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SOFTWARE-BASED METHOD OF DETERMINING THE NECESSARY POPULATION EVACUATION ZONE IN CASE OF A CHEMICAL ACCIDENT

The article analyses the number of chemically hazardous objects in each region of Ukraine and gives the approximate number of hazardous chemicals on them. An example of the most massive accident with the release of chemicals in Ukrainian history (1991-2021) has been given; its causes and consequences have been revealed. It has been proved that the study of effective ways of the population evacuation planning and conducting in case of emergencies is an urgent task today. The analysis of scientific works in this direction has been carried out and the absence of a standard technique for population evacuation planning based on computer simulation of hazardous chemical substances release has been revealed. The purpose of the study is to create a methodology for determining the required evacuation zone on the basis of information technology, which will allow faster and more efficient decision-making and evacuation of the population from the accident zone.

The authors have proposed a method for determining the required evacuation zone parameters based on the use of two existing software products: ALOHA and ArcGIS. ALOHA software allows calculating parameters of required evacuation zone around a chemically hazardous object depending on meteorological conditions, such as wind direction, humidity and ambient temperature. ArcGIS software superimposes obtained parameters with the administrative map of the territory on which, with the help of additional tools, residential and industrial buildings and structures falling into pollution bubble are selected. The end product of such modelling is a list of buildings (with addresses) that need evacuation which can be used by rescue services and the police during the rescue operations. The article gives an example of such modelling for one of the objects in Lviv.

***Key words**: evacuation plan, hazardous chemical, civil protection, computer simulation, ArcGIS software.*

Introduction. The history of mankind has been constantly accompanied by small and large man-made catastrophes, which led to the injury and death of people, the destruction of material values, severe environmental consequences. Among the large number of man-made accidents and catastrophes, chemical disasters are especially dangerous, which is confirmed by many years of sad experience. According to the United Nations (UN) [1], there have been 350 large-scale chemical disasters in the world over the last 30 years. About 100,000 people have been affected; more than 13,000 have been killed and more than 3 million people have been evacuated.

In total, there are more than 1,810 industrial facilities in Ukraine, which store or use more than 283,000 tons of hazardous chemicals (HC), including 9,800 tons of chlorine and 178,400 tons of ammonia.

Table 1 shows the number of chemically hazardous objects (CHO) of high and medium degree of danger with the available amount of HC on them according to [2] as of October 2020.

Table 1 – CHO of high and medium degree of danger in Ukraine [2]

№	Administrative-territorial units	Number of objects	Amount of Hazardous Chemicals, tons
1.	Autonomous Republic of Crimea	no data available	no data available
2.	Vinnytsia Region	2	5058,65
3.	Dnipropetrovsk Region	8	317,85
4.	Donetsk Region (excluding temporarily occupied territories)	18	50946,6
5.	Zhytomyr Region	1	590,1
6.	Zakarpattya Region	4	160,5
7.	Zaporizhya Region	10	3065,3
8.	Ivano-Frankivsk Region	1	3494,72
9.	Kyiv	3	395,9
10.	Luhansk (excluding temporarily occupied territories)	8	29764,1
11.	Lviv Region	6	5834,1
12.	Mykolayiv Region	4	9358,48
13.	Odessa Region	28	66374,1
14.	Poltava Region	4	2906,36
15.	Rivne Region	1	4508,7
16.	Sumy Region	4	3149,3
17.	Kharkiv Region	3	5107
18.	Kherson Region	3	345
19.	Cherkasy Region	4	14547,4
20.	Chernivtsi Region	2	677,7
21.	Kyiv	13	1475,0

In total, about 16 million people (38,5% of the country's population) live in the areas of possible chemical contamination from these facilities.

For the period from 1991 till now several massive accidents with the release of HC have occurred in Ukraine. The major chemical disaster happened at the "Stirol" Concern, located in Gorlivka, Donetsk region, on August 6, 2013 at about 2 pm during the overhaul of the plant. The liquid ammonia pipeline with a diameter of 150 mm and a working pressure of 12 atmospheres was depressurized on the interdepartmental ammonia collector, which led to the release of gaseous ammonia with the formation of the HC cloud. 600 kg of ammonia got into the air and spread rapidly. At the time of the accident, there were about 100 people in the production department.

As a result of the accident, six people died and 26 were injured, 25 of them were hospitalized. The main cause of the accident was called the mistakes of service personnel during the repair work.

During the liquidation of the accident, the population was not evacuated from the buildings adjacent to the facility and the next day the hospitals began to register complaints about feeling unwell. According to official statistics, about 150 appeals of citizens were registered, which connected the deterioration of their health with the accident at PJSC Concern "Stirol".

Therefore, rapid and effective planning and evacuation in such situations can reduce the risk of injury to the population and personnel, which is an urgent task today, given the increase in production, which entails an increase in the amount of HC and changes in processes and equipment.

Literature data analysis and problem statement. Studies [3-6] indicate that the behaviour of the occupants of the residual buildings before the purposeful movement to the exit, known as pre-evacuation behaviour, can greatly affect the total evacuation duration in case of emergency. In addition, it is indicated that the time for the decision-making about evacuation and the time of

population notification directly affects the number of accident victims. An additional negative component that hinders the effective process of gathering people is panic and unpredictability of individual behaviour. In [3], a new model for modelling pre-evacuation behaviour based on the theory of random utility is proposed. The proposed model represents the pre-evacuation behaviour of the simulated agents, taking into account three states of behaviour. The model simulates the condition of each agent in the pre-evacuation period, depending on the personal characteristics of the person and the influence of external factors. However, this model takes into account only the personal qualities of evacuees, which affects decision-making only by those who are in an emergency and does not take into account the speed of response of special rescue units and their decision to evacuate. This model can be used in public institutions, but not for CHO staff.

In [4] the problem of not fully studied human and social behaviour is covered, especially in emergency situations. Decision-making and social interaction processes are taken into account in this work. The results are represented in a dynamic computational model suitable for analyzing human behaviour during evacuation. However, this model does not take into account the peculiarities of decision-making by the person responsible for the liquidation of the accident at CHO, which should be guided by the relevant regulations and instructions.

In models presented in [5,6] time from receiving the first alarm signal to the beginning of the evacuation includes the decision-making period of the accident commander. This model simulates the real situation with the release of CHO.

This model and all the works analyzed above take into account human and social interactions in public institutions, but do not take into account the specifics of emergencies at industrial facilities, the behaviour of personnel and the head of emergency response under ever-changing circumstances. In addition, the chemical and physical properties of the emitted HC, as well as the meteorological conditions that affect the rate of propagation and evaporation of the substance, must be taken into account. In such situations, the use of computer simulation for the forecast spread of HC, taking into account the variable meteorological data will facilitate the decision-making process of the head of emergency response.

There is no certified program that can be used by the emergency response manager to forecast HC emissions, plan and make effective decisions on the evacuation of personnel and the public.

In the works [7-11] the efficiency of computer simulations in areas, buildings and structures for various purposes, taking into account obstacles to evacuation, door locking, physical condition of victims and other structural elements of the building is shown. In [12-14] simulation models of people evacuation from high-rise buildings with decision-making based on computer simulations are presented.

In [15], the decision-making process on the evacuation of people from the sports complex using computer simulation of the capacity of the evacuation exits of the building is considered.

After analysing all the above scientific works, we can highlight the problem of the lack of a standard planning method for population evacuation from the area affected by hazardous chemicals, as a result of an accident at industrial facility. In addition, there is no certified software product in Ukraine that can assist the emergency response manager in predicting the spread of HC, modelling the evacuation zone, and effectively planning and executing the evacuation process.

This problem can be solved by sharing two existing software products ALOHA and ArcGIS to model the required evacuation zone around a high-risk facility depending on weather conditions.

The purpose and objectives of the study. The purpose of the study is to create a methodology for determining the required evacuation zone on the basis of information technology, which will allow faster and more efficient decision-making and evacuation of the population from the accident zone.

To achieve this goal the following tasks were solved:

- to calculate the time of spillage of hazardous chemicals and model their distribution depending on meteorological conditions as a result of a possible accident at one of the high-risk facilities in the city of Lviv using the ALOHA program;

- to model the distribution area of the hazardous chemicals in the administrative territories of the city of Lviv using the ArcGIS program;

- to develop the plan of the order of evacuation of buildings on the basis of the received preliminary modelling data in the form of the table.

Presentation of the main material of the study with a full justification of the results.

1. Calculation of HC spill time and toxic cloud modelling as a result of a possible accident at one of the high-risk facilities in Lviv using the ALOHA program.

The first step in the calculations is to enter the initial data on the accident site and the type of chemical. To do this it is necessary to run the ALOHA program and to select "Location" in the "SiteData" menu. Then the "Location information" dialog box will appear with a list of city names included in the ALOHA location library.

The selected high-risk facility is located in Lviv. Entering first letters (e. g. "lvi") allows going quickly to the section of the list that contains names beginning with these letters. After that it is necessary to choose the proper city name to select it, and to click "Select".

Next step is to set the date and time by choosing "Data & Time". "Date and Time options" dialog box appears in the "SiteData" menu.

After choosing the parameter "Set a constant time" enter the month, day, year, hour and minute for this scenario. ALOHA is configured to enter the time in 24-hour format. (Fig. 1).

Figure 1. Date and time settings.

On the next step it is necessary to select a chemical in the settings menu. In our case it is ammonia. The "Chemical Information" dialog box appears with a list of chemicals in the ALOHA library. After choosing "Pure Chemicals" at the top of the window (set by default) and "AMMONIA" in the list, it is necessary to click "Select" (Fig. 2).
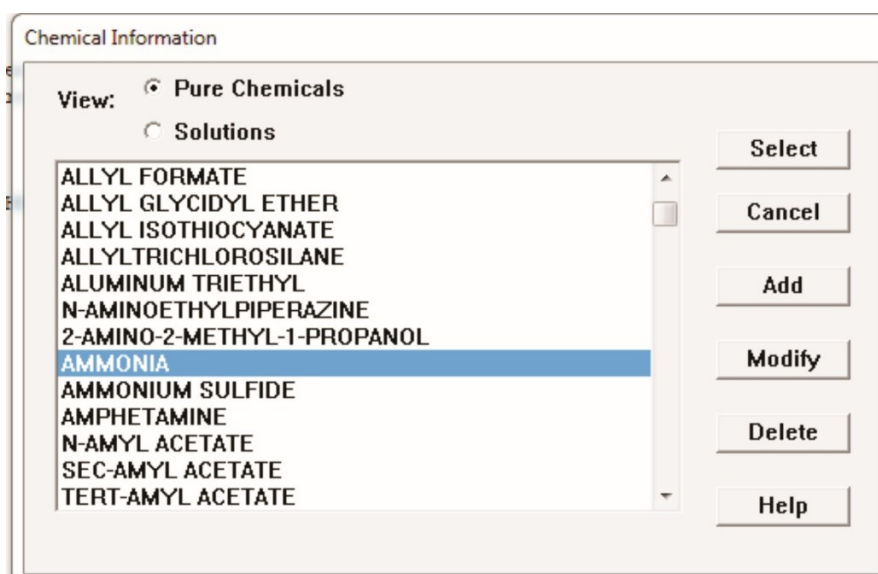
Figure 2. Choice the hazardous chemical.

After choosing the location, time, and chemical the next step is to enter the weather and soil type. It can be done in the "Set Up" menu by moving the cursor to "Atmospheric" and selecting "User Input". The first "Atmospheric options" dialog box appears.

According to [16], the prevailing wind direction for this area is southwest with an average speed of 2.2 meters per second. As we see, there is a residential area to the south of the object and a railway station to the north. So we have to enter "2.2" in the wind speed field, select "meters/sec" and also choose "SW" in the wind direction line (Fig. 3).
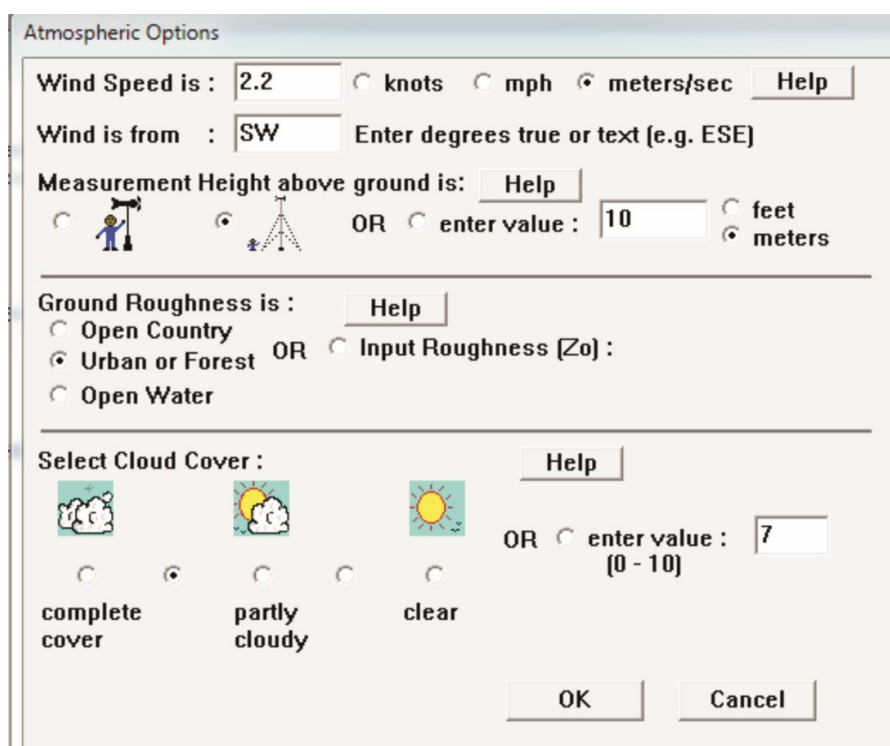
Figure 3. Choice of atmospheric parameters (wind speed, type of relief, cloudiness).

Weather conditions are measured at a height of 10 meters, so it is necessary to select the icon of the tower in the section "Measurement of altitude" and ALOHA will automatically fill the value - 10 meters.

According to the type of terrain the type of relief must be chosen in the option "Ground Roughness" - "Urban or Forest". Next step is to choose the type of cloudiness. In Lviv usually more

than half of the sky is covered with clouds, so it is necessary to choose the second option (between full and partial cloud cover) in the "Select cloud cover" section. The program automatically fills in the value 7 in the digital field. The second "Atmospheric options 2" dialog box appears.

According to [16], the average air temperature for a given area in the spring-autumn period is +20 degrees Celsius, so we enter the value "20" in the air temperature window, and then select "°C". The program uses pre-entered information about wind speed, cloud cover, date and time to automatically select the atmospheric stability class "C", which reflects the conditions of neutral atmospheric stability.

There is no low level inversion in this area, so "No Inversion" is selected. According to [16] the relative humidity is about 50%. We enter the value "50" in the digital field. (Fig. 4).
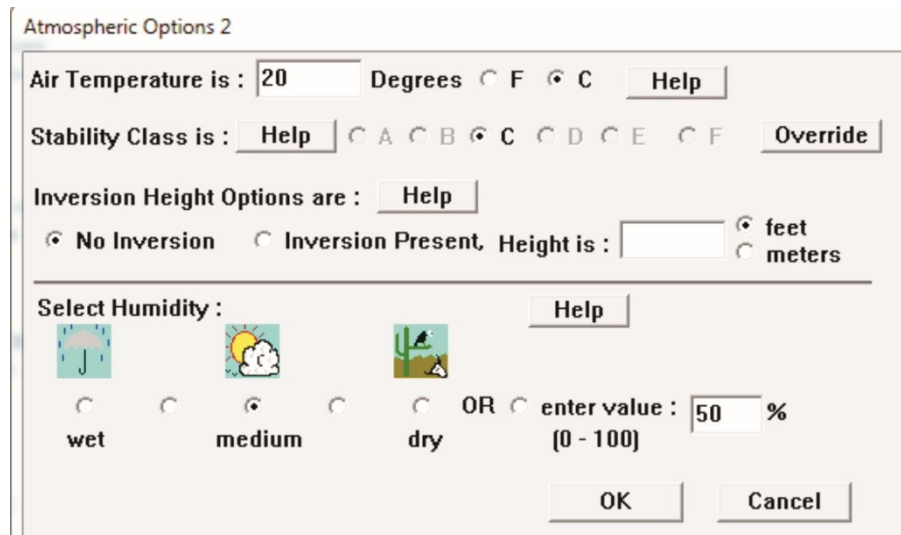

Figure 4. Choice of atmospheric parameters (temperature, inversion, humidity).

After entering the meteorological data the next step is to select the source and type of emission.

In the "Settings" menu it is necessary to move the cursor to "Source" and select "Tank". The "Tank size and orientation" dialog box appears. At the facility ammonia is stored in a vertical tank with a diameter of 1.2 meters so we choose "Vertical cylinder" and enter the height of the tank (the volume is determined automatically). (Fig. 5).
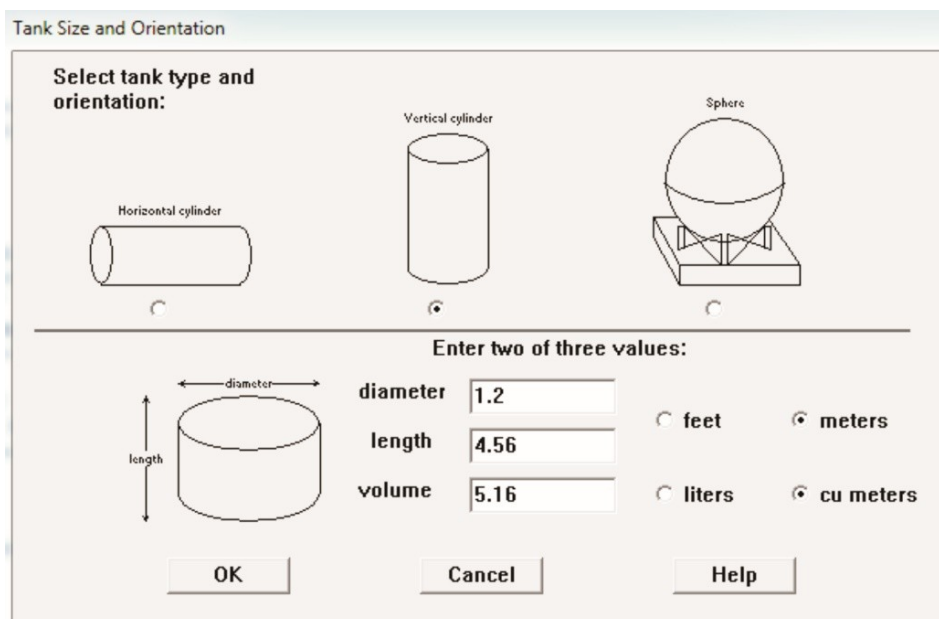

Figure 5. Window for selecting the type and size of the tank.

Next is the window "Chemical state and temperature". Ammonia is stored in the tank as a liquid, so it is necessary to select the option "Tank contains liquid". The substance is stored in the tank at a temperature of -25 degrees Celsius, so in the digital field we enter "-25" and select "C" (Fig. 6).
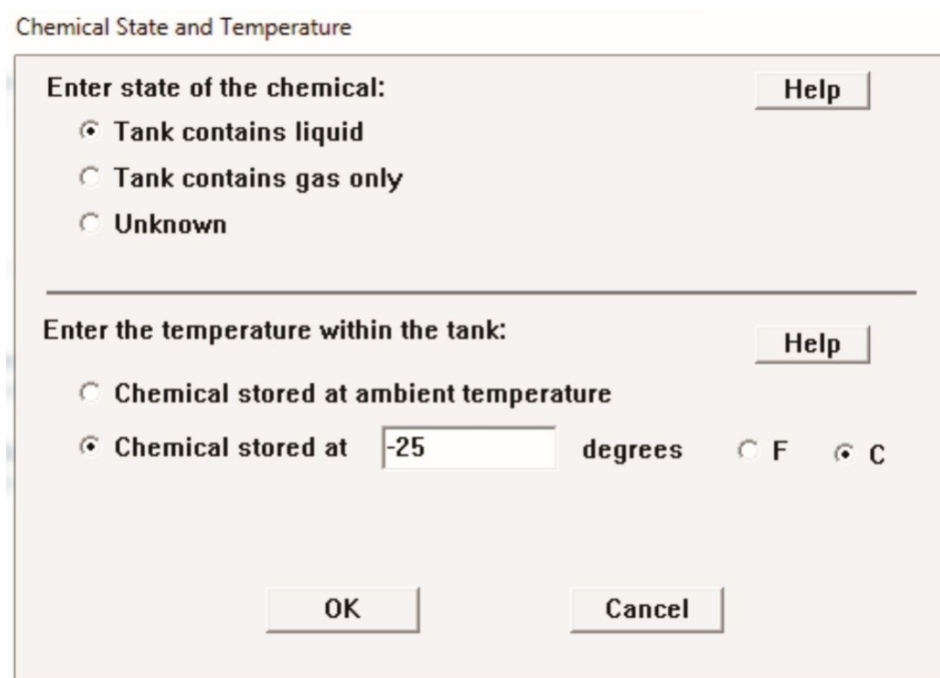

Figure 6. Physical state and temperature selection window.

The next window is "Liquid mass or volume".

According to the requirements of regulatory documents, the tank with ammonia can be filled by no more than 80%, so we enter "80%" in the proper field and the program automatically calculates the volume (Fig. 7).
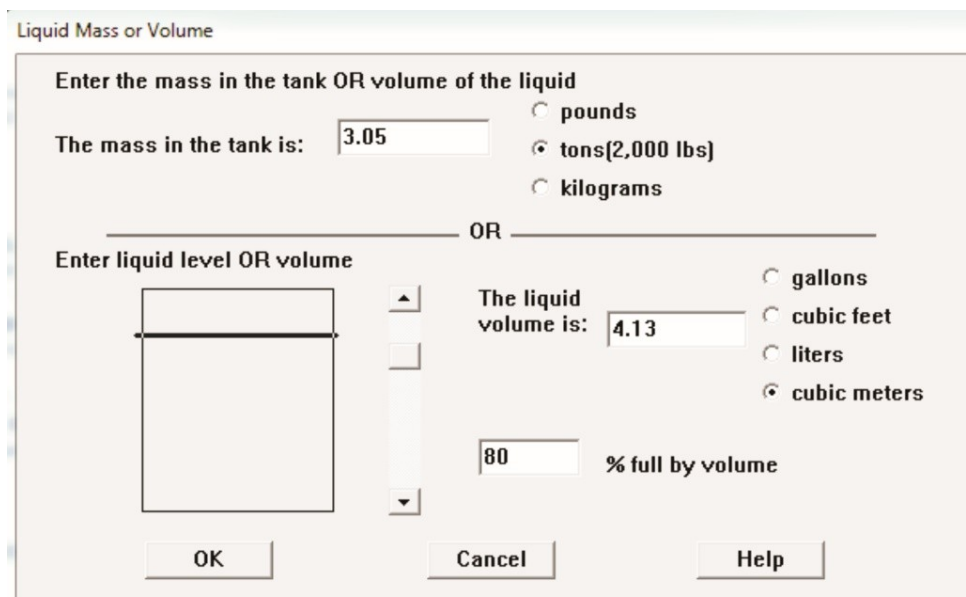

Figure 7. Choice of the mass and the tank volume.

Next window is "Type of tank failure". It allows entering the scenario of the tank destruction. We choose the most likely option that the chemical flows out of the tank without burning and evaporates into the atmosphere (Fig. 8).
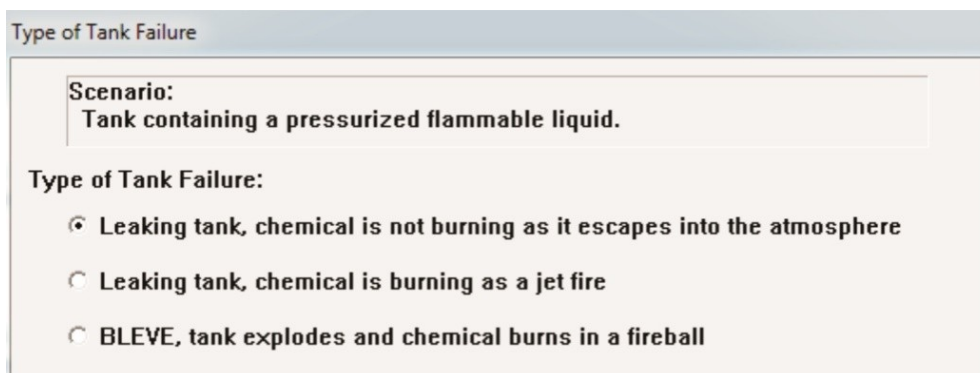
Figure 8. Choice of the tank destruction scenario.

We set the parameters that ammonia flows from a 10 centimetre round hole, so "Circular opening" is selected and "10" in the hole diameter field is entered. We also select "Centimetres" and the option "Hole" (Fig. 9).
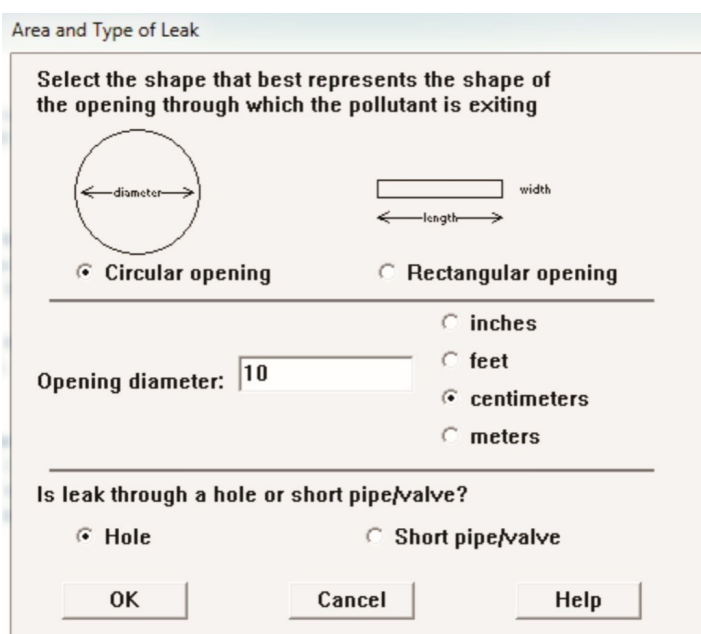

Figure 9. Choice of area and type of outflow.

On the next step "Height of the tank opening" dialog box appears. We simulate the worst case scenario. Due to this scenario the hole is located at a distance of 5 centimetres from the bottom of the tank. After entering the value "5" in the digital string ALOHA fills in other values automatically (Fig. 10)
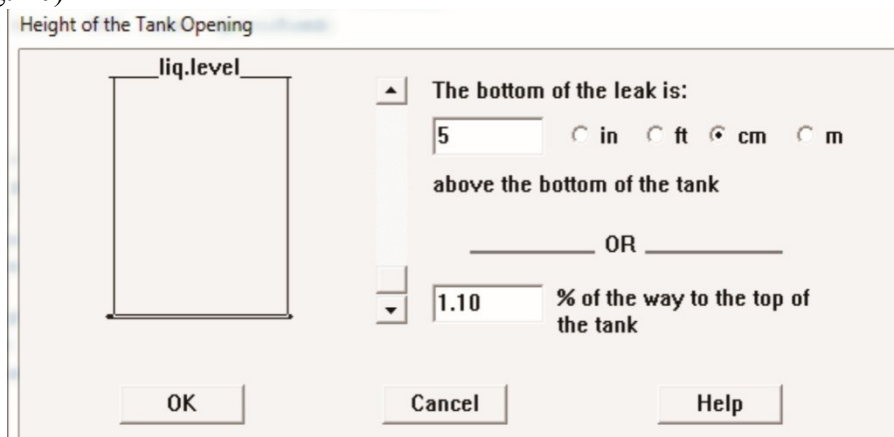

Figure 10. Choice of the height of the hole in the tank.

After that the "Leak parameters" dialog box appears. In this window we can view all entered parameters. The next step is to check the parameters of the calculation model. To do this it we have to select "Parameter" in the "Options" menu. The "Calculation options" dialog box appears, where we need to choose the option "Let ALOHA decide", because the Gaussian dispersion or heavy gas propagation algorithm does not fully describe the ammonia propagation process (Fig. 11).
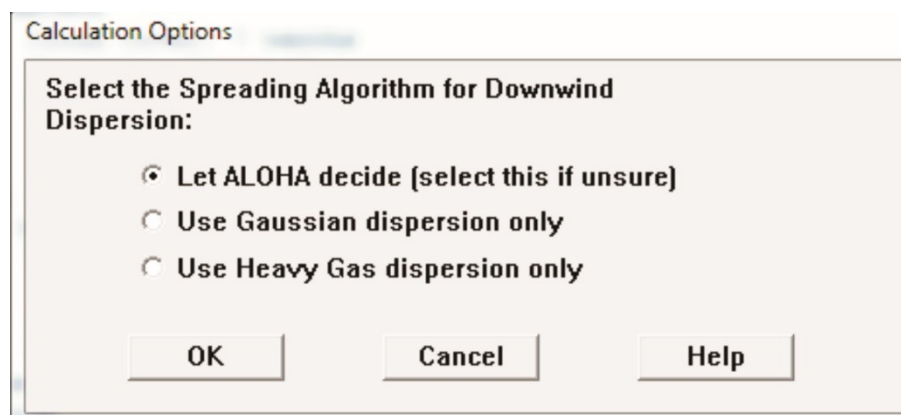

Figure 11. Choice of calculation parameters.

After choosing of calculation parameters it is necessary to select "Display options" in the "Display" menu. We choose metric units (Fig. 12).
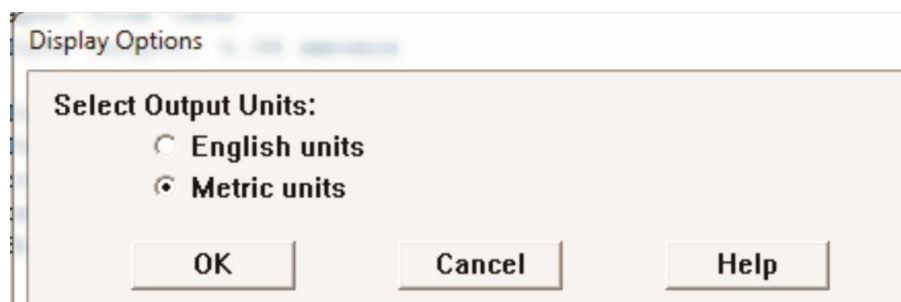

Figure 12. Choice of data display options.

After completing all the previous steps it is necessary to perform a toxic area assessment. To do this we select the toxic area zone in the "Display" menu. The "Hazard To Analyze" dialog box appears (Fig. 13).
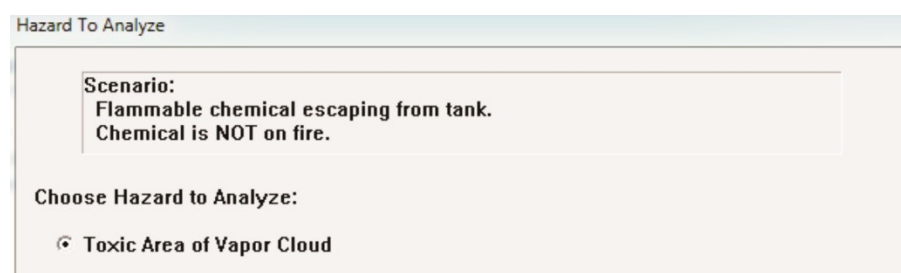

Figure 13. Choice of hazards for assessment.

During the evaporation of the spill, an HC cloud is formed. ALOHA software can simulate three possible hazardous scenarios for an HC cloud: a toxic zone, a flammable zone (an area where an ignition may occur if a cloud collides with an ignition source), or an explosion zone (if an HC vapour explodes). To determine the required evacuation zone, it is necessary to model the assessment of the toxic cloud threat zone, which is the most dangerous for the population and can spread over long distances. Therefore, we choose the option "Toxic area of vapour cloud" and the

levels of toxic concentrations for each of the zones (red, orange and yellow), which are determined depending on the chemical substance (Fig. 14).
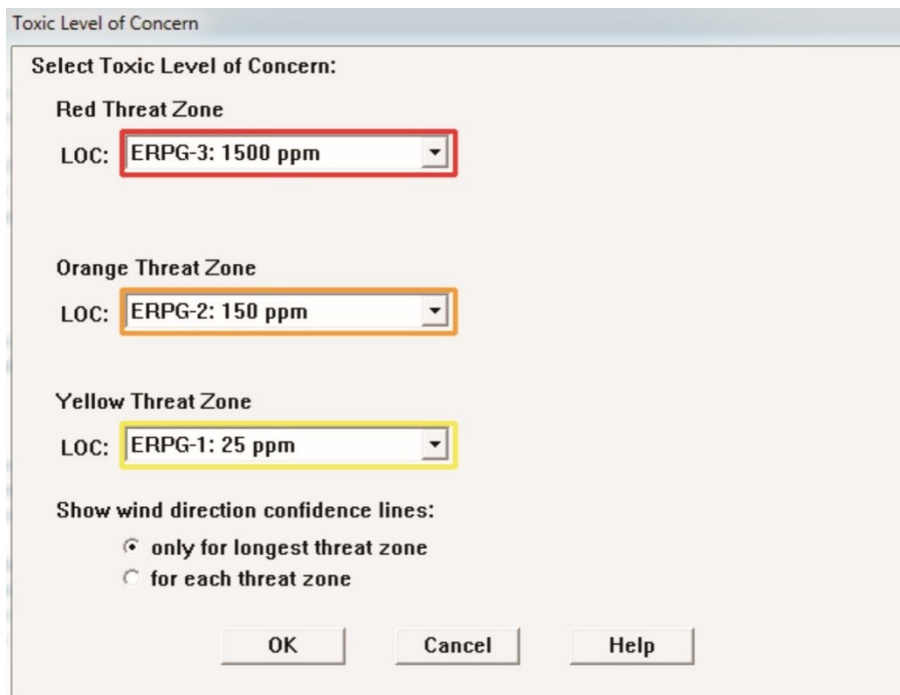

Figure 14. Toxic zone level selection.

Fig. 15 shows the result of calculation - the assessment of the toxic threat zone on each level of pollution for the selected scenario using the program ALOHA.
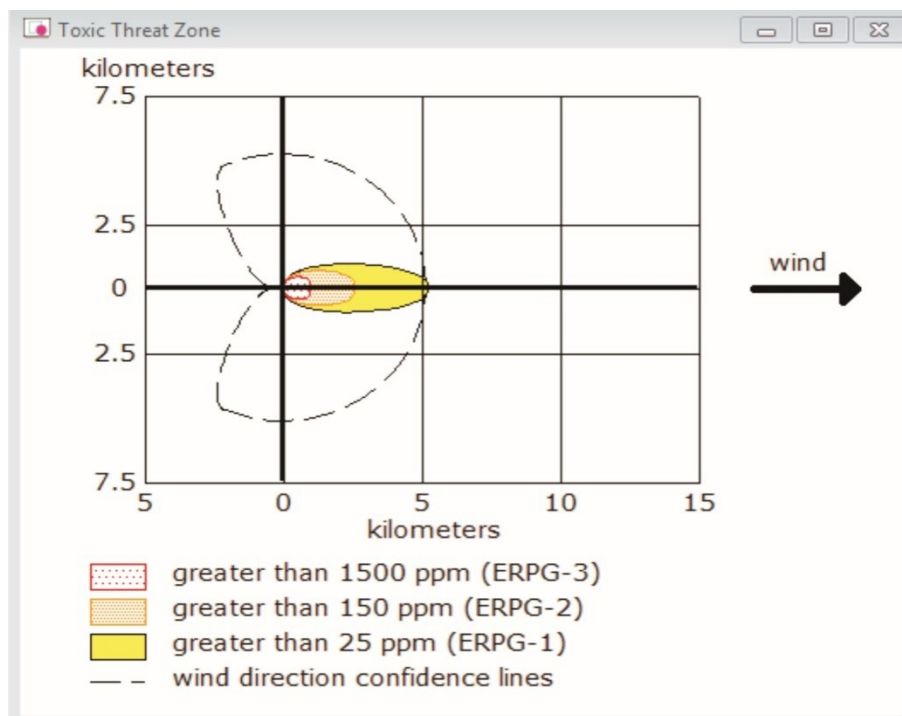
Figure 15. Threat zone assessment for "Toxic cloud modelling" scenario.

2. Modelling of the HC distribution zone in the administrative territories of Lviv using the ArcGIS program. The obtained calculation results are saved in "KML" format via "File - Export treat zone" by additionally entering the exact location of the object where the accident occurred. This format allows transferring the calculated threat zones to Google Earth (Fig. 16) and ArcGIS.

Figure 16. Transfer calculation results to Google Earth (screen image).

Google Earth is good for visualizing results, but for getting accurate plans of buildings, their addresses, and other additional data ArcGIS is more convenient as it has additional tools for identifying objects [17].

The results of calculations transferred to the ArcGIS program have the form as shown in Figure 17.
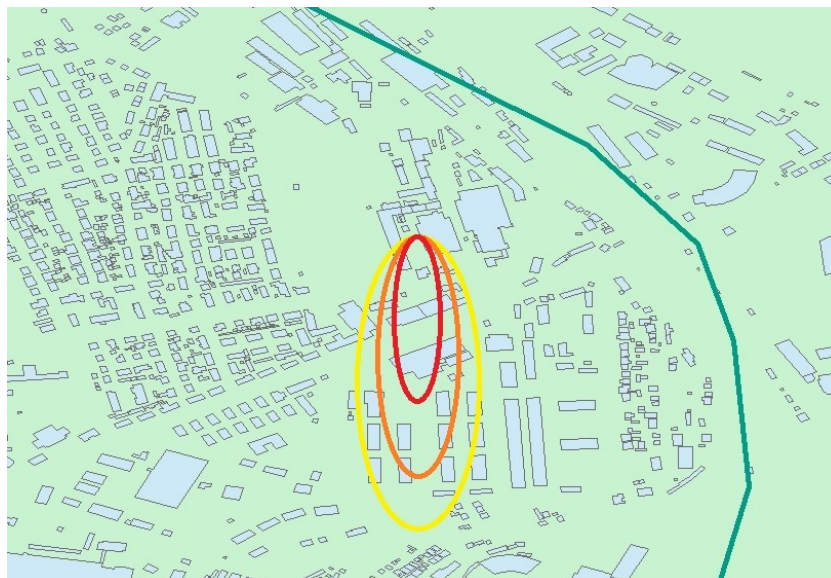

Figure 17. Transfer of calculation results to the ArcGIS program (screen image).

3. The results of determination the required evacuation area in case of a chemical accident using software products ALOHA and ArcGIS. Using ArcGIS tools, buildings and structures that fall into the area of toxic clouds are identified, their exact address and proximity to the accident site are determined. Based on these data, a plan for evacuating the population from buildings is presented in the form of a table (Table 2).

Table 2 – An example of a plan for evacuating people from buildings in case of an accident at a chemically hazardous object

Sequence evacuation	Building address	Floors	Distance to the accident site, m	Number of people (registered), persons
1	Lviv, Modelna street 1	2 floors	20	unknown
2	Lviv, Modelna street 3	9 floors.	25	unknown
3	Lviv, Proektovana street 3	1 floors	30,5	4
…	…	…	…	…
12	Lviv, Proektovana street 5	unknown	32	3

The first column of the table shows the order of evacuation of the house, and the second column shows its address. The following are additional data: number of floors, distance to the accident site and the number of people (registered) at this address. Additional data are desirable, but not always relevant and known.

This plan can be used by emergency services and police during the evacuation of people from buildings and structures. It also can help to assess the transport needs for evacuation.

Discussion results of the method of determining the required evacuation zone based on the use of two software products. The results of the calculations (Fig. 16 and Fig. 17) visualize the scale of possible danger from the release of hazardous chemicals as a result of an accident at a chemically hazardous object located in Lviv. Calculations of concentration parameters (Fig. 15) make it possible to understand all the dangers of exposure to toxic substances on personnel and the population living around the facility. The authors propose to solve the problem of population evacuation by developing a plan for people evacuation from buildings in the form of Table 2. This plan is proposed to be used by rescue units and police during the evacuation of people from buildings and structures.

Of course, Table 2 is not comprehensive and the inclusion of additional parameters (such as the presence of shelters or accurate data on the population) is desirable, but the databases available to the authors do not contain such information, so it may be considered for future research.

Conclusions.

1. Calculations of HC spill time were performed and modelling of HC distribution depending on meteorological conditions as a result of a possible accident at one of the high-risk objects of Lviv with the help of ALOHA program was done;

2. Modelling zone of HC distribution in the administrative territories of Lviv was carried out with the help of ArcGIS tools, which made it possible to identify buildings and structures that fall into the zone of toxic clouds, determine their exact address and proximity to the accident site;

3. The plan with the order of buildings evacuation on the basis of the received preliminary modelling data was obtained in the form of table which is offered to use by emergency rescue units when carrying out evacuation of the population in case of accident on CHO.

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МЕТОД ВИЗНАЧЕННЯ НЕОБХІДНОЇ ЗОНИ ЕВАКУАЦІЇ НАСЕЛЕННЯ У ВИПАДКУ ХІМІЧНОЇ АВАРІЇ ЗА ДОПОМОГОЮ ПРОГРАМНИХ ЗАСОБІВ

В статті проаналізовано кількість хімічно-небезпечних об'єктів в кожному регіоні України та наведено приблизну кількість небезпечних хімічних речовин, що знаходяться на них. Приведено приклад наймасштабнішої аварії за період незалежності з викидом хімічних речовин, розкрито її причини та наслідки. Доведено, що дослідження ефективних способів планування та проведення евакуації населення при виникненні аварійних ситуацій є актуальним завдання сьогодення. Проведено аналіз наукових праць в даному напрямку і виокремлено відсутність стандартної методики планування евакуації населення, що потрапляє в зону ураження небезпечними-хімічними речовинами, за допомогою програмних засобів. Автором запропонована методика визначення необхідної зони евакуації на основі використання двох існуючих програмних продуктів ALOHA та ArcGIS для моделювання необхідної зони евакуації навколо об'єкта підвищеної небезпеки в залежності від метеорологічних умов. В запропонованому методі програмне забезпечення ALOHA використовується для проведення розрахунків під час розливу небезпечних хімічних речовин та моделювання їх поширення в залежності від напрямку вітру, вологості та температури навколишнього природного середовища. На основі моделювання в програмі ArcGIS накладаються зони поширення токсичних мас та адміністративна карта території на якій за допомогою додаткових інструментів виділяються будинки та споруди житлового та виробничого призначення, що потрапляють в цю зону, з яких необхідно провести евакуацію населення, тим самим моделюючи план порядку евакуації. Кінцевим продуктом такого моделювання є список будинків з адресами, які мають бути евакуйовані, що використовуватиметься аварійно-рятувальними підрозділами та поліцією в ході проведення збору людей. У статті наведено приклад такого моделювання для одного з об'єктів міста Львова.

Ключові слова: *план евакуації, небезпечна хімічна речовина, цивільний захист, комп'ютерне моделювання, програмне забезпечення ArcGIS.*