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SUBSTANTIATION OF PROPOSALS ON THE USE OF INSULATING APPARATUS IN THE LIQUIDATION OF EMERGENCIES WITH THE RELEASE OF HAZARDOUS CHEMICALS

В роботі у якості об'єкта дослідження розглядаються технічні можливості використання засобів індивідуального захисту органів дихання. Такі засоби використовують в пожежно-рятувальних підрозділах, під час проведення аварійно-рятувальних робіт, пов'язаних з ліквідацією надзвичайних ситуацій з викидами небезпечних хімічних речовин. Показано, що одним з найбільш проблемних місць участі особового складу пожежно-рятувальних підрозділів є протиріччя між захисними властивостями засобів індивідуального захисту та небезпекою, яка може бути в осередку викиду небезпечної речовини. Це стосується особового складу пожежно-рятувальних підрозділів, які першими починають проведення відповідних аварійно-рятувальних робіт. В результаті навіть при повному виконанні існуючих нормативних вимог робота в ізолюючих апаратах може бути небезпечною для рятувальника.

В основі обраного підходу до вирішення поставленого завдання лежала оцінка можливості забезпечити такий загальний коефіцієнт захисту ізолюючого апарату в зборі з лицевою частиною, який буде перевищувати коефіцієнт токсичної небезпеки середовища. Під час дослідження використовувалось аналітичне визначення вимог до перевірки апаратів на стисненому повітрі, оснащених шолом-масками. Воно показало, що рятувальникам можна працювати в епіцентрі аварії з викидами небезпечних хімічних речовин, якщо під час перевірки герметичності за допомогою приладів при створенні перевірочного розрідження 2000 Па швидкість падіння розрідження не буде перевищувати 32 Па/хв. Проте, експериментальна перевірка отриманих теоретичних результатів дозволяє стверджувати, що в пожежно-рятувальному підрозділі не зможуть добитись виконання цієї вимоги. Підвищення перевірочного розрідження до рівня, який перевищує 1000 Па, супроводжується суттєвим збільшенням підсосу всередину системи «ізолюючий апарат – органи дихання».

Дослідним шляхом підтверджено, що потрібний захист забезпечують апарати на стисненому повітрі, оснащені легеневими автоматами, які створюють підпір повітря в підмасочний простір. При цьому не повинно використовуватись різьбового з'єднання ізолюючого апарата з лицевою частиною. Це дозволило рекомендувати у якості базової комплектації ізолюючих апаратів використовувати апарати на стисненому повітрі, оснащені легеневими автоматами, що створюють підпір повітря в підмасочний простір.

Виключення складають підрозділи, в районі оперативного виїзду яких знаходяться об'єкти, на яких знаходиться велика кількість небезпечних хімічних речовин з коефіцієнтом токсичної небезпеки більше ніж $2,3\times10^5$. В цьому випадку вони повинні комплектуватись комплексами засобів індивідуального захисту ампулізованого типу.

Ключові слова: *небезпечні хімічні речовини, ізолюючий апарат, апарат на стислому повітрі, лицьова частина.*

1. Introduction

Means of personal protection of the respiratory organs, which are in service with the fire and rescue units of the State Emergency Service of Ukraine (hereinafter – SES of Ukraine), were once created in such a way as to ensure the safety of personnel in the worst conditions of a fire. This led to a requirement for a total protection factor, which should be more than 5000 [1]. To date, in accordance with the Code of Civil Protection of Ukraine [2], rescuers take part not only in extinguishing fires, but also in conducting emergency rescue operations. Including in carrying out rescue operations related to the liquidation of emergency situations with the release of hazardous chemicals.

Therefore, it is urgent to investigate the technical possibilities of using personal respiratory protective equipment when performing emergency rescue operations related to the liquidation of emergencies with the release of hazardous chemicals.

2. The object of research and its technological audit

As the object of research, technical capabilities of using personal respiratory protective equipment during emergency rescue operations related to the elimination of emergencies with the release of hazardous chemicals were selected.

Even with the full implementation of existing regulatory requirements, work in isolators can be dangerous for the rescuer. Therefore, a technological audit of such object and the results of relevant studies based on it will help to eliminate the contradiction between the protective properties of personal protective equipment and the danger that may be in the hotbed of an emergency situation.

3. The aim and objectives of research

The aim of research is determination of the requirements that must be met when choosing a kit for personal respiratory protective equipment for the situation of emergency response in the epicenter of an emergency situation with the release of hazardous chemicals.

To achieve this aim, it is necessary to perform the following tasks:

1. Analytical determination of tactical and technical characteristics of insulating devices in assembly with the front part.
2. Assessment of requirements for verification of the equipment of personal respiratory protective equipment.
3. Experimental verification of the possibility of achieving the necessary indicators.
4. Rationale for recommendations on the selection of a complete set of personal protective equipment in the fire and rescue unit.

4. Research of existing solutions of the problem

The problem of the participation of rescuers in the liquidation of emergencies with the release of hazardous chemicals is promising. The problem of the participation of rescuers in the liquidation of emergencies with the release of hazardous chemicals is being investigated in the leading countries of the world. So, in the USA in the standard NFPA 1500-2002 [3, 4] it is emphasized that the Federal Emergency Management Agency is responsible for preparing fire-fighting units for localization and elimination of all emergency situations. Based on this, in accordance with the general requirements of OSHA [5], the organization and staffing structure of the fire brigade is determined not only by the requirements of 29 CFR 1910.156 [6], but also by the requirements of the OSHA 1910.134 respiratory protection standard [7].

Standards NFPA 1001 [8] and WAC 296-305-05109 [9] justify the minimum requirements for work in personal protective equipment, specific to the possible conditions for carrying out rescue operations. These conditions are summarized in the standard NFPA 1991 [10], where the personal protective equipment of rescuers is divided into four levels. In this case, A-level insulating suits provide protection against direct exposure to a hazardous substance. A characteristic feature of suits of this type is that the insulating apparatus is located in a sub-suit space, where an overpressure is created. For B-level suits, the last effect is not the place, even if the insulating device is inside the suit. In this case, rescuers in the units should not only be able to work in protective equipment, but also taking into account the restrictions on their use, carry out appropriate maintenance [11]. In addition, in [12] noted the need to check the insulating apparatus for the possibility of using it the floor of the insulating suit (level B) when operating under the conditions of the use of chemical warfare agents. However, specific indicators and appropriate methods of checking the insulating apparatus are not listed.

A similar situation exists in Europe, where protective clothing is divided into six types. The analysis of the standards of PrEN 943 [13] and PrEN 1511 [14] shows that they are strongly correlated with the levels used in the USA. However, specific quantitative indicators are also not given. For example, in Great Britain, the structure of fire and rescue services is determined taking into account the fire danger of a particular area [15] and all possible threats, including those related to chemical hazards [16].

At the same time, in recent studies of issues related to ensuring the integrity of insulating devices, it is assumed that they must ensure safety under the worst conditions that can be during a fire. Proceeding from this, a change in the security of the gas defenders is considered depending on the type of the front part of the insulating apparatus [17], or how short-term sucking increase inside the insulating apparatus, depending on the severity of the work [18]. Sometimes considered somewhat varies the security of gas defenders depending on the characteristics of the person (in [19] it is noted that the pits inside the apparatus vary with the presence of a mustache or beard). The basis is a check for tightness in gas chambers with a comparison of verification methods [20]. At the same time, the toxic hazard coefficient is assumed to be virtually the same (quantitatively corresponding to the worst fire conditions), in accordance with which the concentration of the control substance varies. In addition, studies are under way to increase the resistance of protective materials to the hazard, including the reduction of the toxic effects of ionizing radiation [21]. Also, studies are underway to change the minimum leakage from under the face piece through hermetic seals during operation [22].

In Ukraine, the procedure for selecting the means of protection for emergency rescue operations in the management of emergencies with the release of hazardous chemicals is regulated in [23]. However, even for the operation in the complex of personal protective equipment of the first type, it does not specify the features of the choice of the insulating device depending on its placement (inside or outside the suit). At the same time, in [24] it was shown that using a certified insulating suit and any insulating device inside the protective clothing provides a level of protection that allows working in the epicenter of an emergency situation with the release of chlorine $\left(K_{TH}\left(Cl_2\right)=3{,}6\cdot 10^6\right)$.

The peculiarities of work in isolating apparatuses relative to an accident at the neutralization station of rocket fuel components, when the toxic hazard factor (K_{TH}) at the epicenter of an emergency can be reached $3.85\cdot 10^5$, were considered in [25]. It was shown that in this case it is advisable to use compressed air apparatus (CAA), however, it was not possible to examine the inside of the front part. As was not considered in [26], where the technique of choosing the front part was proposed and it was shown that when the requirements [27] were satisfied, the coefficient of protection of the regenerative respiratory apparatus $K_p(RRA)=2.95\cdot 10^4$, and the compressed air apparatus $K_p(CAA)=4.93\cdot 10^5$.

Thus, in order to substantiate proposals for the use of insulating apparatuses in the liquidation of emergency situations with the release of hazardous chemicals, it is

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necessary to assess the necessary tightness of the insulating device assembled with the front part.

5. Methods of research

5.1. Analytical determination of tactical and technical characteristics of insulating apparatuses in assembly with front parts. At the heart of the solution of the task in view is to provide such a general protection coefficient of the isolating apparatuses (IA) assembly with the front part (FP), which will exceed the coefficient of toxic environmental hazards.

At the same time, it is necessary to take into account that in the case of rescue operations for the liquidation of an emergency situation (ES) with the release of hazardous chemicals (HC), one should not use a mouthpiece box with a mouthpiece and nose clip. Since in this case the face and eyes of the rescuer remain open. That is, it is necessary to analyze the FP in the form of a mask (M), a helmet mask (HM), and a mask with excessive pressure in the under-mask space (UMS) with the corresponding [28] protection coefficients $K_{p2}(M)\geq 10^4$, $K_{p2}(HM)\geq 10^6$ and $K_{p2}(UMS)\geq 10^7$.

The obtained results make it possible to estimate, given [27, 39], the normative protective properties of the insulating suit (IS), the overall protection coefficient of the IA in assembly with the FP in the case of equipping the CAA with a helmet mask:

$$K_p(RRA,HM)=\frac{K_{p1}(RRA)\cdot K_{p2}(HM)}{K_{p1}(RRA)+K_{p2}(HM)}\geq$$
$$\geq 2.9\cdot 10^4 < K_p(IS)\geq 7\cdot 10^4. \quad (1)$$

It is evident that when working in the RAA, first of all, it is necessary to focus on its protective properties. Analogous calculations for CAA (Table 1) indicate that when using CAA assembled from the HM on the IS exactly the properties of protective clothing determine the level of protective effectiveness of the complex of personal protective equipment.

Table 1

The total protection coefficient of the compressed air apparatus

protection coefficient	Front part		
	Mask	Mask with excessive pressure in the UMS	Helmet mask
K_{p1}	4.87×10^5		
K_{p2}	10^4	10^7	10^6
Kz	9748	464261	327443

Analysis of the results of Table 1 shows that even during rescue operations in the case of emergencies associated with propellant components ($K_{TH(100\%NO_2)}=3.85\cdot 10^5$), the use of CAA equipped with masks with excessive pressure in the UMS should ensure the safety of rescuers.

5.2. Evaluation of the requirements for tightness testing using instruments in the fire and rescue unit. In addition, it is seen that in the case of equipping the CAA with a helmet mask, the indicator of the overall protection coefficient ($K_p=3.27\cdot 10^5$) is close enough to that considered. So, in the case of helmet masks, it is necessary to increase the requirements for the indicators that are monitored during the second test (tightness testing using instruments [30]), since in this case the protection factor of the IS should be not less than:

$$K_{p1}\geq\frac{1}{\frac{1}{K_{TH(100\%NO_2)}}-\frac{1}{K_{p2}(HM)}}=6.26\cdot 10^5. \quad (2)$$

Since the IA protection factor can be considered [29] as:

$$K_{p1}=\frac{\omega_l}{\omega_{s1}}, \quad (3)$$

where $\omega_l\approx 40^{-5}\ l/\mathrm{min}$ the air flow rate when operating in compressed air [28]; ω_{s1} – sucking inside the system «apparatus – breathing organs», l/min.

During the second check, it is necessary to ensure that the condition $\omega_{s1}\leq 6.39\cdot 10^{-5}\ l/\mathrm{min}$.

At the same time it is known [1]:

$$\omega_{s1}=\frac{0.4\cdot\frac{\Delta p}{\Delta t}\cdot V_a\cdot\sqrt{\frac{P_i}{P_p}}}{m\cdot P_a}, \quad (4)$$

where $\Delta p/\Delta t$ – the rate of discharge drop during the tightness test with the help of instruments, Pa/min; V_a – volume of air supply system at discharge, l; P_i – resistance of the IS inhalation at the appropriate load, Pa; P_p – vacuum in the air supply system during the test, Pa; m – coefficient that takes into account that the air supply system is not rigid; P_a – atmospheric pressure, Pa.

According to [28], for CAA, the volume of the air-supplying system with a discharge does not exceed the dead space of the apparatus, that is $V_a\leq 0{,}2\ l$. The exhalation valve should work when a vacuum of no more than 300 Pa is created. Condition (2) when creating, for example, a test vacuum of 2000 Pa is performed if the rate of the drop in the vacuum is:

$$\frac{\Delta P}{\Delta t}\leq\frac{\omega_{s1}\cdot m\cdot P_a}{0.4\cdot V_a\cdot\sqrt{\frac{P_i}{P_p}}}=$$
$$=\frac{6.39\cdot 10^{-5}\cdot 0.16\cdot 10^5}{0.4\cdot 0.2\cdot\sqrt{\frac{300}{2000}}}=32\ \mathrm{Pa/min}. \quad (5)$$

The analysis of expression (5) shows that the experimental verification of the obtained indices can be carried out with the help of equipment that is used during the second check of insulating devices (checks with the help of special equipment). In this case, the procedure of actions will correspond to those regulated by the operational and technical documentation for the apparatus of the manufacturing plant [30] or SES normative documentation [27].

5.3. Experimental verification. According to [27, 30], the apparatus for checking the IS tightness is designed for checking insulating devices equipped with HM. Therefore, when testing the CAA, which were equipped with masks or masks with air support in the UMS, a modernized device of Aerotest manufacturer [31] was used (Fig. 1).

The experimental studies were carried out as follows. Vacuum in the UMS is created in the range from 2000 Pa to 750 Pa. In each case, the time (min) and the magnitude of the fall (Pa) of the rarefaction were attempted. Before calculating the parameters characterizing the tightness, it was assumed that at the beginning of work in the II respiratory ventilation ω_a is approximately 20 l/min, and when working in the CAA, respiratory ventilation is 40 l/min.

Fig. 1. Upgraded Aerotest

Three CAAs were selected, which differed in the type of connection (threaded or fitting) CAA with the selected face and air-breathing resistance (from an elevated 600–650 Pa to a standard one – less than 300 Pa).

6. Research results

The obtained results of the rate of discharge drop $\Delta p / \Delta t$ are given in Table 2. In accordance with (5), the indices of sucking into the system «CAA-respiratory organs» (Table 3) were calculated and, in accordance with (3), the real protection coefficients of the examined CAA (Table 4). The results of calculations of the overall protection factor of the CAA assembly with the FP are shown in Table 5. In a generalized form, the obtained results are shown in Fig. 2–4.

Table 2

The results of the experimental evaluation of the rate of pressure drop $\Delta p/\Delta t$, Pa/min

P_p, Pa	P_i (thread), Pa			P_i (fitting), Pa		
	650	300	200	600	300	200
2000	850	825	800	200	150	140
1500	700	700	675	150	100	90
1250	500	500	475	110	60	50
1000	400	400	380	75	35	25
750	340	340	325	50	20	15

Table 3

Evaluation of the sucking rate into the apparatus on compressed air, l/min

P_p, Pa	P_i (thread), Pa			P_i (fitting), Pa		
	650	300	200	600	300	200
2000	2.42E-03	1.60E-03	1.55E-03	5.70E-04	2.91E-04	2.71E-04
1500	2.30E-03	1.57E-03	1.51E-03	4.94E-04	2.24E-04	2.01E-04
1250	1.80E-03	1.23E-03	1.16E-03	3.97E-04	1.47E-04	1.23E-04
1000	1.61E-03	1.10E-03	1.04E-03	3.02E-04	9.59E-05	6.85E-05
750	1.58E-03	1.08E-03	1.03E-03	2.33E-04	6.33E-05	4.74E-05

Table 4

Evaluation of the protection coefficients of the compressed air apparatus

P_p, Pa	P_i (thread), Pa			P_i (fitting), Pa		
	650	300	200	600	300	200
2000	1.65E+04	2.50E+04	2.58E+04	7.02E+04	1.38E+05	1.48E+05
1500	1.74E+04	2.56E+04	2.65E+04	8.10E+04	1.79E+05	1.99E+05
1250	2.22E+04	3.27E+04	3.44E+04	1.01E+05	2.72E+05	3.27E+05
1000	2.48E+04	3.65E+04	3.84E+04	1.32E+05	4.17E+05	5.84E+05
750	2.53E+04	3.72E+04	3.89E+04	1.72E+05	6.33E+05	8.43E+05

Table 5

Evaluation of the overall protection factor of the compressed air assembly with the FP

K_{p1}	Mask	Helmet mask	Mask with overpressure
1.00E+05	9.09E+03	9,09E+04	9,90E+04
2.00E+05	9.52E+03	1,67E+05	1,96E+05
3.00E+05	9.68E+03	2,31E+05	2,91E+05
4.00E+05	9.76E+03	2.86E+05	3,85E+05
5.00E+05	9.80E+03	3.33E+05	4.76E+05
6.00E+05	9.84E+03	3.75E+05	5.66E+05
8.00E+05	9.88E+03	4.44E+05	7.41E+05
9.00E+05	9.89E+03	4.74E+05	8.26E+05

An analysis of the results shows that in the fire and rescue unit they can't achieve the fulfillment of the condition (5). Since the increase in the test pressure to a level that exceeds the value given in the operational documentation, is accompanied by a significant increase (Table 2, Fig. 2) sucking inside CAA. In addition, it is established that during emergency rescue operations in the outbreak center with HC emissions, it is impossible to use insulating devices that require the use of a threaded connection of the TSA with the front part (Fig. 3).

To ensure that rescuers can work under the worst conditions associated with the emission of gaseous HCs, CAA should be equipped with a mask with air support in the UMS, which has nipple connections to the apparatus (Fig. 4).

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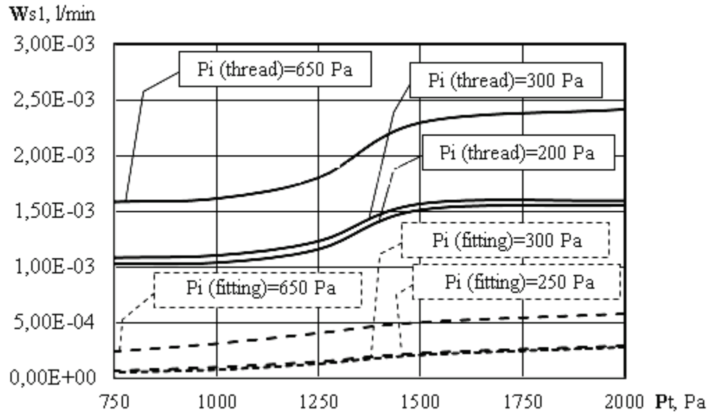

Fig. 2. Dependence of sucking in the compressed air apparatus from the test pressure

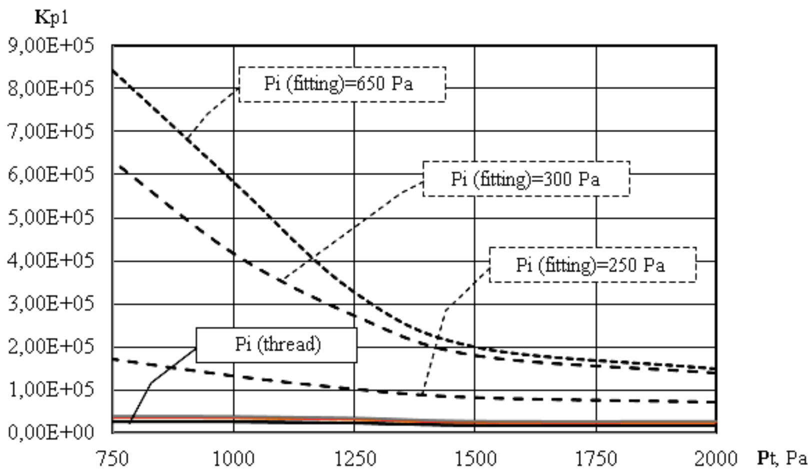

Fig. 3. Dependence of the protection coefficient of apparatus compressed air apparatus on the test pressure

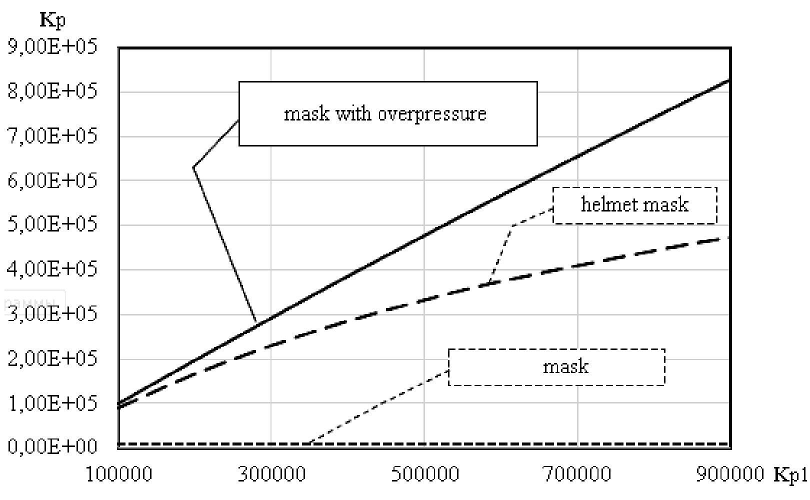

Fig. 4. Dependence of the total protection factor on the type of the front part

Taking into account the high sensitivity of the suction, and therefore the tightness of the insulating device to the pressure at which the respiratory automaton operates (Fig. 2, 3), it is advisable to consider the possibility of a hardware reduction of this pressure to 200 Pa. During cleaning and washing the apparatus, it is necessary to pay special attention to the drying of the respiratory automaton. Continuous monitoring requires no valve adherence to the valve seat.

7. SWOT analysis of research results

Strengths. The positive effect of the research object on its internal factors is to ensure the safety of the first fire and rescue unit in eliminating emergencies with HC emissions, while reducing the time for performing typical operations. The personnel uses insulating devices that are the floor of protective clothing, rather than very expensive insulating suits of ampoule type, using specialized parts and require additional special training from the rescuers.

Weaknesses. The negative impact of the research object on its internal factors is the impossibility of using compressed air devices equipped with respiratory automatic devices in the emergency area with a toxic hazard ratio of more than 2.3×10^5. Such devices provide air support in the UMS, during the operation of rescuers.

Accordingly, this requires the personnel to thoroughly study the areas of their exit and the ability to monitor the actual state of the hazard with the help of existing control devices. In addition, it is not possible to use regenerative breathing apparatus and compressed air devices that have a threaded connection of the front part to the apparatus, and also require specification of the regulatory requirements for the procedure for servicing personal respiratory protective equipment.

Opportunities. Opportunities for further research are a comparative assessment of the time to eliminate emergencies with the release of hazardous substances that are stored at high-risk sites in the Donetsk and Luhansk regions. Also in the complexes of personal protective equipment level A and level B, when in the latter over the protective suit there are compressed air devices equipped with masks with respiratory automatic devices that provide air support in the UMS, or helmet-masks.

Threats. Until recently, the problem was determined only for Ukraine and was not considered in detail. In the leading countries of the world, specialized units operate in the hotbed of emergencies with emissions of highly toxic hazardous substances.

8. Conclusions

1. The results of the analytical determination of the characteristics of insulating devices assembled with the front parts showed that the use of regenerative respiratory apparatus in carrying out emergency rescue operations in a hotbed of an emergency with HS emissions is possible only within an insulating suit. In the case where the insulating device is located on top of the protective

clothing, it is possible to work only in compressed air devices. Such devices are equipped with helmet masks (and in this case the coefficient of toxic hazard of the medium should be $K_{TH} \leq 3.27 \cdot 10^5$) or masks with air overpressure in the UMS ($K_{TH} \leq 4.64 \cdot 10^5$). In the latter case, it makes it possible to conduct emergency rescue operations in the hearth of one of the most dangerous for Ukraine emergency situation associated with the emission of propellant components ($K_{TH(100\% NO_2)} = 3.85 \cdot 10^5$).

2. The evaluation of the requirements for checking the tightness of compressed air equipment equipped with helmet-masks showed that they can be used in the liquidation of emergencies with emissions of propellant components. In this case, when checking the tightness of the insulating device assembly with the front part using instruments (second check of the insulating apparatus), the rate of the vacuum drop should not be more than 30 Pa/min when creating a control vacuum of 2000 Pa.

3. The experimental verification showed that in the fire and rescue unit they can't achieve an analytically definite condition, in which the apparatus compress the air equipped with a helmet mask, it is possible to work in an emergency situation with emissions of propellant components. In addition, it is determined that when eliminating emergencies with the release of hazardous chemicals, it is not possible to use insulating devices that involve the use of a threaded connection between the device and the front.

4. As a basic configuration of isolating devices in fire and rescue units, which can be used for the first localization of emergency situations with the emission of gaseous HCs, it is advisable to use apparatus in compressed air. Apparatus should be equipped with pulmonary automatic devices, providing air support in the UMS.

Exceptions are subdivisions, in the area of operational departure of which there are facilities containing a large number of hazardous chemicals with a toxic hazard ratio of more than 2.3×10^5. In this case, they must be equipped with complexes of personal protective equipment ampoule type.

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