RESEARCH ARTICLE | NOVEMBER 01 2023

On the issue of risk management of emergencies, taking into account the effect of the accumulation of damage FREE

Valeriy Eliseev ✉; Oksana Myrgorod; Oleksandr Pyrohov; Dina Lazarieva

AIP Conf. Proc. 2840, 050002 (2023)
https://doi.org/10.1063/5.0170841

On the Issue of Risk Management of Emergencies, Taking Into Account the Effect of the Accumulation of Damage

Valeriy Eliseev[1,a)], Oksana Myrgorod[2], Oleksandr Pyrohov[2] and Dina Lazarieva[3]

[1]*Institute of Public Administration and Scientific Research on Civil Defence, Vyshgorodskaya Str., 21, Kyiv, 04074, Ukraine*
[2]*National University of Civil Defence of Ukraine, Chernishevska Str., 94, Kharkiv, 61023, Ukraine*
[1]*Odessa State Academy of Civil Engineering and Architecture, Didrikson str., 4, Odessa, 65029, Ukraine*

[a)] *Corresponding author: eliseev1941@ukr.net*

Abstract. An essential condition for the successful functioning of the system of protection of the population and territories of the state is to build an effective strategy for managing the risks of emergencies and its implementation in order to increase the readiness and efficiency of a unified state civil protection system.
In modern conditions, the strategy has been an integral part of risk management in almost all developed countries.
Issues of state security in general, security in emergencies (ES), including the management of this security have recently been considered as a strategic task of the state. The Civil Protection Code of Ukraine stipulates [1] that civil protection is a function of the state to protect the population and territories from emergencies by preventing such situations, eliminating their consequences in peacetime and in special periods and is carried out on the principle of maximum, economically justified risk reduction occurrence of an emergency. Therefore, one of the priority areas of development of the State Emergency Service of Ukraine is the introduction of an effective system of emergency prevention to reduce deaths. The Civil Protection Code of Ukraine defines the term of emergency prevention as a set of legal, socio-economic, political, organizational and technical, sanitary and hygienic and other measures aimed at performing such basic tasks as risk assessment, safety regulation, early response to emergencies.
Therefore, the scientific substantiation of the mechanism for assessing the risks of emergencies is a problematic issue, especially taking into account the effect of the accumulation of damage.

Keywords: emergency, safety, risk, damage, risk management.

INTRODUCTION

In the scientific literature, a significant amount of scientific research has recently appeared on the solution of the problem of risk management in various fields of activity.

Considerable attention is paid to research on risk assessment in the field of life safety. However, in all studies there is no mechanism to account for the effect of accumulation of damage, when the impact of several adverse factors (natural, man-made, social, military) emergency situation of the object level on the scale of destruction can move to local, regional and possibly state level.

Thus, in work [2], the authors consider emergency risk management as a process of decision-making and implementation of measures aimed at ensuring the minimum possible (permissible) risk.

In [3] it was found that to solve the problems of monitoring there are different subsystems that are disconnected, heterogeneous, hardware and software incompatible, focused on monitoring and assessing the state of individual components of the environment and natural resources.

In the study [4], emergency risk management is considered as a set of methods, techniques and measures that allow to some extent to predict the occurrence of risk events and take measures to reduce them.

In [5] the method of threshold semi-adaptive scaling transformation is constructed. The method provides the calculation of periodic sections that adequately reflect the dynamics of real complex dynamic systems in the natural and technical spheres.

IX International Conference on Actual Problems of Engineering Mechanics (APEM2022)
AIP Conf. Proc. 2840, 050002-1–050002-7; https://doi.org/10.1063/5.0170841
Published by AIP Publishing. 978-0-7354-4721-9/$30.00

In [6], the authors assess the risk of emergencies in the region in order to implement preventive measures to prevent emergencies, to accumulate the necessary funds and resources for effective emergency response with minimal losses.

S. Tkach in the study [7] formulates the mechanism of emergency risk management as a set of tools, methods, forms and means of interaction of risk management entities to develop and implement management decisions aimed at preventing emergencies, reducing and overcoming the consequences of their impact.

Thus, the term emergency risk management is defined as the art of carrying out the activities of a structure in a dangerous natural, man-made, social or military situation, based on forecasting or assessing the risk and methods of reducing it.

RECENT RESEARCH, RESEARCHES AND PUBLICATIONS RESULTS

The Law of Ukraine "On Basic Principles of State Supervision (Control) in the Sphere of Economic Activity" [8] defines risk as a quantitative measure of danger, taking into account the likelihood of negative consequences of economic activity and possible losses from them. This can be represented by a formula

$$R_{HC} = P_{HC} \cdot W_{HC}, \quad (1)$$

where R_{HC} – is the risk of emergencies;

P_{HC} – the probability of occurrence of emergencies;

W_{HC} – losses from emergencies.

The types and levels of risks used in technical documentation when assessing the level of danger of technical objects of the state are given in the "Methodology for determining risks and their accepted levels for declaring the safety of objects of increased danger" [9].

Separate dangerous phenomena, dangerous objects are compared with each other in terms of the magnitude of risks. The methodology determines the acceptable and maximum permissible risk for hazardous facilities, calculated taking into account the scale of the hazard and the location of other hazardous enterprises in the region. The total risk of undesirable consequences should not exceed the established acceptable risk.

The main quantitative indicators of the risk of death of people are determined by territorial, social and individual [9].

Territorial risk (Rt) - the probability of death of a person within a year, located in a certain territory, from possible sources of danger to the object. The level of acceptable risk is $R\,t \leq 10\text{-}5$.

Social risk (Rs) - the probability of death of people (more than 10 people) in a given region during the year from possible sources of danger of technical facilities, taking into account the probability of their presence at the facility. The level of acceptable risk is $Rs \leq 10–5$.

Individual risk (Ri) - the probability of death of a person from possible sources of a dangerous object during the year, taking into account the probability of being at the object. The level of acceptable risk is $Ri \leq 10\text{-}6$.

The purpose of this article is to develop a mathematical apparatus for assessing the risks of emergencies, taking into account the effect of damage accumulation.

MATERIALS AND METHODS OF STUDY

Currently, there is growing concern in the world in connection with a tangible increase in the number of natural, man-made, social and military emergencies. This requires steps to be taken to improve the management of security levels.

One of these measures is the transition to emergency risk management methods based on risk analysis and assessment as a quantitative characteristic of danger to the population [10, 11], surface water pollution [12] and the environment [13, 14] from hazardous objects [15, 16]. At the same time, the risk should be assessed not only in normal conditions of accident-free operation, but also in case of emergency situations of a man-made, natural, social and military nature.

When calculating an individual's risk of death, various factors must be taken into account, such as:

dangerous factors of social, military, technogenic and natural character;

the possibility of occurrence of hazardous events, the characteristics of the power of these events, the territorial distribution of sources of threat;

protection of objects in relation to the damaging factors of sources of danger;

financial and material costs for the implementation of measures to prevent the impact of hazardous factors.

Natural factors are understood as undesirable consequences of hazardous natural processes and phenomena, man-caused - dangerous man-made phenomena (accidents at technical facilities). Social factors are possible negative consequences from dangerous social processes (deterioration of the socio-economic situation of the state, significant differentiation of the population in terms of income received, the presence of population groups living on the verge of poverty) and phenomena (terrorism, crime, alcoholism, drug addiction, etc.). Dangerous reasons of a military nature are connected with the consequences of the introduction of modern weapons. Modern means of destruction include nuclear, chemical, bacteriological and newly developed types of weapons.

From the point of view of quantitative assessment, the risks of a social, military, man-made and natural nature are measured by the probabilistic value of losses over a certain period of time. An early risk forecast, identification of the main factors, and taking measures to reduce it should form the basis of risk management.

From another point of view, risk management is the development and justification of rational activity programs in order to effectively implement decisions in the field of security. The main thing in this activity is the process of optimal allocation of limited resources for risk reduction in order to achieve an acceptable level of safety of the population and the environment according to criteria that take into account economic and social factors. This process is based on environmental monitoring and risk analysis.

The concept of risk management defines that risk management is a targeted activity to implement a rational way to reduce risk to a level that society considers acceptable, taking into account resource and time constraints [17].

RESEARCH RESULTS

The management process is based on the emergency risk management system. For effective emergency risk management, it is necessary to create and develop:

emergency prevention system and mechanisms of state risk regulation;

the system for responding to and eliminating the consequences of emergencies, to increase the speed of rapid response to emergencies and the implementation of priority life support and rehabilitation of the affected population, to increase the capacity of technical means and improve the technology of emergency rescue operations;

a system for training the management staff of government bodies, specialists and the public for actions in emergency situations in order to reduce the risks and scale of emergencies.

The structure of the risk management system should include the following main elements:

setting acceptable risk levels based on economic and social factors;

environmental monitoring and emergency forecasting;

risk analysis for the life of the population and decision-making on the implementation of protection measures;

rational distribution of funds and resources for measures to prevent risk reduction and reduce the scale of emergencies;

carrying out rescue and recovery operations in case of emergency.

The risk analysis scheme should include:

environmental monitoring;

hazard identification;

analysis (assessment and forecast) of the threat;

analysis of the distribution of hazardous factors in the territory;

calculation of emergency risk;

calculation of individual risk for the population;

comparing the risk with an acceptable risk and deciding on the appropriateness of taking protective measures;

justification and implementation of rational protection measures;

preparation of forces and means for carrying out emergency rescue operations;

creation of the necessary reserves to reduce the scale of emergencies.

Based on the risk analysis scheme, the disaster risk management methodology includes:

environmental monitoring;

hazard identification;

calculation of the probability of occurrence of ES - RES;

calculation of expected losses from ES - Wes;

risk calculation - Res = Res * Wes;

comparing the parameters $R_{ES} \leq R_{PR}$ and making a decision on further regulation of the hazard level;

risk zoning;

planning and implementation of organizational, engineering and sanitary and hygienic measures to reduce the level of danger.

On the basis of the methodology, we will present a generalized emergency risk management scheme (FIGURE 1).

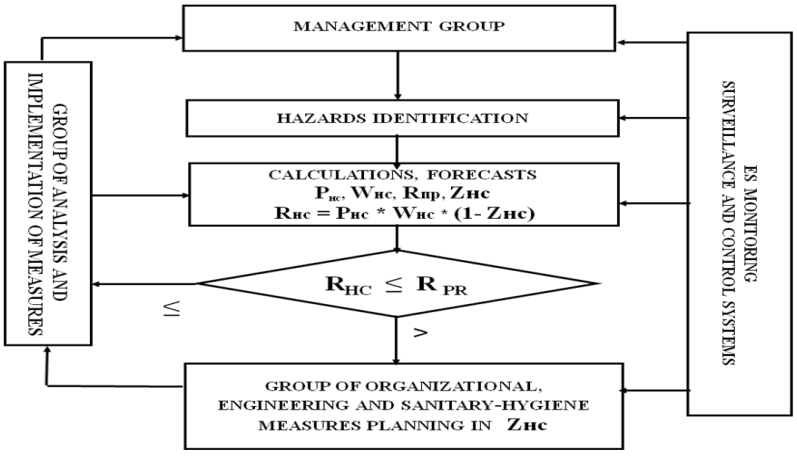

FIGURE 1. Generalized scheme of emergency risk management

International experience in dealing with emergencies shows that some states are forced to seek help in order to eliminate large-scale emergencies. An effective organization of civil protection of the population at the national level is impossible without broad and active international cooperation.

The reasons that encourage the international community to join forces to address the challenges of large-scale emergencies include:

the global nature of individual emergencies;

cross-border spread in some cases of hazards in emergency situations.

The transition to a system of analysis and management of emergency risks serves as the basis for ensuring a guaranteed level of security for a citizen, society, and state. The main directions of the state policy on risk management are:

formation of a legislative and regulatory framework for security based on the principles of risk management, taking into account the requirements of the European Union;

introduction of risk regulation and use in the mechanisms of state regulation of safety;

financial support for research and development of methods, techniques for analyzing and assessing the risks of emergency situations, forecasting their development;

use of a risk-based approach in security management;

development of state programs for socio-economic development based on a risk-based approach.

In order to quantify the magnitude of the risk, it is necessary to know all the possible consequences of a certain action and the likelihood of the consequences themselves. Probability means the possibility of obtaining a specific numerical result.

The quantitative assessment of damage from emergencies depends on many factors, for example, on the number of people who were in the danger zone, the amount of material assets located there.

The expected consequences of an emergency are defined as losses. Each individual type of loss has its own quantitative expression. For example, the number of dead, injured or sick, the area of the contaminated territory, the area of the burnt forest, the cost of destroyed structures, etc.

Based on the risk formula (1), the main measure of the degree of danger is the probability with which it can manifest itself.

Determining the probability of occurrence of emergencies.

Probability is a numerical characteristic of the possibility that a random event will occur under conditions that can be reproduced an unlimited number of times. Probability is the basic concept of the branch of mathematics called probability theory [18].

An event is called random when its outcome cannot be known in advance. Even when the consequences of an incident are expected, their impact may be so complex that it is impossible to deduce a consequence from them

logically and consistently. For example, if you flip a coin, then the side on which the coin falls determines the position of the hand and the coin in the hand, speed, torque, etc. However, it is impossible to track all these factors, so the result can be considered random.

When calculating the probability of occurrence of emergencies using the methods of probability theory, we will take the designation of probabilities Pes (t) - the probability of occurrence of emergencies for a period of time t, Pn (t) - the probability of not occurrence of emergencies for t and the normalizing condition Pes (t) + Pn (t) = 1. To simplify the calculations and writing formulas, we will accept the stationary mode of operation, i.e. $\rightarrow \infty$, P_{ES} (t) $\rightarrow P_{ES}$ [18] .

The main difficulty and laboriousness of risk forecasting is to determine the probability of an emergency, especially when this probability depends on several factors, and with the onset of destructive processes, this probability increases, taking into account the influence of these factors with the so-called damage accumulation effect.

In the beginning, we will consider the methodology for calculating the probability of an emergency, taking into account two factors, each of which can lead to an emergency with probabilities.

$$\begin{aligned} P^1{}_{ES} &= P^1{}_O + P^1{}_L + P^1{}_R + P^1{}_S, \\ P^2{}_{ES} &= P^2{}_O + P^2{}_L + P^2{}_R + P^2{}_S, \end{aligned} \tag{2}$$

where are the indices o, m, p, d (o - ES of the object level, m - ES of the local level, p - ES of the regional level, d - ES of the state level).

Let us write the total compatible probability of occurrence of an emergency from two factors P (2) ns with the effect of damage accumulation in general form

$$P^{(2)}{}_{ES} = 1 - (1 - P^1{}_{ES})(1 - P^2{}_{ES}) = P^1{}_{ES} + P^2{}_{ES} - P^1{}_{ES} P^2{}_{ES}. \tag{3}$$

The normalizing conditions for the probabilities P ^{1} and P ^{2} are:

$$\begin{aligned} P^1{}_N + P^1{}_O + P^1{}_L + P^1{}_R + P^1{}_S &= 1; \\ P^2{}_N + P^2{}_O + P^2{}_L + P^2{}_R + P^2{}_S &= 1, \end{aligned} \tag{4}$$

where $P^1{}_N$, $P^2{}_N$ – probabilities of non-occurrence of emergencies from the first and second factors.

To solve the problem of determining the probabilities, we fill in the matrix of compatible probabilities of occurrence of emergencies (Table 1)

TABLE 1. Matrix of compatible disaster occurrence probabilities

$\mathbf{P^n_i}$	$\mathbf{P^1_N}$	$\mathbf{P^1_O}$	$\mathbf{P^1_L}$	$\mathbf{P^1_R}$	$\mathbf{P^1_S}$
$\mathbf{P^2_N}$	$P^1_N P^2_N$	$P^1_O P^2_N$	$P^1_L P^2_N$	$P^1_R P^2_N$	$P^1_S P^2_N$
$\mathbf{P^2_O}$	$P^1_N P^2_O$	$P^1_O P^2_O$	$P^1_L P^2_O$	$P^1_R P^2_O$	$P^1_S P^2_O$
$\mathbf{P^2_L}$	$P^1_N P^2_L$	$P^1_O P^2_L$	$P^1_L P^2_L$	$P^1_R P^2_L$	$P^1_S P^2_L$
$\mathbf{P^2_R}$	$P^1_N P^2_R$	$P^1_O P^2_R$	$P^1_L P^2_R$	$P^1_R P^2_R$	$P^1_S P^2_R$
$\mathbf{P^2_S}$	$P^1_N P^2_S$	$P^1_O P^2_S$	$P^1_L P^2_S$	$P^1_R P^2_S$	$P^1_S P^2_S$

We define the required probabilities as the sum of pairwise products of the matrix over rows and columns:

$$\begin{aligned} P^{(2)}{}_N &= P^1{}_N P^2{}_N \\ P^{(2)}{}_O &= P^1{}_N P^2{}_O + P^1{}_O P^2{}_N + P^1{}_O P^2{}_O \\ P^{(2)}{}_L &= P^1{}_L + P^2{}_L - P^1{}_L (P^2{}_R + P^2{}_S) - P^2{}_L (P^1{}_L + P^1{}_G + P^1{}_S) \\ P^{(2)}{}_p &= P^1{}_p + P^2{}_p - P^1{}_R P^2{}_p - P^1{}_R P^2{}_S - P^1{}_S P^2{}_p \\ P^{(2)}{}_S &= P^1{}_S + P^2{}_S - P^1{}_S P^2{}_S \end{aligned} \tag{5}$$

where P $^1{}_N$, P $^2{}_N$ - compatible probabilities of occurrence of emergencies from two factors.

We write down the total compatible probability of occurrence of an emergency from two factors P $^{(2)}{}_{ES}$

$$P^{(2)}_{ES}=P^{(2)}_{O}+P^{(2)}_{R}+P^{(2)}_{p}+P^{(2)}_{S}. \quad (6)$$

Using these dependencies by the method of successive calculation of the next pair of factors, etc. we calculate the compatible probability of an emergency from n factors.

$$P^{(n)}_{ES}=P^{(n)}_{O}+P^{(n)}_{L}+P^{(n)}_{p}+P^{(n)}_{S}. \quad (7)$$

Moreover, with each subsequent calculation of the probability of an emergency, the probability $P^{(n)}_{S}$, the probability of the worst case of an emergency, will increase. That is, the damage will accumulate.

Determination of losses from emergencies and their consequences.

In order to determine the size of losses, a methodology for assessing damage from the consequences of emergency situations has been developed [19].

All losses are divided into types depending on the actual damage caused, in particular from:

loss of life and health of the population;
destruction and damage to fixed assets; destruction of property and
products;
non-production due to the termination of production;
seizure or violation of agricultural land;
loss of livestock;
loss of timber and other forest resources;
fisheries losses;
destruction or deterioration of the quality of recreational areas;
air pollution;
pollution of non-agricultural land;
damage caused to the natural reserve fund.

Using those given in the methodology, having calculated by formula (6) the probability of occurrence of emergencies from n-factors $P^{(n)}_{ES}$ and having determined the losses from the consequences of emergencies $W^{(n)}_{ES}$, we calculate the value of the risk of emergencies.

$$R_{ES}=P^{(n)}_{ES}\cdot W^{(n)}_{ES}. \quad (8)$$

CONCLUSIONS

The development of an effective emergency risk management system and its implementation is the main prerequisite for improving the readiness and efficiency of the functioning of the unified state system of civil protection to prevent and overcome the consequences of emergencies.

The developed model makes it possible to quantitatively predict the expected risks of emergencies, material or financial losses from them, taking into account the effect of accumulation of damage, and to plan organizational, engineering and sanitary and hygienic measures to reduce the level of danger.

The complexity of the calculations determines the need to use computer technology in the implementation of this task. Therefore, the further direction of scientific research on this issue is the development of computer programs for calculating the probabilities of occurrence of emergency situations, taking into account the effect of accumulation of damage, possible material or financial losses, and on the basis of this, the determination of the expected risk of emergency situations.

REFERENCES

1. Zakon Ukrainy vid 02.10.2012 r. № 5403-VI, *"Kodeks tsyvilnoho zakhystu Ukrainy"* (K, 2012).
2. S.A. Dykan, O.U. Zyma, *Bezpeka v haluzi ta nadzvychainykh sytuatsiiakh [Elektronnyi resurs]* Rezhym dostupu: https://pidruchniki.com/86062/bzhd/bezpeka_v_galuzi_ta_nadzvichaynih_situatsiyah
3. O. Popov, A. Iatsyshyn, V. Kovach, V. Artemchuk, D. Taraduda, V. Sobyna, D. Sokolov, M. Dement, T. Yatsyshyn, *Conceptual approaches for development of informational and analytical expert system for assessing the NPP impact on the environment, Nuclear and Radiation Safety*. (2018) DOI: 10.32918/NRS.2018.3(79).09.

4. O.P. Miahchenko, *Bezpeka zhyttiediialnosti liudyny ta suspilstva [Elektronnyi resurs]* Rezhym dostupu: https://pidruchniki.com/1584072026949/bzhd/bezpeka_zhittyediyalnosti_lyudini
5. B. Pospelov, E. Rybka, V. Togobytska, R. Meleshchenko, Yu. Danchenko, *Construction of the method for semi-adaptive threshold scaling transformation when computing recurrent plots* (Eastern-European Journal of Enterprise Technologies, 2019), 4(10), 100, pp. 22–29.
6. R.A. Osin, O.M. Mezentseva, *Otsinka ryzyku vynyknennia nadzvychainykh sytuatsii tekhnohennoho ta pryrodnoho kharakteru v rehionalnomu vymiri [Elektronnyi resurs]* Rezhym dostupu: http://naukam.triada.in.ua/index.php/konferentsiji/45-p-yatnadtsyata-vseukrajinska-praktichno-piznavalna-internet-konferentsiya/302-otsinka-riziku-viniknennya-nadzvichajnikh-situatsij-tekhnogennogo-ta-prirodnogo-kharakteru-v-regionalnomu-vimiri.
7. S.M. Tkach, *Upravlinnia ryzykamy investytsiinoi diialnosti v rehioni: teoretychni osnovy ta prykladni aspekty: monohrafiia* (Lviv: DU «Instytut rehionalnykh doslidzhen imeni M. I. Dolishnoho NAN Ukrainy», 2015).
8. Zakon Ukrainy vid 05.04.2007r. № 877-V *«Pro osnovni zasady derzhavnoho nahliadu (kontroliu) u sferi hospodarskoi diialnosti»*.
9. Postanova Kabinetu Ministriv Ukrainy vid 15.02.2002 r. № 175 *«Pro zatverdzhennia Metodyky otsinky zbytkiv vid naslidkiv nadzvychainykh sytuatsii tekhnohennoho i pryrodnoho kharakteru»*.
10. O. Popov, A. Iatsyshyn, V. Kovach, V. Artemchuk, D. Taraduda, V. Sobyna, D. Sokolov, M. Dement, T. Yatsyshyn, I. Matvieieva, *Analysis of possible causes of NPP emergencies to minimize risk of their occurrence* (Nuclear and Radiation Safety, 2019), 1(81), pp. 75–80.
11. S. Ragimov, V. Sobyna, S. Vambol, V. Vambol, A. Feshchenko, A. Zakora, E. Strejekurov, V. Shalomov, *Physical modelling of changes in the energy impact on a worker taking into account high-temperature radiation* (Journal of Achievements in Materials and Manufacturing Engineering, 2018), 91(1), pp. 27–33.
12. O. Rybalova, S. Artemiev, M. Sarapina, B. Tsymbal, A. Bakhareva, O. Shestopalov, O. Filenkoб *Development of methods for estimating the environmental risk of degradation of the surface water state* (Eastern-European Journal of Enterprise Technologiesб 2018), 2(10–92), pp. 4–17.
13. B. Pospelov, E. Rybka, R. Meleshchenko, S. Gornostal, S. Shcherbak, *Results of experimental research into correlations between hazardous factors of ignition of materials in premises* (Eastern-European Journal of Enterprise Technologies, 2017), 6 10 (90), pp. 50–56.
14. B. Pospelov, E. Rybka, R. Meleshchenko, P. Borodych, S. Gornostal, *Development of the method for rapid detection of hazardous atmospheric pollution of cities with the help of recurrence measures* (Eastern-European Journal of Enterprise, 2019), 1/10 (97), pp. 29–35.
15. V. Sadkovyi, B. Pospelov, V. Andronov, E. Rybka, O. Krainiukov, A. Rud, K. Karpets, Yu. Bezuhla, *Construction of a method for detecting arbitrary hazard pollutants in the atmospheric air based on the structural function of the current pollutant concentrations* (Eastern-European Journal of Enterprise, 2020), 6/10 (108), pp. 14–22.
16. O. Popov, A. Iatsyshyn, V. Kovach, V. Artemchuk, D. Taraduda, V. Sobyna, D. Sokolov, M. Dement, V. Hurkovskyi, K. Nikolaiev, T. Yatsyshyn, D. Dimitriieva, *Physical features of pollutants spread in the air during the emergency at NPPs* (Nuclear and Radiation Safety, 2019), 4(84) pp. 11.
17. Rozporiadzhennia Kabinetu Ministriv Ukrainy vid 22.01.2014 r. № 37-r *"Pro skhvalennia Kontseptsii upravlinnia ryzykamy vynyknennia nadzvychainykh sytuatsii tekhnohennoho ta pryrodnoho kharakteru"*.
18. E.S. Venttsel, *Teoryia veroiatnostei* (M. Nauka, 1969).
19. Nakaz Ministerstva pratsi ta sotsialnoi polityky Ukrainy № 637 vid 04.12.2002r. *«Pro zatverdzhennia Metodyky vyznachennia ryzykiv ta yikh rivniv dlia deklaruvannia bezpeky obiektiv pidvyshchenoi nebezpeky»*.