Forecasting the Environmental Risk and the Outcome of the Impact of a Chemical Accident on the Environment

M N Zherlykina, Y A Vorob’eva, S A Jaremenko

1Department of housing and communal services, Voronezh State Technical University
Voronezh, Voronezh, 20-letiya Oktyabrya ,84, 394000 Russia

E-mail: zherlykina@yandex.ru

Abstract. The methodical approach to forecasting of ecological risk and the outcome of the impact of harmful substances on the environment is presented in the event of an accident at chemical enterprises. The application of these solutions in the design of industrial facilities will allow for the provision of measures and methods to prevent a potential threat with the establishment of the amount of permissible damage not exceeding environmental and socio-economic standards. The risk assessment for the environment, the facility personnel and the population living in the nearest area is based on the methods of reliability theory, probability theory and mathematical statistics. Integration of the theory of reliability and mathematical statistics makes it possible to implement approaches to determine the quantitative assessment of the probability of implementing dangerous factors using the "event tree". Quantitative assessment of the emission of harmful substances as a result of an accident at a hazardous facility suggests possible ways to achieve the maximum permissible value of their surface concentration. To make a rational decision, it is necessary to predict and assess the permissible risk of damage in case of accidents, in which case it can be concluded that the chosen purification method is effective.

1. Introduction

The main purpose of the predictive determination of the magnitude of environmental risk in the event of emergence of harmful emissions at chemical plants is to provide in advance the measures and ways to prevent a potential threat with establishing the amount of permissible damage not exceeding environmental and socio-economic standards.

The risk assessment for the environment, the facility personnel and the population living in the nearest area is based on the methods of reliability theory, probability theory and mathematical statistics.

The methods of reliability theory make it possible to clarify the parameters of the operability of operation of equipment and, accordingly, the accident rate of technological processes with the formation of dangerous factors of emergency situations.

Methods of mathematical statistics are used to identify initiating events leading to the implementation of emergency and post-emergency scenarios for the development of emergency situations based on a priori accepted reference frequency characteristics.

Integration of the theory of reliability and mathematical statistics makes it possible to implement approaches to developing a quantitative assessment of the probability of implementing dangerous factors using the "event tree".
The essence of the risk assessment is reduced to the identification of accidents, which are sources of hazardous factors, and the attendant conditions for this. The main factors of detection are:

- statistical data on the occurrence of an accident with emission of harmful substances, obtained on the basis of the experience of liquidation of emergency situations;
- analytical assessment of the technological regulations of production to identify the locations of hazardous substances, their thermodynamic parameters and the conditions under which dangerous factors can be formed.

The estimated severity of the consequences is ranked into four levels [1, 2, 3, 4, 5]:

1. first is a refusal with negligible consequences;
2. second is an uncritical refusal, which may lead to a delay in the fulfillment of the task, but does not pose a threat to the environment, the facility itself and human health;
3. third is a critical failure, which quickly and with a high probability can cause significant damage to the facility, but creates a negligible threat to the environment, life and health of people;
4. fourth is a catastrophic failure, which quickly with a high probability can cause significant damage to the environment, for the facility.

When assessing the third and fourth level, a quantitative approach should be used, and for the fourth rank this approach is mandatory.

An analysis of the hazard of the facility in the event of an emergency situation with a mass emission of harmful substances should be carried out in blocks on the basis of a detailed study of the condition of the facility in accordance with the requirements [5, 6, 7], regulatory documentation in the field of industrial safety, and also taking into account the analysis of accidents that occurred on this and similar objects.

The initial data for the development of a project for forecasting and assessing environmental risk and the outcome of the impact of the accident on the environment are: a brief description of the facility; block diagram of the process object; Characteristics of hazardous substances, including: name of harmful substance, molecular formula, physical and chemical parameters (molecular weight, odor, color, boiling point, density under normal conditions), data on explosion hazard and fire hazard, reactivity, corrosivity, toxic hazard, nature of effects on the human body, individual means of protection, first aid measures for the injured, and methods for transferring (neutralizing) the substance to a safe state.

The purpose of forecasting and assessing environmental risks in the event of an emergency at industrial facilities associated with handling hazardous substances should be aimed at identifying the main causes of accidents and assuming possible ways to achieve the normative value of the surface concentration of harmful substances.

Based on the analysis of scenarios for the development of an emergency situation for a number of chemical, fire-hazardous and explosive enterprises, a sequence of constructing a probable "event tree" is proposed:

- determination of the nature of the technological process with the identification of harmful substances characteristic of the given production;
- construction of the "event tree" according to the methodology described in [5];
- establishment of an approach to the assessment of the probability of each event occurring during the course of an accident with the release of harmful substances (explosive, fire-hazardous, non-explosive, non-flammable);
- the identification of events, the outcome of which is the release of a harmful substance, requiring measures to be taken to establish means for purifying emissions or dispersing them.

This approach allows you to take into account the properties of harmful substances and determine the ways to achieve their concentration in the surface layer of the atmosphere equal to the maximum allowable in the working area, \( MAC_{wa} \), previously not absorbed in [8 ... 14].

The significance of the ventilation emission of harmful substances in the prediction of an emergency at a chemical plant \( X \) is given by a mathematical dependence:
\[ f(n) = \frac{1}{\pi \cdot (1+n^2)} \]  

where \( n \) – number of the same type of occurrences in the premises of the chemical plant shop where the emission of harmful substances, determined from statistical data, occurs.

The probability that the value of \( X \) falls on the segment from 0 to \( n \):

\[ P \ 0 < X < n = \int_{0}^{n} f(n) \ dn. \]  

The probability of occurrence of emission of harmful substances in a chemical production room is presented in the form of a dependence:

\[ P_X = \frac{1}{\pi} \int_{0}^{n} \frac{dn}{1+n^2}. \]  

In Figure 1, an example is given of constructing an "event tree" (fragment) in the event of an emergency at an industrial facility according to the above approach.

![Event Tree](image)

**Figure 1.** "Event Tree" (fragment) in the event of an emergency at an industrial facility.

Application of the method at the design stage will increase the safety of industrial facilities and find optimal solutions for neutralizing the unacceptable impact of an accidental release on the environment.

Assessment of environmental risk in the emission of harmful substances is based on the construction of a logical scheme, which takes into account various initiating events and possible options for their development. The probabilities, \( P_i \), of the realization of each of the branches of the logical scheme according to the mathematical dependence are calculated:
where $i$ – emission source of harmful substances; $\Theta^*$ – probability number; $a_i$ – correction factor for recording the frequency of technological operations, determined by [5, 15 ... 22]; $\theta_i$ – correction factor to take into account the level of security organization, is determined by [5, 15 ... 22]; $\varphi$ – loss of airtightness at an emergency emission of harmful substances; $\lambda$ – failure rate of the elements of the process equipment, determined by [5, 15 ... 22]; $Z$ – fraction of the mass of vapor-gas substances participating in the explosion according to [5]; $V_r$ – volume of the room, m³; $\overline{G_a}, \overline{G_s}$ – specific emissions of harmful substances under normal technological conditions and in case of accident, respectively, mg/(m³·h); $K_{pa}$ и $K_{ps}$ – multiplicity of air exchange during the operation of the ventilation system under normal operating conditions and during an accident, respectively, 1/h; $q_{pa}$ – maximum concentration of explosives at a distance $x$, m, from the source of emission; $n(t)$ – number of devices (nodes) that have failed for a period of time from $t - \Delta t/2$ to $t + \Delta t/2$; $m$, $n$, $F$ – dimensionless coefficients that take into account the conditions for the escape of the gas and air mixture from the source mouth, the rate of sedimentation of harmful substances in the atmospheric air; $\eta$ – cleaning efficiency, %, [23]; $q_{oa}$ – maximum permissible concentration of harmful substance in the working area, mg / m³; $H$ – height of emission source, m; $C$ – gas and air mixture consumption, m³/s; $\Delta T$ – difference between the temperatures of the gas and air mixtures and atmospheric air, °C.

Calculations are carried out for given distances from the place of initiation of the accident. When predicting the outcome of a chemical accident, the conditional probability $P_{ai}$ of human injury is determined at different distances $R$ from the outdoor installation when the i-th branch of the logic circuit is implemented – "event tree". Graphic dependencies $P_{ni} = f(R)$ are constructed.

On the general plan of the enterprise, around the source of emergency release of explosive explosive explosives, zones of destruction are constructed, and for each of these zones, the conditional probabilities $P_{ni-j}$, the human lesions (zone number), mean (zone); the average number of people who are constantly in the j-th zone.

Calculate the expected number of affected people in the implementation of the i-th branch of the logical scheme for mathematical dependence:

$$N_l = \sum_{i=1}^{l} P_{ni} \cdot N_f^i,$$

where $k$ – number of affected zones of attack, chosen on the basis that outside the $k$-th zone all values $P_{ni} \leq 10^{-2}$ year⁻¹, a b k-th at least one of the values $P_{ni} > 10^{-2}$ year⁻¹.

Social risk is calculated using mathematical dependence:

$$P_{social} = \sum_{l=1}^{L} P \cdot N_f^i,$$

where $l$ – number of branches of the logical scheme for which $N_f^i \geq N_0^i$ ($N_0^i$ – expected number of affected people for whom social risk is assessed).

If for all branches of the logic circuit the condition $N_f^i < N_0^i$, then consider pairwise combinations of branches of the logical scheme for which the condition is fulfilled:

$$N_f^{i_1 \cdot i_2} = N_f^{i_1} + N_f^{i_2} \geq N_0^i.$$

In this case $P_{social}$ is calculated by the mathematical dependence:

$$P_{social} = \sum_{l=1}^{L} P \cdot N_f^i \cdot P \cdot N_f^i,$$

where $P \cdot N_f^i \cdot P \cdot N_f^i$ – probability of realizing the branches $i_1$ and $i_2$ of the event tree.

In the dependence (8), summation is carried out over all pairs of branches of the logic circuit.
The definition of social risk consists of the following stages:

distances from 100 to $R_{social}$, m, and every 100 m. The division of the territory within which the explosive release occurred is divided into zones where $R_{social}$ – distance that includes the territory of the enterprise from the source of the release of explosives, garden areas, residential buildings and other;

division into zones characteristic of the investigated object is carried out: first zone is the territory of the industrial premises with the number of people $N_{A}$; second zone is the territory occupied by the horticultural areas (the number of permanent residents is $N_{B} = \rho_{B} \cdot S$, $\rho_{B}$ – population density, $S$ – area occupied by the horticultural areas); third zone is the territory occupied by the residential area (the number of people permanently staying is $N_{C} = \rho_{C} \cdot S$, $\rho_{C}$ – population density, $S$ – residential area, m$^2$);

for greater accuracy of calculation, the territory of the second and third zones is divided into the territories following one another after every 100 m, and the number of people $N_{B}$, $N_{C}$.

Using the graph (Figure 2) and the mathematical dependence (8), we determine the conditional probabilities of human injury by the zones and the expected number of people suffering from $N_{i}^p$ in the implementation of the corresponding variants of the logical scheme (for the first zone, the determination is made along the external boundary).

![Figure 2. Dependence of the conditional probability of human injury $P_{Ni}$ at different distances from the source of emission of harmful substances: 1 – fire of the strait; 2 – "the fireball"; 3 – combustion with the development of excessive pressure; 4 – threshold value $P_{Ni} = 1 \cdot 10^{-2}$ \text{ year}^{-1}.

2. Conclusion

Thus, the methodology for calculating social risk allows you to determine the possible number of people affected as a result of an accidental release of harmful substances and to estimate in monetary terms the amount of harm caused to their health.

Forecasting the environmental risk and the outcome of the impact of a chemical accident on the environment, it is possible to assess the degree of the impact of an accidental release of harmful substances on the environment, to establish the efficiency of the ventilation system in an industrial enterprise and to take the necessary measures for cleaning or dispersing pollutants, harm to human health.

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