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Review

REQUIREMENTS TO RESPIRATORY PROTECTION FOR WORKERS (WORLD PRACTICES REVIEWED)

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A great number of workplaces in Russia do not conform to sanitary-hygienic requirements and it results in wide use of personal respiratory protective equipment (PRPE). Choice on such equipment and its application are not regulated by the existing legislation in the RF in great detail as it is the case in developed countries. As a result, employers apply PRPE that is not efficient enough, or such equipment is not used properly, and it leads to diseases occurrence.

Our research goal was to reveal requirements to PRPE application which, when met, would reduce risks for workers' life and health as greatly as it is only possible.

Our research object was personal respiratory protective equipment (PRPE).

We compared requirements to selecting and applying PRPE in the USA, Australia, Great Britain, Canada, and West Germany and also took into account requirement and experts' recommendations existing in several other countries. When comparing, we tried to focus on key elements that determined whether PRPE applied in due time was able to prevent exposure to air contamination. Such key elements included choice on PRPE suitable for work under extremely hazardous conditions; permissible application of PRPE with different structure (expected protective efficiency); individual selection and testing whether a mask is fit for a face; timely replacement of respirator filters; requirements to skills of workers and their supervisors.

Our research revealed that results of PRPE application and requirements fixed for employers were most comprehensively estimated and well-grounded in the USA. The most favorable situation with quality and availability of materials on how to select and apply PRPE for workers, specialists, and supervisors is also in the USA. Results obtained via the performed comparison allow recommending US Standard 29 CFR 1910.134 as a basis for developing similar requirements in Russia.

Key words: *PRPE, efficiency of personal protective equipment, protective efficiency, respirators, prompt-hazardous concentration, insulating properties of a mask, respirator filters, health risk reduction.*

There are different methods used to protect workers from contaminants in the air; if we rank them in a descending order as per their efficiency, we get the following: changes in a technology aimed at eliminating/reducing contamination; equipment being placed into sealed casing; automation and remote control; ventilation; protection with time. Should exposure exceed MPC even in case these methods are used, then employers usually avail to the last and the least reliable protection means, namely personal respiratory protective equipment (PRPE). In order to achieve maximum possible effects produced by their use, there are requirements to them fixed in developed countries. These requirements regulate PRPE selection and procedures on their proper use. Requirements applied in the USA or the European Union (EU) were used as basic ones when national requirements in many countries were developed.

A growth in number of workplaces where air contamination exceeds MPC has resulted in wider PRPE use in the Russian Federation. Their distribution among workers is regulated by «Typical branch standards for free distribution of protective clothing», results obtained via special assessment of working conditions (The Federal Law 426-FZ), and «Methodology for assigning lower hazard categories for

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working conditions»[1, 2, 3]. But these documents don't take into account either protective efficiency of PRPE with different structure (different types) or the necessity to apply this equipment properly. Absence of specific requirements to PRPE selection and application makes errors more probable and results in elevated health risks for workers.

The present work focuses on comparing requirements an employer has to meet in Australia (AS), Bulgaria (BG), the United Kingdom (UK), Canada (CA), the USA (US), France, Germany (DE), China (CH), Ukraine (UA), and Japan (JP) as well as recommendations for an employer provided in South Korea (SK). We also gave certain recommendations on developing a document that would regulate PRPE selection and application in the RF. Links to requirements are given as per an abbreviation given in brackets after a country name or as per any other source[4].

We compared all these requirements as per certain key moments that determined how efficiently applied PRPE protected respiratory organs; it allowed us to spot out basic differences in regulatory documents existing in different countries.

When it comes down to application conditions and requirements to an employer we should note the following**.** The Standard applied in the USA (US) was developed to be used everywhere in a country where there was unified state legislation on labor protection. The EU standard was developed to be applied in some countries (DE, BG, and UA) with certain differences in their national legislations as regards labor protection requirements. Therefore, certain key moments that influence efficiency of protection provided for workers (who use PRPE properly and in due time) are much more strict and concrete in (US) than in the EU. Besides, to control whether the requirements are met in (US), an instruction for inspectors was developed; it describes in detail what should be inspected and how an inspection should be accomplished when assessing workers' provision with PRPE as well as how to make legal claims on the matter[5].

There are also differences in requirements applied in the USA and EU as regards *protection for workers employed at workplaces with extremely hazardous working conditions*. Workers who are exposed to contaminants concentration that is immediately dangerous

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[1] On Approval of the Typical standards for free distribution of protective clothing, protective foot wear, and other personal protective equipment for workers employed at any industry and/or at any workplace with adverse and(or) hazardous working conditions, as well as workers who have to perform their work tasks under specific temperature conditions or under exposure to contamination: The Order by the RF labor Ministry issued on December 09, 2014 No. 997n (Registered in the RF Ministry of Justice on February 26, 2015 No. 36213). *KonsultantPlus*. Available at: http://www.consultant.ru/document/cons_doc_LAW_175841/ (18.06.2020) (in Russian).

[2] On special assessment of working conditions: The Federal Law issued on December 28, 2013 No. 426-FZ (last edited on December 08, 2020). *KonsultantPlus*. Available at: http://www.consultant.ru/document/cons_doc_LAW_156555/a2d1f36be57aa07bb3d5a9867a8200ff79552c6e/ (18.06. 2020) (in Russian).

[3] The Methodology for assigning lower hazard categories for working conditions in case workers employed at workplaces with adverse working conditions use efficient personal protective equipment that was certified as per obligatory certification procedures corresponding to relevant technical regulations. Moscow, 2015, 13 p. (in Russian).

[4] AS – AS/NZS 1715:2009. Selection, use and maintenance of respiratory protective equipment. Sydney, Joint Technical Committee SF-010 Publ., 2009, 105 p.

BG – BDS EN 529:2006. Respiratory protection. Recommendations for selection, use, care and maintenance. Guide. Sofia, The Bulgarian Institute for Standardization Publ., 2010, 54 p.

CA – Z94.4-11. Selection, use, and care of respirators. Ottawa, Canadian Standards Association Publ., 2012, 126 p.

DE – DIN EN 529:2006 Atemschutzgeräte – Empfehlungen für Auswahl, Einsatz, Pflege und Instandhaltung – Leitfaden, Brüssel, Europäisches Komitee für Normung Publ., 2005, 51 p.

JP – JIS T 8150:2006. 保守管理方法び使用及，選択の呼吸用保護具. Tokyo, JSA Publ., 2006, 22 p.

SK – Guide H-82–2012. Ulsan, Korea Occupational Safety and Health Agency (KOSHA) Publ., 2012, 24 p.

UA – DSTU EN 529:2006 PRPE. Recommendations on selection, use, maintenance and service. Labor code 135. Kiev, 2008, 47 p.

UK – BS 4275:1997. Guide to implementing an effective respiratory protective device programme. London, Technical Committee PH/4, BSI Publ., 1997, 64 p.

US – OSHA Standard 29 CFR 1910.134. Respiratory Protection. Cornell Law School Publ. Available at: https://www.law.cornell.edu/cfr/text/29/1910.134 (08.08.2020).

[5] CPL 2-0.120. Inspection procedures for the Respiratory Protection Standard. Occupational Safety and Health Administration, 1998. Available at: https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_id=2275&p_table=DIRECTIVES (18.08.2020).

for life or health (IDHL or a situation when PRPE absence for ~ 30 minutes results in death or significant irreversible damage to health) should be properly protected. To provide such protection, the US legislation allows using only insulating PRPE (that protect from any contamination for a predictable period of time) with full face masks (they protect eyes and face skin and contaminated air can penetrate into gaps between a full face mask and a face not so efficiently as it is the case with half masks). Air should be fed into a mask in such PRPE in such way so that there is excessive pressure in it when a person breathes in (it reduces risks that contaminations penetrate into a mask when there are gaps between it and a face it protects). IDLH concentrations were estimated for approximately 400 substances [1].

Requirements applied in other countries are quite similar but there are no estimated IDHL concentrations in AS, BG, DE, UA, UK, SK, and JP. AS, CA, and UK apply concentrations estimated in the USA. When (basic) hose-equipped PRPE is used in Canada or the USA, it is required to be also equipped with auxiliary autonomous respirator in case air-feeding though a hose is distorted during evacuation. AS and BS legislation also requires basic hose PRPE to be equipped with auxiliary one (for evacuation) but it is not necessarily a respirator (as it is in the USA) but it can also be filtrating PRPE in certain cases.

When it comes to *assigned protection factors* we can mention the following. Should concentration be lower than immediately dangerous for life or health one, PRPE with different constructions can be applied (provided they truly protect from exposure). To assess protective PRPE capabilities, experts usually apply protection factors (PF) as a ratio between substances concentrations in the air outside and concentrations in inhaled air. When a PRPE type is selected, Assigned PF or APF are usually applied. These PF were developed by experts for PRPE with any construction; when PRPE are selected correctly and they are certified according to the existing legislation, these PF should be reached at *workplaces* in most cases. Studies on PRPE PF performed in laboratories and at workplaces revealed that they tended to be lower in the latter case and laboratory values should not be used to assess efficiency at workplaces [2]. When developing assigned PF in the USA, experts analyzed results obtained via PF measuring at workplaces and due to it they managed to take into account significantly lower actual PRPE efficiency (US) [3]. The same approach was applied in BS and similar values were obtained (Table 1).

To take into account differences between laboratory efficiency and actual one, experts in (UK) used the best available data obtained via 32 studies focusing on PF at workplaces, ¾ out of them having been performed in the USA. Therefore, assigned PF values for filtrating PRPE without air-feeding (with full face masks and half masks) and with air-feeding (into a helmet/hood) are similar in the UK and the USA.

The difference is partially due to experts in the USA relying on «the worst case» in their estimations and experts in the UK considering that it was impossible to wear a mask for 8 hours so their PF were estimated for working under exposure to contaminated air only during a part of a shift (up to 1 hour without air-feeding). Overall, small assigned PF values are due to detected low PF when they were measured at workplaces [6–10]. High PF can be obtained for PRPE with air-feeding into full face masks. But it was shown in several studies that efficiency could go down significantly [10]. As a result, in the UK assigned PF was reduced from 2,000 to 40. Efficiency of such PRPE at workplaces was not studied at all in the USA and Canada and it can explain why APF value is significantly high (=1,000).

In other countries labor-consuming and expensive PF measurements at workplaces were either not accomplished or they were rather rare; as for results obtained in foreign studies, they were sometimes neglected [5–10]. As a result, assigned PF are significantly higher in many countries than in the UK or the USA, and differences in efficiency estimated in laboratories and at actual workplaces are also neglected (to a various extent).

Table 1

Assigned PF (APF, maximum values[1])

Country[2] → Face ↓	US	UK	CA	AS	China	JP	SK	France	DE	Min PF[3]
Filtrating without air-feeding										
Half masks	10	10/20[4]	10	10	10	10	10	20	30	2.2
Full face masks	50	20/40[4]	50	100	100	50	100	40	400	11; 17
Filtrating with forced air-feeding										
Half masks	50	–	50	–	50	50	50	40	500	16; 19
Full face masks	1000	40	1000	> 100	1,000	100	200	40	500	12; 15
Helmet / hood	25/1,000	40	25/1,000	> 100	25/ 1,000	25	200	40	100	23; 28
Insulating with forced air-feeding										
Half masks	1,000	–	50	50	50	50	50	200	100	–
Full face masks	2,000	2,000	1,000	> 100	1,000	1,000	1,000	~250	1,000	–
Helmet / hood	25/1,000	40	1,000	> 100	25/1,000	25	1,000	100	–	–
Autonomous respirator	10,000	2,000	10,000	> 100	> 1,000	5,000	2,000	Max	≥ 1,000	–

Note:

1 – means values for cases in which: efficient filters are used; air is fed when needed under pressure, or permanently. When selecting PRPE, one should remember that its assigned PF should be higher than MPC excess ratio;

2 – data on China were obtained via research; data on France, from a manual[6] [4];

3 – means they are minimal PF obtained for this PRPE at workplaces [5–10];

4 – means that the 1st value is given for protection from gases; the 2nd, from aerosols.

When EU (DE) standard was accepted in former socialist countries in Europe, it brought some interesting results. Experts in BG or UA didn't know that efficiency at workplaces was lower than laboratory efficiency and they failed to understand why the same PRPE had different assigned PF in different EU countries[7]. As a result, assigned PF values were not fixed in Bulgaria or Ukraine at all, and a relevant text from DE standard was just translated mechanically without any proper understanding. Developed requirements to employers do not prevent them from selecting non-efficient PRPE. When the State standard GOST 12.4.299-2015 was developed in the RF by «Roskhimzashchita Corporation» JSC, a section with data on assigned PF was deleted completely[8].

Aspects related to a mast being fit for a face are included into regulatory documents. The most widely spread filtrating PRPE pump air through a filter due to rarefying under a mask when inhaling. And still a part of inhaled air is contaminated as it penetrates respiratory organs via gaps between a mask and a face. Should filters be selected properly, this penetration becomes a basic way for contaminations introduction into a mask and determined overall PRPE efficiency. To reduce risks that contaminated air may penetrate through gaps due to a mask being unfit for a face or a worker not knowing how to wear a mask properly, it is required in the USA that a mask should be selected individually to fit a face and penetration should be estimated with *Fit test* devices [11]. There are 6 check-ups for the matter that are described in detail in US and CA. In other countries such check-ups are either not described (UK) or they are not obligatory (only recommended).

When *PRPE are certified* in the USA and China, testers' faces should be similar to faces

[6] M. Gumon. Les appareils de protection respiratoire. Choix et utilisation. 2-th edition. Paris, Institut National de Recherche et de Securite (INRS), 2017, 68 p. (in Russian).

[7] For reference: DE standard contains data on APF in 5 countries.

[8] State Standard GOST 12.4.299-2015. PRPE. Recommendations on selection, application, and technical maintenance. *Internet i Pravo*. Available at: https://internet-law.ru/gosts/gost/60298/ (18.09.2020) (in Russian).

Figure. Changes in End-of-Service Life Indicators (ESLI) when filters are applied to protect from: mercury (to the left) and acetone (to the right)

of most workers [12, 13]. To select testers properly, anthropometric examinations were performed and approximately 4 thousand workers were examined including three-dimensional scanning of a head and face. When certification is performed in the EU and RF, it is recommended to exclude testers with their faces not being fit to masks. The US market is better protected from low quality products.

Timely *gas mask filters replacement* is an obligatory component in providing workers' safety. Durability of any gas mask filter that purifies contaminated air is limited and greatly depends on application conditions[9]. In the last century a moment for timely filters replacement was usually determined by olfactory organs reaction to gas smell in a mask. However, people react to smells of some gases only in case their concentration is significantly higher than MPC; we should also remember that people tend to have different sensitivity to smells (for example, data from 32 different sources gave the following range for acetic acid: from 0.001 to 500 mg/m^3, and its single maximum MPC is 5 mg/m^3) [14]. If gas concentration is growing steadily (as sorbent in a filter becomes saturated), then olfactory organs sensitivity can go down (hydrogen sulphide). Adaptation to a smell due to long-term work under exposure to it, respiratory diseases, and attention being focused on a work task make filter replacement «as per smell factor» rather unreliable. In the USA an employer should replace filters according to schedules (when their durability is calculated or measured for known working conditions) or with ESLI indicator use (Figure) [15, 16].

In other countries there are similar requirements but they can be not so strict or specific. For example, in 2017 a program that is used in Germany to calculate filters durability was available at Dräger web-site[10] but only in English.

As for requirements to training provided for workers it is specifically defined in US and CA what kind of training should be provided for workers. Employers in the EU are obliged to train workers but training contents and learning procedures are clearly not specified; requirements to training are more specific in the USA.

Feedback or assessing effects produced by PRPE application was actually accomplished only in the USA. In 2001–2002 there was a wide-scale questioning performed in the country that focused on how PRPE was selected and applied (the questioning contained 37 questions and more than 30 thousand organizations gave their replies to them) [17]. Requirements that had been valid for more than 30 years turned out to be violated; in small organizations violations were rather frequent and sometimes also rather serious. Questioning results were applied in planning activities aimed at improving PRPE construction and requirements to their application. We haven't been able to find any data on similar research in other countries.

Results and discussion. High quality PRPE (provided they don't have any defects and are selected and applied properly) can protect a worker in case they are applied in due time. The best requirements out of all the examined ones stipulate that PRPE should corre-

[9] Kaptsov V.A., Chirkin A.V. Gas mask filters replacement (lecture). *Wikibook*. Available at: https://ru.wikibooks.org/wiki/Замена_противогазных_фильтров_СИЗОД_(лекция) (18.06.2020) (in Russian).

[10] Dräeger, Hazardous substances database VOICE. *Dräeger*. Available at: https://www.draeger.com/en-us_us/Chemical-Industry/Onlineservices/Draeger-VOICE (18.06.2020).

spond to working conditions as per both their protective properties and acceptability (physiological loads on a worker). Protective properties of any PRPE can be easily estimated but it is not the case with acceptability. There are only sporadic recommendations on the matter given in several documents. It partly explains why PRPE are frequently neglected even when air is contaminated. Requirements to PRPE application, even high quality ones, do not guarantee that extreme exposure is eliminated completely; they only reduce its probability.

Requirements existing in the USA and UK take into account differences between PRPE protective properties at workplaces and in laboratory conditions to the maximum possible extent. But filtrating PRPE with air-feeding into a full face mask are better examined in the UK. Bearing that in mind, application of such PRPE should be limited in the RF in the same manner as it is the case with filtrating PRPE without forced air-feeding into a mask.

According to western experts' common opinion that was reflected in standards, PRPE is not a reliable means for health protection but it still reduces exposure and risks of occupational diseases (but it is still unclear to what extent). In the RF PRPE is selected and applied in a different way. There are no specific requirements to PRPE selection and application, and suppliers tend to constantly overestimate their efficiency; workers are provided with PRPE that do not correspond to working conditions and are not fit for workers' faces; gas mask filters can be replaced later than they should be. It results in elevated risks of extreme exposure and occupational diseases are rarely prevented due to PRPE use [18]. It is necessary to provide better motivation for employers to improve working conditions for their workers. To enhance effects produced by PRPE as auxiliary protection means, there should be requirements to their application developed in the country using the most complete and scientifically well-grounded foreign ones (US, UK).

By coincidence, concrete and scientifically grounded requirements to protection from biological aerosols exist only in CA. They should be used when developing a relevant section in requirements to PRPE selection in the RF.

PF measurements at workplaces allowed revealing that efficiency of certain PRPE at workplaces was significantly lower than that estimated in laboratory conditions. It allowed calculating such assigned PF that would be obtained at workplaces provided their proper and timely use; still they would be obtained not for all workers but for most of them, and not in all cases, but in most of them. It is still impossible to predict or measure exposure for each individual who uses PRPE. Biological monitoring procedures can be used to reveal extreme exposure for each individual worker. But Biological MPC are being developed rather slowly in the RF (in 2014 biological MPC were developed for 5 substances and none of them has been implemented so far; 50 biological MPC are developed in the USA; and even in Bulgaria 17 biological MPC are developed and implemented) and it should be accelerated[11,12].

Finally, use of the most widely spread PRPE (without forced air-feeding into a mask) results in a worker being exposed to carbon dioxide in a concentration that can be up to 2 times higher than maximum single MPC. It makes timely and proper PRPE use physiologically impossible for some workers as it can lead to diseases [19, 20]. In some countries employers are not recommended to select PRPE without air-feeding for long-term work but there are no specific requirements on the matter. It is necessary to make employers take these risks into account via developing requirements to medical examinations and work and leisure regimes for workers. Accordingly, certification tests for PRPE should include CO_2 concentration measurements for different

[11] ACGIH Threshold Limit Values & Biological Exposure Indices for Chemical Substances and Physical Agents. – Ohio: ACGIH, Cincinnati, 2016, 276 p.

[12] Ordinance № 13 of 30 December 2003 on the protection of workers from the risks associated with exposure to chemical agents at work. Effective from 31.01.2005. Appendix № 2. *The Bulgarian Legal Portal*. Available at: https://www.lex.bg/bg/laws/ldoc/2135477597 (18.09.2020).

air expenditure (inhaling volumes), and these data should be included into a certificate and be available to an employer.

Our analysis allowed us to come to the following **conclusions**.

1. Even the best existing foreign requirements to PRPE selection and application do not allow either taking into account their negative physiological effects on workers or preventing workers from neglecting them when they are exposed to contaminated air.

2. Requirements existing in the USA are the most acceptable ones as a basis for developing similar requirements in the RF since they are the most comprehensive ones when it comes to all key moments that determine protection efficiency and conditions of their application (they were developed for just one state).

3. According to western experts, PRPE application induces spontaneous occupational selection since those workers who can't adapt to wearing PRPE just change their job. It is advisable to have this selection prior to workers start performing their work tasks in contaminated air. When a worker has his or her probation period and is not exposed to contamination, he or she should constantly wear PRPE with a register that records down periods of PRPE use. And if it turns out that a worker is able to permanently use PRPE in safe conditions, he or she can be moved to a workplace with exposure to contaminated air.

4. To better reveal extreme exposure cases, it is necessary to use biological monitoring procedures more widely; to speed up biological MPC development, experts can use BEI ACGIH as a basis for their development.

5. To improve control over working conditions, it seems advisable to return to use of public sanitary inspectors. It is necessary to develop requirements to this occupation, their responsibilities, and relevant legal grounds for their activities.

6. To reduce a number of situations in which PRPE is not used in contaminated environment, it is necessary to start using PRPE that is integrated into technological processes; for example, when a worker puts a mask off, a gauge gives a relevant signal and production equipment is stopped and blocked.

Certification system in the RF allows several organizations to issue certificates for PRPE (it can be done by only one organization in the USA). Certificates contents can be completely incorrect[13]. It is necessary to give the right to certify PRPE to only one organization (for example, any scientific research institute that deals with occupational diseases). All kinds of tests that can't be accomplished in such an institute can be performed, for example, by PPE laboratories at A.I. Burbazyan's Federal Medical Biophysical Center (and it is well in line with existing practices when a certifying organization delegates actual tests to the third party and only issues certificates). It will allow ceasing anti-gas filters certification in such cases when their manufacturer doesn't provide them with data that allow establishing a period of time during which filters provide actual protection without using subjective reactions from workers' olfactory organs. It will also allow revoking certificates or not granting them in case manufacturers provide consumers with false information overestimating PRPE efficiency. It is necessary to expand test procedures and add measuring exposure to carbon dioxide for a worker given different volumes of air expenditure.

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[13] «Test-S – Petersburg» tested several filtrating half masks (manufactured by «Respiratorniy complex» LLC with added sorbent). They were tested just as anti-aerosol ones but it was stated in a certificate that PRPE could be used for protection from gases. «ProdMashTest» certified «Lepestok-200» as an elastomer full face mask with panoramic glass.

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