The explanation for this is that the effects of buoyancy decrease with distance due to the mixing of the cloud with the surrounding air [19]. As a result, the distance to a dangerous concentration of ERPG2=3 ppm according to the calculations of the RODOS system is 38 km, which is within a significant interval of the corresponding distances according to the models [17]. The lower limit of this interval is ≈20 km (obtained by interpolating the lower limits of the intervals depicted in Fig. 2 to a value of 3 ppm), and the upper limit is ≈46 km (obtained by extrapolating the upper limits of the intervals in Fig. 2 to a value of 3 ppm).

As can be seen from Fig. 2, the difference between the calculations of all models is large — almost 10 times, and the level of discrepancy practically does not decrease with distance, although the effects of buoyancy cease to affect cloud

propagation. The corresponding discrepancies between the distances from the source to the places where the fixed concentration is reached are also very significant, as mentioned above. In addition to negative cloud buoyancy effects and differences in the results of evaporation submodels, such differences in calculated concentrations could be explained by the difficulties in accurately calculating the propagation of pollutants near the surface, where horizontal velocity gradients are large. This leads to the effect of "shear dispersion" and the corresponding additional dilution of the substance concentration [20].

RESULTS OF CALCULATIONS OF THE AMMONIA EMISSION IN CHERNIHIV

By using the proposed methodology, we carried out modeling of the spread of ammonia vapors after damage to the ammonia pipeline during the shelling of one of the industrial facilities in Chernihiv on March 23, 2002 [21]. Since the total volume of ammonia emission is unknown, in this work the estimate $m0$=50 tons was accepted. Such a mass corresponds to a spill through a hole with a diameter of 10 cm at a pressure in the container of 100 psig = 689 kPa for about 4 min [17]. The pressure of 689 kPa is close to the typical pressure in ammonia pipelines of 862 kPa [22]; therefore, the error in the given estimate is determined mainly by the unknown spill time.

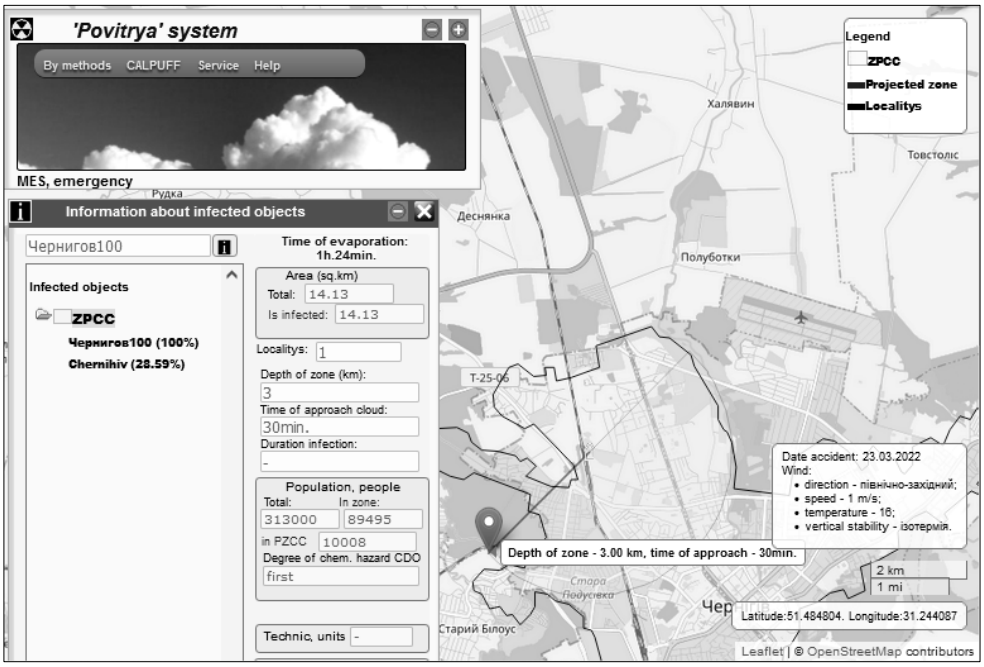

Fig. 3. The results of the calculation by the "Povitrya" system of the consequences of an accident in Chernihiv with a leak of 50 tons of ammonia

Fig. 3 shows the results of calculations of the "Povitrya" system for the scenario under consideration. The meteorological conditions in the calculations were identical to those observed on the day and time of the accident: northwest wind, wind speed 1 m/s, air temperature 16 °C, stability category C. The calculated cloud propagation depth was 3 km. The calculated evaporation time according to

the model [3] was $\tau = 84$ min, and the corresponding value obtained according to the model [4] $\tau = 62$ min. According to the calculations, the mass of the primary cloud was m_1=11.7 tons, that is, approximately 23% of the total emission volume.

To simulate the propagation of the cloud by the RODOS system, the evaporation time of the cloud was taken to be $\tau = 60$ min. The simulation was carried out on the basis of meteorological data calculated by the WRF–Ukraine weather forecasting system. The RODOS system performed calculations on two computational grids:

1) calculation with the minimum resolution of the spatial grid, which is equal to 50 m, and the total size of the calculation area is 40×40 km (hereinafter referred to as "grid 1");

2) calculation with a coarser minimum resolution of the spatial grid, which is equal to 500 m, and the total size of the computational area is 400×400 km (hereinafter referred to as "grid 2").

Fig. 4 shows the calculated concentration field one hour after the start of the emission when the concentration values in the near zone around the emission are maximum (this is the point at which the emission stops). According to [18], the maximum concentration of ammonia that does not threaten the occurrence of irreversible or other serious health effects is ERPG2=150 ppm=105 mg/m^3. The isoline of the corresponding concentration is shown in Fig. 3. The maximum distance from the emission point to this isoline, according to RODOS calculations, was: $L = 1.8$ km. The corresponding value of the cloud propagation depth calculated by the "Povitrya" system according to the model [3] is 3 km. This discrepancy can be considered small given the typical discrepancies between models discussed in the previous section.

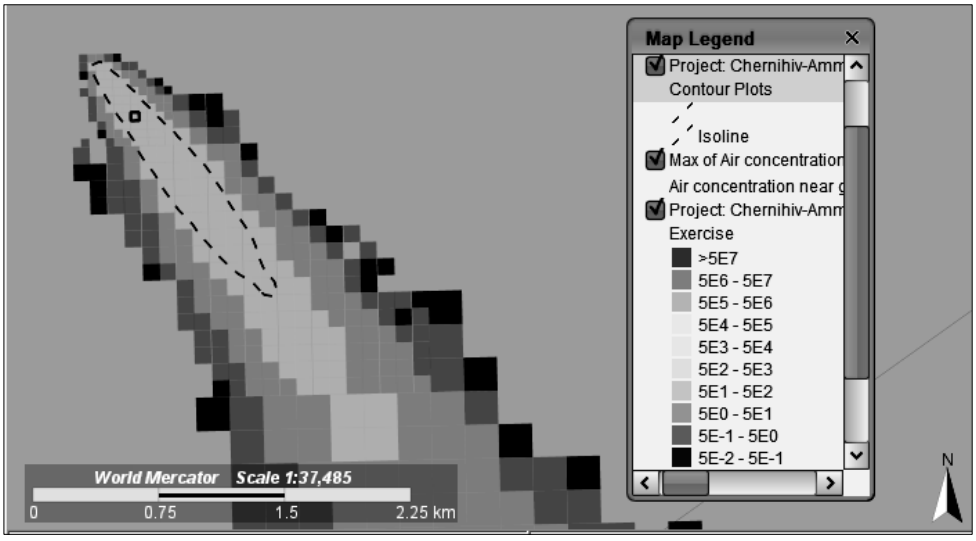

Fig. 4. Ground air pollutant concentrations calculated by the RODOS system (mg/m3) as a result of the emission of 50 tons of ammonia one hour after the start of the emission; the calculation was performed on grid 1 for meteorological conditions on March 23, 22; dashed isoline corresponds to the concentration of 150 ppm=105 mg/m^3 (normative value of ERPG2 according to [18])

Fig. 4 shows a cell with the maximum concentration value, which is equal to 910 mg/m^3 and is reached at a distance of 200 m from the source. According to [18],

ammonia concentrations of 1050 mg/m^3 and higher are deadly. In the considered scenario, such concentrations are not achieved, which is consistent with the above media report that, according to preliminary data, there were no casualties caused by this event. But it should be noted that, according to the information [3], a conservative estimate when calculating an accident at an ammonia pipeline or a product pipeline can be considered an outflow of a substance in the amount of 500 tons. When calculating such a conservative scenario by the RODOS system for meteorological conditions on March 23, 2022, the size of the affected area in the direction of the wind, which corresponds to the above value of the lethal concentration, is 1.8 km.

Fig. 5 shows the isolines of the concentration of 0.2 mg/m^3 calculated by the RODOS system on grid 2 for different time moments after the accident. According to the Order of the Ministry of Health of Ukraine No. 52 dated December 14, 2020, the value of 0.2 mg/m^3 for ammonia is the maximum permissible concentration (MPC). As can be seen from the location of the isolines shown in Fig. 5, at first the cloud moves to the southeast, but over time the wind changes direction, and the cloud continues to move in a northeasterly direction. MPC exceedances are observed during 9.5 hours of cloud movement at distances up to 75 km, after which concentrations become lower than MPC. Owing to the dilution of the cloud

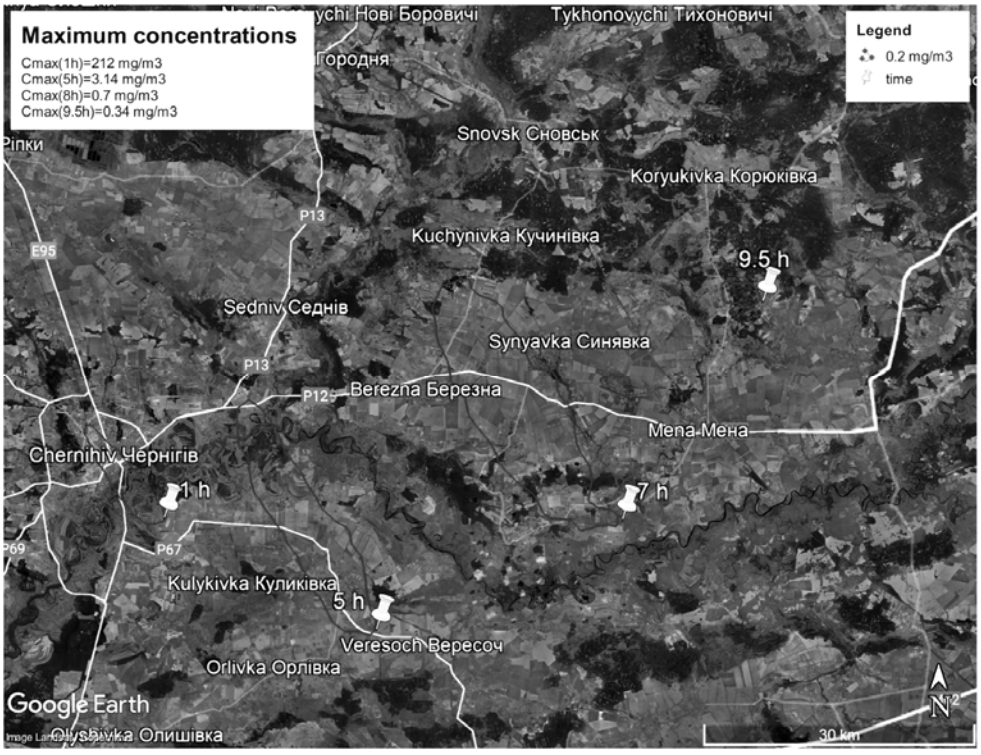

Fig. 5. Isolines of surface concentrations of ammonia corresponding to the standard MPC=0.2 mg/m^3, calculated by the RODOS system on grid 2 for different time moments after the accident in Chernihiv (1, 5, 7, 9.5 h) for meteorological conditions on March 23, 2022. For each time, the figure shows the maximum concentrations in the cloud

and the corresponding increase in its horizontal and vertical dimensions, the maximum concentrations in the cloud rapidly decrease. The maximum value achieved within each isoline depicted in Fig. 5 is also shown in the figure. Calcu-

lation on a coarse grid leads to a strong underestimation of the concentration near the source: one hour after the start of the emission, the maximum value on grid 2 is 212 mg/m^3, while on grid 1 the corresponding value is 910 mg/m^3. However, over time, this difference disappears. For example, 5 hours after the start of the emission, the maximum concentrations calculated on both grids differ by less than 10%.

The time dependence of the maximum concentrations calculated by the RODOS system on grids 1 and 2 with an interval of 1 hour is shown in Fig. 6. Since the results are presented only for the times when the cloud is in the computational domain, the time series corresponding to the plot for grid 2 is longer than for grid 1. To test the sensitivity of the results to the model used, in addition to the LASAT model that was predominantly used in this work. Fig. 6 shows the results of the DIPCOT model, also available in the RODOS system. Although DIPCOT also uses a Lagrangian approach to modeling stochastic particle motions in a turbulent medium, in contrast to LASAT, DIPCOT particles are characterized by finite sizes, that is, they are "puffs", as discussed above.

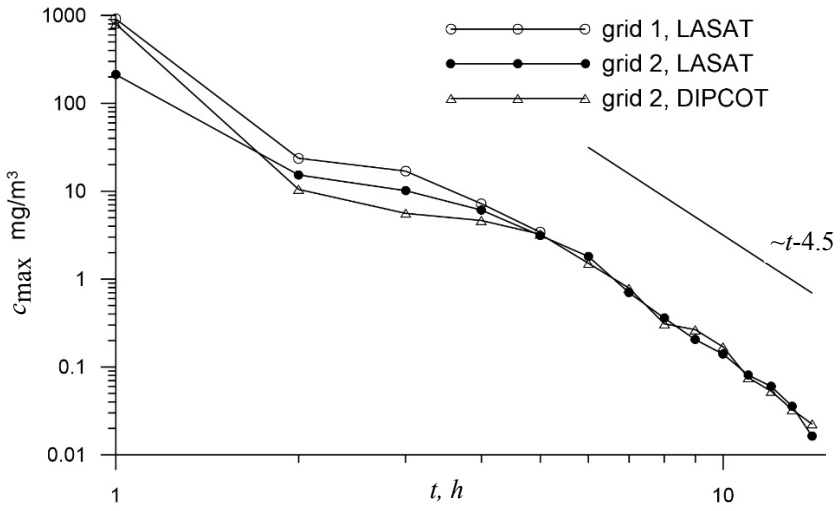

Fig. 6. Dependence of the highest concentrations in the computational area on time after the start of the emission according to the results of RODOS calculations on grids 1 and 2; for grid 2, the results of two RODOS models are presented: LASAT and DIPCOT; the results are presented only for the times when the cloud is inside the computational domain

From the graphs presented, it can be seen that in all calculations three time intervals can be distinguished: 1) $1 < t \le 2$ hours, the maximum concentration decreases rapidly; 2) $2 < t \le 4h$, the concentration decreases slowly; 3) $t > 4h$, the concentration drops rapidly again. The interval $0 < t \le 1$ h is not considered, since during this period an emission occurs and the maximum concentration is approximately constant. As can be seen from the above results, during intervals 1) and 3) the maximum concentration decreases with time approximately as:

$$c_{\max} \sim t^{-4.5}, \tag{3}$$

and the corresponding asymptotics is also shown on the graph. This dependence of the maximum concentration on time is in accordance with the classical results of the theory of turbulent motion of particles, according to which the vertical and

horizontal dimensions of a medium particle after an instantaneous emission increase following the dependence [23]:

$$\sigma \sim t^{3/2}. \quad (4)$$

Indeed, in the case of an instantaneous emission of a substance, if the height of the emission (puff) above the Earth's surface is much less than its characteristic vertical size σ_v, that is typical for the long-term existence of the puff [24], the maximum concentration on the Earth's surface will be determined by the dependence $c_{\max} \sim \sigma_h^{-2}\sigma_v^{-1}$. Substituting expression (4) into the last relation, we obtain the asymptotic dependence (3), which agrees with the graphs in Fig. 5 at time intervals 1) and 3). Some deviations from this dependence on time intervals 1) and 3) are explained by the fact that for turbulent dispersion in real meteorological fields that vary in time and space, no analytical relationships for the sizes of puffs with time can be fulfilled exactly.

It should be noted that, according to theoretical studies in [23], when the duration of the movement of puffs is much longer than the Lagrangian integral time scale of turbulence in the atmosphere (i.e., several hours after the emission), the law of growth of puff's sizes (4) should be replaced by more slow dependence $\sigma \sim t^{3/4}$. Then the time dependence of the maximum concentration would be described by the relation $c_{\max} \sim t^{-2.25}$, which obviously does not occur according to the calculations of both RODOS models, the data of which are presented in Fig. 6. Such a discrepancy between theory and model calculations may be the subject of further research.

A sharp slowdown in the rate of fall of the maximum concentration occurs in time interval 2) from the second to the fourth hour after the emission, exactly when the direction of the cloud movement changes from southeast to northeast. This is associated with the advancement of the pressure trough from the north and the corresponding change in wind direction. At this time interval, the wind speed drops below 0.5 m/s for a short time. Hence calm conditions arise when the existing cloud moves almost without mixing. Within two hours, a stable transport is established in the northeast direction, the wind speed increases to 3.5 m/s, and mixing is restored.

CONCLUSIONS

In the present work, we studied the possibility of the combined application of screening models for assessing the characteristics of emission sources during accidents at hazardous chemicals storage and transportation facilities with complex models of atmospheric transport, functioning as part of state-of-art environmental decision support systems, for calculating air pollution in a wide range of spatial and time scales – from ~100 m to ~100 km. The evaporation time and the mass of the primary cloud in case of an accidental spill of a substance are calculated by using the web system "Povitrya" based on the calculation of screening models for assessing affected areas in emergency situations at industrial facilities. These parameters are then used to set the emission intensity and calculate the atmospheric transport by the RODOS system of the European Union for nuclear emergency response. The advantage of using simplified screening models in comparison with

the more complex models of releases results from the fact that relatively few parameters need to be specified for the application of simplified models (volume of the spill, storage and meteorological conditions, type of terrain). The values of the corresponding parameters could be estimated in real-time.

The chlorine concentrations calculated in this way for the scenario of an accidental release are compared with the results of international models specially designed to calculate the spread of heavy gases. It was found that the concentrations calculated by the RODOS system for this scenario are consistent with the results of other models at distances of more than 5 km and are underestimated at shorter distances. This is due to the effect of negative buoyancy on the propagation of the chlorine cloud. With distance, the effects of buoyancy cease to affect cloud propagation, and as a result, the distance to a dangerous concentration, according to RODOS calculations, is within the interval of the results of other models.

The proposed approach was used to analyze the spread of ammonia vapor as a result of damage to the pipeline in Chernihiv on March 23, 2022, caused by hostilities. The amount of ammonia emission for this event is unknown. A conservative estimate of the emission of 500 tons for this event leads to an estimate of the length of the affected area according to the RODOS system up to 1.8 km from the source in the direction of the wind. Based on information from the media about the absence of victims, an assumption was made about the emission of 50 tons of ammonia. Based on the calculations of the RODOS system using the data of the WRF–Ukraine meteorological forecasting system, it was estimated that, due to the spread of the cloud, the maximum permissible concentration of ammonia, MPC = 0.2 mg/m3, was exceeded at distances up to 75 km from the point of emission. Exceeding the MPC in a certain area means that the cloud could have a dangerous effect on the organisms located in the corresponding area. An assessment of the degree of such exposure can be made based on the results of the models used in this work, but requires the involvement of experts in toxicology and is not the subject of this article.

The temporal behavior of the highest concentrations calculated by the RODOS system was analyzed. The dependence of maximum concentrations on time is asymptotic, close to $c_{\max} \sim t^{-4.5}$, which is consistent with the classical asymptotic relation $\sigma \sim t^{3/2}$ for the time dependence of the size of puffs (instant emissions) during their turbulent mixing in the atmosphere on time intervals smaller than the Lagrangian integral time scale of turbulence t_L. However, since the propagation was calculated for time intervals up to 15 hours, which is more than t_L, in future theoretical studies on atmospheric dispersion, it would be necessary to clarify the possibility of fulfilling the dependence $\sigma \sim t^{3/2}$ on large time intervals.

The method of combining screening models for evaluating the characteristics of sources in the case of severe man-made accidents at industrial facilities with state-of-art models of atmospheric transport studied in this work can be used to forecast the consequences of such events for the environment and people, for the development of new and improved decision support systems for environmental safety management, and to assess risks due to operation of industrial objects.

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INFORMATION ON THE ARTICLE

Ivan V. Kovalets, ORCID: 0000-0002-5553-3299, The Institute of Mathematical Machines and Systems Problems of the Ukraine National Academy of Science, Ukraine, e-mail: ivkov084@gmail.com

Viacheslav P. Bespalov, ORCID: 0000-0001-6841-1533, The Institute of Mathematical Machines and Systems Problems of the Ukraine National Academy of Science, Ukraine, e-mail: bespalovviacheslav@gmail.com

Svitlana Ya. Maistrenko, ORCID: 0000-0002-1316-9732, The Institute of Mathematical Machines and Systems Problems of the Ukraine National Academy of Science, Ukraine, e-mail: maistrsv@ukr.net

Oleg I. Udovenko, ORCID: 0000-0001-5679-8291, Ukrainian Centre for Water and Ecology Issues, Ukraine, e-mail: oleg.udovenko@gmail.com

ВИКОРИСТАННЯ СИСТЕМ ПІДТРИМАННЯ РІШЕНЬ З ЕКОЛОГІЧНОЇ БЕЗПЕКИ ДЛЯ МОДЕЛЮВАННЯ ЗАБРУДНЕННЯ АТМОСФЕРИ ВНАСЛІДОК ХІМІЧНИХ АВАРІЙ / І.В. Ковалець, В.П. Беспалов, С.Я. Майстренко, О.І. Удовенко

Анотація. Досліджено можливість комбінованого застосування скринінгових моделей для оцінювання характеристик джерел у разі аварій на об'єктах зберігання небезпечних речовин зі складними моделями атмосферного перенесення у складі сучасних систем підтримання рішень для розрахунку атмосферного забруднення у широкому діапазоні просторових і часових масштабів. Час випаровування у разі аварійного розливу, оцінений скринінговими моделями, використовується для задання інтенсивності емісії і розрахунку атмосферного поширення системою ядерного аварійного реагування RODOS. Для аварії в Чернігові 23.03.2022 оцінено, що перевищення граничної допустимої концентрації аміаку 0.2 мг/м^3 відбувається на відстанях до 75 км від джерела. Залежність розрахованих максимальних концентрацій від часу має асимптотичний характер близький до $c_{\max} \sim t^{-4.5}$ до 15 год після викиду, що узгоджується з асимптотичним співвідношенням $\sigma \sim t^{3/2}$ для часової залежності розмірів хмар у разі турбулентної дисперсії миттєвих викидів.

Ключові слова: атмосферна дисперсія, система RODOS, небезпечні речовини, аміак, LASAT, DIPCOT, система «Повітря».