Methods for the timely replacement of cartridges in respirators

Employees working in a polluted atmosphere, use respirators for health preservation. If the air in the workplace is polluted with noxious gases, they often use cheap and comfortable air-purifying respirators (APR). These respirators provide employees breathable air due to the cleaning of contaminated ambient air with gas canisters or cartridges. The service life of such canisters and cartridges - is limited, and they have to be replaced in a timely manner to preserve the health of workers. Canisters and cartridges' replacement can be carried out in various ways. *(Canisters and cartridges are named "cartridges" in this text late - for brevity).*

1 The principles of purification of polluted gases in air-purifying respirators

1.1 Absorption

Capture noxious gases may be accomplished by the sorbents[1]. These materials (activated carbon, aluminium oxide etc.) have a large specific surface area and can absorb gases. Typically, such sorbents used in the form of granules, and cartridge case is filled with them. Contaminated air travels through the bed of sorbent granules in the cartridge, and movable harmful gas molecules collide with the surface of the sorbent, and remain therein. The sorbent is saturated the molecules caught, and gradually loses its ability to capture the gases. So, contaminated air can pass through the saturated sorbent to the layers of fresh sorbent. The concentration of harmful substances in the purified air after prolonged use of the cartridge increases, and may exceed the Permissible Exposure Limit PEL. Therefore, the service life of the gas cartridge using absorption for cleaning polluted air - is limited. The bond strength between the captured molecule and sorbent has a small, and the molecule is able to separate from the sorbent and get into the air again. The ability of the sorbent to capture the gases depends on: the properties of the gases and their concentrations, the air temperature, the air relative humidity, the rate of air consumed by the employee, and many other factors. Activated carbon can be saturated with chemicals that make more stronger ties with molecules of trapped gases - to improve the capture of a number of harmful gases. The saturation of the activated carbon with iodine - improves the capture of mercury; saturation of metal salts - improves the capture of ammonia; saturation metal oxides - improves capture acid gases[2].

1.2 The chemical reaction between the gas and the absorber (chemisorptions)

The ability of some harmful gases to react chemically with some other substances can be used to capture them. For example, the authors[1] describe the ability of copper salts to form complex compounds with ammonia. Creating strong links between the gas molecules and the sorbent may allow one to use of gas canisters repeatedly - if it has sufficient unsaturated sorbent. The service life of such cartridges is limited.

1.3 The catalytic decomposition

Some harmful gases can be neutralized through catalytic oxidation. For example, one may use hopcalite to oxidize toxic carbon monoxide, CO to harmless carbon dioxide. But the effectiveness of this catalyst strongly decreases with relative humidity increases. Therefore, there are some drier (desiccant in the canisters (before such catalysts). A polluted air always contains water vapor, and after the saturation of the desiccant - catalyst ceases carbon monoxide neutralization. The service life of such cartridges is limited.

1.4 Combined canisters

If employer use combined (multigas) cartridges, that provide air purification from a combination of different harmful gases, they apply gas cartridges with such sorbents or/and catalysts, that is necessary to capture the gases; and such canister are subject to all relevant constraints.

2 The old methods of timely replacement of APR canisters

Depending on harmful gases used canisters and the using of respirators, timely replacement of the canisters was conducted in different ways. (and sometimes carried out now).

2.1 The use of subjective reactions of an employee's sensory system on the increased concentration of harmful gases under the mask

The use of cartridges in the contaminated atmosphere leads to saturation of the sorbent, chemical absorbent (or the dryer — when using catalysts). As a result, the concentration of harmful gases in the air (that is purified with cartridges) gradually increases. The ingress of harmful gases in the inhaled air can lead to the reaction of the employee's sensory system: odor, taste, irritation of the respiratory system, dizziness, headaches, and other health impairments (up to loss of consciousness).[3]

These signs (known in the U.S. as "warning properties") indicate that one must leave the polluted workplace area, and replace the cartridges with a new one. (This can also be a symptom of a loose fit the mask to one face and the leakage of unfiltered air through the gaps between the mask and the face). Historically, this method of timely replacement is the oldest.

The advantages of this method — if harmful gases have warning properties at concentrations less then 1 PEL, the replacement of cartridges will be produced in a timely manner (in most cases, at least); the application of this method does not require the use of special cartridges (more expensive) and accessories; replacement happens when one need to do it — after the sorbent saturation, and without any calculations; the sorption capacity of the cartridges is fully expired (which reduces costs for respiratory protection).

The disadvantage of this method is that some of harmful gases have no warning properties. For example, there are list of more than 500 harmful gases in the[4], and more than 60 of them have no warning properties, and there are **no any** such information for more than one hundred of them. So, if one use warning properties to replace cartridges, this lead to breathe air with excess harmful gas concentration in some cases. The table contain a list of same chemicals, that have no warning properties (it based on average employee sense system reaction to the smell, taste ets)

and so on.

These concentrations, in which people feel the smell – is an "averages" concentrations. If the concentration of the odor detection threshold is equal 1 PEL, than a significant proportion of people do not feel the smell at this concentration.

Obviously, if the threshold odor of pentaborane is 194 PEL; and if the concentration of pentaborane in air is 10 PEL, one cannot timely change cartridges with using smell - it is impossible at all. In such conditions, cartridges could be used forever. The document has an incomplete list of harmful gases that have no or poor warning properties; and a document listed gases for which no established - whether preventative properties or not.

Practice has shown that the presence of warning properties not always leads to the timely replacement of cartridges. Different people have different individual sensitivity to the exposure of gases; and they react to the smell of the same substance at different concentrations. The tutorial[5] mentions a study[6] that showed that on average 95 % of a group of people has an individual threshold of olfactory sensitivity in the range of from 1/16 to 16 from the mean. This means that 2.5% of people will not be able to smell at a concentration 16 times greater than the average threshold of perception of a smell. The threshold of sensitivity of different people can vary by two orders of magnitude. That is, 15 % of people do not smell at concentrations 4 times higher sensitivity threshold. The value of threshold smell greatly depends on how much attention people pay this. The sensitivity of people may be reduced, for example - when colds and other diseases. It turned out that worker's ability to detect the smell also depends on the nature of the work to be performed — if it requires concentration, employee don't react to the smell. Prolonged exposure to harmful gases at low concentration can create a olfactory fatigue, which reduces sensitivity. In all of these cases employees can be exposed with harmful substances with the concentration larger then 1 PEL; and it may lead to the development of occupational diseases.

This was the reason of the ban to use this method of cartridges replacement in the U.S. since 1996 (the Occupational Safety and Health Administration OSHA standard)[3].

2.2 The increase in mass of the cartridges with desiccant

To protect workers from carbon monoxide often use cartridges with catalyst - hopcalite. This catalyst does not change its properties over time of use, but when it moistened, the degree of protection significantly reduced. Because water vapor is always present in the air, the polluted air is dehumidified in the cartridge (for use of the catalyst). Due to the fact that the mass of water vapor in polluted air is much greater than the mass of harmful gases, trapping moisture from the air leads to a significantly higher increase in the mass of cartridges than the trapping gases. This is a substantial difference, and it can be used to determine whether to continue to use gas cartridges further without replacement. The cartridge was weighed, and a decision can be made based on the magnitude of increase of its mass. For example, the book[7] describes gas cartridges (model "CO"), which were replaced after weight gain (relative to initial) on 50 grams.

2.3 Other ways of determining the need to replace cartridges

The documents[7][8] described Soviet cartridges (model "Г"), designed to protect from mercury. Their service life was limited to 100 hours of use (cartridges without particle filter), or 60 hours of use (cartridges with particle filter), after which it was necessary to replace the cartridges with a new one.

The documents[9][10] describe a non-destructive method of determining the remaining service life of used and new gas cartridges. Polluted air was pumped through the cartridge. The degree of purification of air depends on how much unsaturated sorbent is in the cartridge. Therefore, accurate measurement of gas concentration in the cleaned air allows one to estimate the amount of the unsaturated sorbent. Polluted air (1-bromobutane) was pumped for a very short time, and therefore, such tests do not reduce the service life considerably. The sorption capacity decreased due to absorption of this gas by the amount of about 0.5% of the sorption capacity of a new cartridge. The method was also used for 100% quality control of cartridges, manufactured by the English firm Martindale Protection Co (10 microliters 1-bromobutane injected into the air stream), and to check the cartridges issued to workers in firms Waring Ltd and Rentokil Ltd. This method was used in the Chemical Defence Establishment in the early 1970s. The experts who developed this method, received a patent [11].

The document[12] briefly describes two methods of objective evaluation of the degree of saturation of the sorbent in the cartridges. It recommends using spectral and microchemical methods. The spectral method is based on determining the presence of harmful substances in the cartridge by sampling with subsequent analysis on special device (стилоскоп). Microchemical method is based on layer-by-layer determination of the presence of harmful substances in the sorbent by sampling with subsequent analysis by chemical method. If the air is contaminated with the most toxic substances, the book is recommended to limit the duration of use of the cartridges, and it recommended to apply the spectral method (arsine and phosphine, phosgene, fluorine, organochloride, organometallic compounds), and microchemical methods (hydrogen cyanide, cyanogens).

Unfortunately, in both cases, there is no description of how to extract a sample of the sorbent from the cartridge housing (the housing is usually not detachable), and will it be possible to use the cartridge after this test, if the test shows that it is not a lot of saturated sorbent.

3 Modern methods of determining the necessity of cartridges replacement

3.1 Timely replacement of cartridges on a schedule that is developed on the basis of an assessment of their expected service life

Cartridges certification provides a minimum value of their sorption capacity. This value corresponds to a certain period of service in certain circumstances. US OSHA occupational safety and health standard for working with 1,3-Butadiene indicates the specific limits of the service life of the cartridges[13].

In Germany cartridges against Carbon monoxide are classified according to DIN 58620:2007: low capacity (class 20), medium capacity (class 60) and high capacity (class 180). The class equates the nominal service life in minutes[14].

3.2 Testing the cartridges in a laboratory

If the company has a laboratory that has the right equipment, specialists can skip the contaminated air through the cartridge and to determine degree of it cleaning. This method enables one to determine the service life in an environment where the air is contaminated with a mixture of different substances that affect on their capture with sorbent (one affects on another capture). Service life calculation methods for such conditions have been developed relatively recently. However, this requires accurate information on concentrations of noxious substances, and they often are not permanent.

Tests in laboratories can identify what is the balance of the service life of the cartridges after their use. If the remainder is large, similar cartridges in such circumstances can be used over a longer period of time. In some cases, large balance allows the use of cartridges repeatedly. This method does not require accurate information on concentrations of harmful substances. The cartridge replacement schedule is drawn up on the basis of the results of their testing in the laboratory. This method has a serious drawback. The company must have a complex and expensive equipment and trained professionals (for using it) - is not always possible. According to a poll[15], cartridges replacement in the United States was carried out on the basis of their laboratory tests on approximately 5% of all organizations.

Research to determine whether it is possible to calculate the service life of respirator's cartridges (if one know the conditions of their use) were conducted in developed countries since 1970-ies. This allows one to replace cartridges in a timely fashion - without the use of sophisticated and expensive equipment.

3.3 Computer programs for calculating the service life of the cartridge

The world's leading manufacturers of respirators offered its customers a computer program for calculating the service life already in the 2000.

3M program[19] allowed to calculate the service life of the cartridges exposed with more than 900 harmful gases and their combinations (in 2013). The MSA program[20] allow to take into account hundreds of gases and their combinations. Both programs take into account the concentration of harmful gases and air consumption (light, medium or heavy work), and other conditions. Drägerwerk has developed a large database on harmful chemicals VOICE (*registration required for its use*). There is a program for calculation of service life of cartridges (End-of-ServiceLife Calculator) in this database (*US version*), which takes into account the gas concentrations in the contaminated air and in the cleaned air (*user option*); temperature, pressure and humidity; allows one to select the intensity of the work of 7 possible and encourages the use of full-face masks with higher air pollution[23] . Jerry Wood (and many other specialists) work in the field of mathematical modeling of service life of cartridges in the United States. For a long time[24][25][26][27][28][29][30] J. Wood designed and developed a mathematical model and software which now allows one to calculate not only the service life of the cartridges (with known characteristics, such as sorbent properties, its quantity and the geometric shape and dimensions of the cartridges) when it exposed to one harmful gas, but when it exposed to gas mixtures (in which some substances interfere the capture of the other) at different temperature, relative humidity and air flow. Adsorption isotherm of Dubinina-Radushkevicha[31] is used to perform calculations. Now OSHA uses Wood development in program Advisor Genius[32]. The program takes into account the sorbent properties, geometry of the cartridge and the conditions of its application.

3.3.1 Influence of air flow rate, the concentration of harmful substances, and temperature and relative humidity of contaminated air on cartridges service life

Scott developed a computer program [33] that operates at an air temperature from −10 to +40° C and a relative humidity of from 3% to 95%; air consumption of 20-80 l/min, and takes into account more than 300 hazardous substances as well as their combinations. The following are examples of calculating the impact of temperature and relative humidity on the service life of the Scott cartridge (742 OV-organic compounds) (left), and impact of vapor concentration and air flow (right) when exposed to

The North respirator 7700 with cartridges RT 41 (ammonia) with ESLI. The indicator is in the field of view of the employee *(oval window in the center changes color after saturation of the sorbent)*

*This file is the scheme of installation of the cartridge with End of Service Life Indicator (**ESLI**) on a half-mask respirator, so that the ESLI is visible during operation. The color change shows that the cartridges will cease to capture ammonia, and the employee should leave the workplace to replace the cartridges*

various substances (pressure 1 atm).

Cartridge lifetime decreases with increasing humidity and/or temperature; and when the concentration and/or air flow is increased. But if one use special cartridges for water-soluble gases, affection of relative humidity on service life may be different: service life 3M cartridge 6004 (ammonia/methylamine) not change then relative humidity increases from 65 to 90% *(6 hours 48 minutes at 25°C, ammonia concentration 250 ppm = 10 PEL, air consumption at hard work).*

The merit of this way of replacing the cartridges is that it allows an employers to use normal, "common" cartridges, and if they have the exact data, they may replace them in time. The downside is that because of air contamination is often not constant, and the nature of the work to be performed is not always stable (that is, the flow of air through the cartridges is not permanent), it is recommended to use working conditions for calculations, equal to the worst (for reliable protection of workers). But in all other cases cartridges will be replaced with partially used sorbent. This increases the costs of respiratory protection due to more frequent cartridges replacement. In addition, calculation accuracy is reduced when very high relative humidity, because the mathematical model does not take into account some of the physical effects in such cases.

3.3.2 Influence of chemical composition of air contaminants on the service life of the respirator cartridges

Information about cartridges service life previously (prior to the development of computers and the Internet) was printed on paper[34]. A catalogues (1974[35] and 1982[8]) contain information about the service life of all of the standard Soviet cartridges when exposed to 63 common harmful gases when their concentrations of 5, 15, 100 or even 1000 PEL. The table below provides some of this information for cartridge (model "A", with particle filter). It's easy to see that service life is highly dependent on the chemical composition of air contaminant.

Information from this document was cited in the[36]; and any other work in this field could not be found in RF.

3.4 Use of End of Service Life Indicators (ESLI)

*End of Service Life Indicator (**ESLI**). The saturation of the sorbent mercury vapor leads to the change of the color (circle in the center) from orange to brown*

If the cartridges have a device that warns of an employee of the approaching expiration of the term of service life (End of Service Life Indicators, ESLI), the signals of such devices can be used for the timely replacement of cartridges. ESLI can be active or passive. Passive indicators often use sensor that changes color. This element is installed in the cartridge at some distance from the filtered air outlet (to color change occurred before the harmful gases begin to pass through the cartridge). An active indicators is use signal from sensor to emit a light signal (or turn on a sound alarm) to inform an employee that he must left the contaminated atmosphere and changed the cartridge.

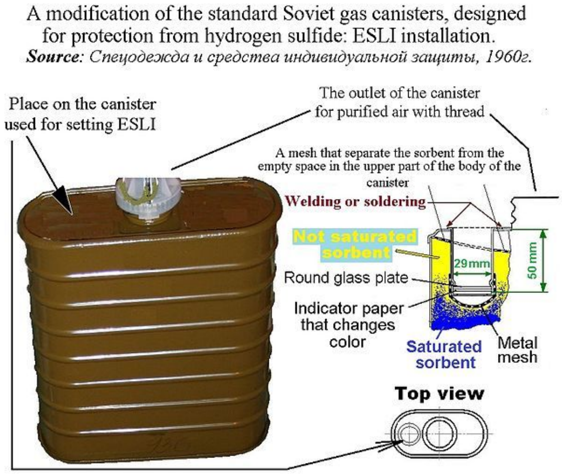
Specialists from the NIOSH developed the requirements for such indicators[37]. In particular, they must be activated before it will pass 90% of service life - to allow an employee to get away from the polluted atmosphere sooner. Passive indicators should be made so that the employee could see color-change element without respirator mask doffing. The requirements embodied in the standard for respirators certification 42 CFR 84 (for example - in section 84.255)[38].

3.4.1 Passive ESLI

The document[39] stated that the first passive indicator was developed in 1925[40]. This ESLI used the indicator paper, situated along the transparent window, elongated in the direction of the cartridge inlet to the outlet. Length is not painted plot in the window allowed to determine which part of the sorbent is not utilized yet.

Indicator set in the in-mask space was patented in Germany in 1957[41]. The downside of the indicator was the fact that he has worked with a large enough concentrations — under the mask, in the inhaled air.

American Optical Corporation received several patents for ESLI for respirator cartridges, that are intended to be used for protection from water soluble and water insoluble organic compounds (in 1979)[42]. Unfortunately, the main problem when using this indicator was that his shelf life (before use) was significantly less than the shelf life of the sorbent and cartridge: indicator changed its color over only 2 years after the date of manufacture. Therefore, these ESLI not be approved in Japan[43].



File with scheme of passive End of Service Life Indicator, developed in the 1960s in the USSR to protect employees from hydrogen sulfide. The device was made by a modification of a standard gas canisters.

Many cartridges with ESLI was removed from sale in 2002 because of changing color element was not visible to the employee without taking off the mask [44].

North Safety Products manufactures several types of cartridges with passive ESLI - for protection against acid gases (hydrogen chloride, hydrogen fluoride, sulfur dioxide, hydrogen sulfide); from ammonia; and from mercury and chlorine. The disadvantage of these indicators is that they may prevent working only on certain gases, and fail to adequately warn when used in an atmosphere polluted by different gases.

3M manufactures and sells the cartridges with a passive indicator: 3M 6009[45] and 60929[46]. They are designed to protect against mercury and chlorine.

Advantage of passive ESLI is their low cost, but the downside is that worker should keep an eye on them to detect their reaction. The nature of the work to be performed is not always allows it. In addition, it is necessary to have good lighting to detect color change. Workers who have problem with perceiving different colors cannot use such cartridges.

Respirator for protection against hydrogen sulphide was developed in the USSR in 1960[47]. Standard cartridge was upgraded at the expense of the tie-in of the indicator, that change its color when hydrogen sulfide approaching to the outlet for the cleaned air.

The cartridges are made of transparent material and color change sorbent (from ion exchange resins) are mentioned in[48]. In the another article, an author write that the use of such cartridges avoids their premature replacement[49]. In 2015 the company in Nizhny Novgorod region manufactured cartridges for protection against acid gases, which have fully transparent body and a sorbent, which changed its color after saturation.

3.4.2 Active ESLI

Active indicators used light or audible alarm for employee notification that is triggered by a sensor, that is usually installed in cartridge. Such indicators allow one to replace the cartridges on time in any light, and do not require the worker to pay attention to the color of the indicator. They can also be used by workers who badly distinguish different colors.

The document[39] indicates that one of the first active indicators was developed in 1965. There are two wires installed to the cartridge, and they are connected using wax[50]. An organic vapor compounds softening the wax, and wires touch each other, and turn on a warning light. Deficiencies were its complexity and dependence of result from the air temperature.

Some developers have started to use chemical resistors and semiconductor sensors later.

Respirator with a sensor located after the cartridge was developed in 2002 in Japan[51].

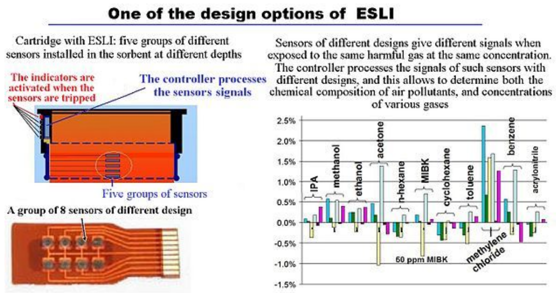
Respirator with a semiconductor sensor located between the cartridge and the mask was developed in 2003[52]. The disadvantage of the device was a great energy consumption — needed replacing batteries every shift.

A patent on an inexpensive fiber optic sensor, fixed in[53] was received in 2002. This device was inexpensive, easy, and able to respond in a variety of harmful substances.

Cyrano Sciences has developed an "electronic nose", which consisted of 32 different sensors in 2002. Processing of their signals with microcomputer allowed to determine the existence of various harmful substances[54]. Different organizations are actively developing better ESLI[39].

Despite the presence of solutions for technical problems; and the availability of the established certification requirements to the active ESLI, during the period from 1984 (first certification standard with requirements for active ESLI) until 2013 nor one cartridge with active ESLI was approved in the US. It turned out that the requirements for the cartridges are not quite exact, and requirements for employers are under no obligation to use these indicators quite specifically. Therefore, respirators' manufacturers fear of commercial failure when selling a new unusual products - although they continue to carry out research and development work in this area. Examination of the use of respirators showed that in the U.S. more than 200 thousand workers may be exposed to excessive harmful gases due to the late replacement of cartridges. So, Laboratory of PPE (NPPTL) at the NIOSH began to develop an active indicator. After the completion of the work, by its results, the legal requirements will be clarified, the requirements of the employer will be formulated, and the resulting technology will be transferred to industry - for use in new improved RPD[39].

4 Reusing cartridges

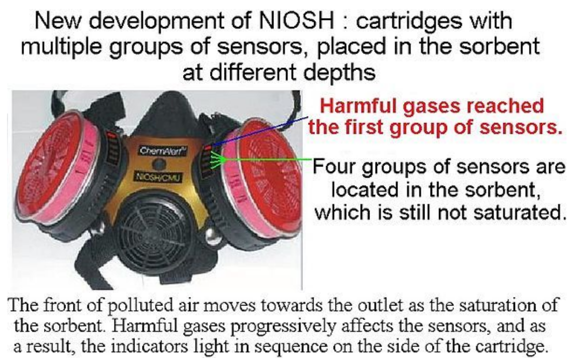


Sensors for End of Service Life Indicator (ESLI), developed in US

If the cartridge contains a lot of the sorbent and if the concentration of contaminants is low; or if the cartridge was used for a short duration of time, after completion of its use, it still has a lot not saturated sorbent (which can capture gases). This may allow use such cartridges again.

The molecules of an entrapped gases may de-absorb during storage of the cartridge. Due to the difference of concentrations inside the body of the cartridge (at the inlet concentration is greater; at the outlet for purified air concentration is lesser), these de-absorbed molecules migrate inside the cartridge to the outlet. The study of cartridges exposed to methyl bromide showed that this migration can impede the re-use after storage[55]. The concentration of harmful substances in the purified air may exceed the PEL (even if clean air is pumped through the cartridge). To protect workers ' health, U.S. law does not allow reuse cartridges, when exposed to harmful substances, which are able to migrate (even if the cartridge has many non-saturated sorbent after the first use). According to the standards, "volatile" substances (able to migrate) are considered a substances with a boiling point below 65 °C. But studies have shown that at the boiling point above 65 °C the reuse of the cartridge may be unsafe. Therefore, the manufacturer must provide the buyer with all information required for the safe use of cartridges. So, if the period of continuous service life of the cartridge (calculated by the program - see above) exceeds 8 hours (tables 4 and 5), the legislation may limit their use to one shift.

The paper[30] provides a procedure for calculating the concentration of harmful substances in purified air at the start of the re-use of cartridges (which allows one to determine exactly where they may be safe reused). But these scientific results are not yet reflected in any standards or guidelines on the use of respirators. It is interesting to note that the author of the article, working in the US, did not even try to consider the use of gas cartridges for the third time (or more). On the website of the author one can download for free a computer program that allows one to calculate the concentration of harmful substances immediately after the start of re-use of the cartridge (which allows one to determine if this is safe)[56].



A NIOSH respirator with an active End of Service Life Indicator (ESLI) [57].

Cartridges of great size, which contain a lot of the sorbent, was widely used in the USSR and continue to be used in the RF. A large sorption capacity of these cartridges mitigating the impacts of the migration of harmful gases during the storage of previously used cartridge (to some extent). As a result — because of the rare occurrence of this phenomenon, and due to the fact that in RF manufacturers of respirators are not responsible for the consequences of their use (and the employer is seldom responsible for damaging the health of workers), different authors explicitly and systematically recommend the use of cartridges repeatedly. For example, the authors recommended the use of cartridges for several months in[58]. Such guidelines do not allow one to determine when this can be done safely (and how many times), and when — not.

5 The application of particle filtering facepiece half-mask respirators for protection against harmful gases

Fibrous filter materials that can capture not only aerosols but also gaseous substances were developed in the 1970s. They contained or small particles of the sorbent between the fibers, or special fibers capable to absorb gases[59][60]. The small diameter of the sorbent particles or fibers greatly increases the area of gas absorption surface, which improves the air purification.

However, the mass of sorbent in this respirator is significantly less than in conventional replaceable gas cartridges for elastomeric masks (mass of the cartridges for half masks is limited to 300 grams[61][62], and the typical mass of the sorbent in them is about 60 grams). Therefore, the service life of this respirators will be much less. The study[63] showed that it can be, for example, one to two hours. This complicates their use for protection against harmful gases at concentrations exceeding the 1 PEL. However, the air in the filtering facepiece mask moves through the filter not only from outside to inside, but from inside to outside too (when breathing out - even in the presence of an expiratory valve). Moist exhaled air humidifies the sorbent. This can greatly reduce the service life (when exposed to, for example, vapors of organic solvents, table 4), and makes the use of gas filtering facepiece respirators in conditions, there gas concentration is more than 1 PEL even more problematic.

An air temperature is often below 0°C in the RF. The study[64] showed that the resistance to breathing in many of the (common particle) filtering facepieces (used in clean air) begins to exceed the allowable value within 15 to 30 minutes at a temperature of $-5 \div -15$°C. This is due to the accumulation and freezing of moisture inside the filter material, making it difficult to pass air through it. Such accumulation of moisture and ice formation on the surface of sorbent particles and/or gas absorption fibers of the filter material can't allow them to catch harmful gaseous substances - at all. However, some RF RPD sellers[65] suggest consumers use a filtering facepiece respirators when concentrations of gaseous air pollutants is significantly higher than the 1 PEL. Such recommendations are unparalleled in the industrialized countries, and such use is not stipulated by the legislation of developed countries governing the selection and application of RPD: in the U.S.[66], in the UK[67] and in Germany[68]. Finally, these recommendations are not warranted. Moreover, existing software does not allow to determine the duration of service life (as such application is not possible in countries where programs have been developed, and therefore not included in the programs at all).

Such particle-gas filtering facepiece respirator can be used for protection from harmful gases only when their concentration does not exceed 1 PEL - that is, when they are not as dangerous to health, and just annoying working (smell, etc.)[69].

6 The legal requirements for the timely replacement of respirator's cartridges

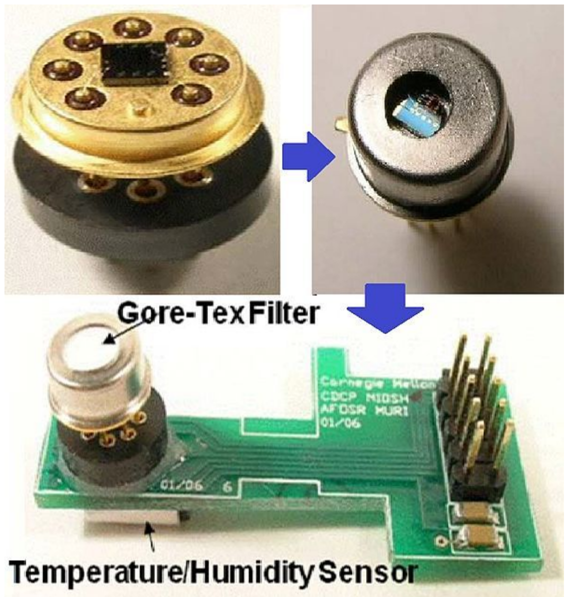
Promising full facepiece respirator equipped with (ESLI)*[57]*

Since it is not always possible to replace cartridges in a timely manner through the use of odor of these gases, OSHA (in the Ministry of Labour of the USA) has banned the use of this method of determining the end of its service life. The employer is obliged to use only two ways to replace cartridges[66] : on schedule, and by using ESLI (because only these methods provide reliable preservation of workers' health). Instructions to inspectors (OSHA) provides specific guidance on inspection of implementation of such requirements[70]. On the other hand, the state requires manufacturers to provide the consumer with all the necessary information that allows one to make schedule for timely cartridges replacement. Similar requirements exist in the standard on occupational safety, governing the selection and application of RPD in EU[71]. In England a tutorial on the selection and use of respirators recommends obtain information from the manufacturer, and replace the cartridges on a schedule, or use ESLI, and prohibits reuse cartridges after exposure of volatile substances that can migrate[72].

State standards governing the selection and use of respirators were not developed neither in the USSR, nor in RF (1991-2014). Therefore, the legislation has no specific requirements to the employer in respect of timely replacement of cartridges. Imperfect RF legislation equates the complex technical device – RPD - to protective clothing and footwear, not discerning the respirators used for protection against gases, from respirators used for protection against aerosols[73]. Manufacturers usually do not provide the consumer enough information that allows them to define the service life in different conditions. So, in fact, the only way of replacement cartridges is the use of worker's reaction on gas odor; that is not always possible to preserve the health of workers. Moreover, actively introduces the idea that the responsibility for the use of (certified) respirator borne solely by the employer:

> Responsible for the selection and application of adequate and appropriate PPE for specific purposes lies with the employer[74]

— but not the manufacturer[75][76] (which gives the buyer no necessary information), and not the state (which withdrew from performing their regulatory duties).



Sensor for (End of Servise Life Indicator ESLI)*[57]*

7 Regeneration gas cartridges

Molecules of harmful gases adsorbed by activated carbon, do not form strong bonds with them, and can deabsorb. Some harmful gases reacts with the sorbent and form strong bonds. Special technologies have been developed for the recovery of used cartridges. They created conditions that have stimulated de-sorption caught earlier harmful substances. This used steam or heated air in the

1930s [77][78] or other methods[79]. Processing of the sorbent was carried out after its removal from the body of the cartridge, or without removing.

Specialists tried to use as the absorber ion-exchange resin in 1967. The authors proposed to regenerate the sorbent by washing it in a solution of alkali or soda[80].

The study[55] also showed that cartridges can be effective regenerated after exposure to methyl bromide (when they are blowing with hot air 100÷110°C, flow rate 20 l/min, duration about 60 minutes).

The regeneration of sorbents used consistently and systematically in the chemical industry, as it allows one to save money on the replacement of the sorbent, and as the regeneration of industrial gas cleaning devices can be carried out thoroughly and in an organized manner. But in the mass use of gas masks by different people in different conditions it is impossible to control the accuracy and correctness such regeneration of respirators' cartridges. Therefore, despite the technical feasibility and commercial benefits, regeneration of respirators' cartridges is not carried out.

8 Conclusion

Conditions of use of respirators for protection against harmful gases in the RF is not normal[81]. Specifically, there are no legal requirements to the employer, setting out rules for the use of respirators; specialists do not teach the selection and use of respirators; no adequate textbooks; manufacturers do not provide consumers with information that helps determine the life of the cartridges. Therefore, the timely replacement of cartridges can be a serious problem. This problem may become particularly acute if the air is polluted with substances that do not have warning properties.

The use of respirators in the US in the 1970s took place in somewhat similar conditions[82]. This prompted American specialists to try to completely prevent the systematic use of respirators (their use is allowed only in the repair, maintenance, etc.). The law required the employer to use exceptionally supplied air RPD for protection against harmful gases, that have no warning properties[5]. The use of supplied air respirators may be the only way to reliably protect workers in circumstances when there is no ESLI, and it is impossible to calculate the service life.

Legislation in the United States[66] and in the EU[67][68] allows employer to use of only an supplied air respirators when employee works in conditions where air pollution is IDLH (because of the risk of not timely replacement of cartridges).

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10.1 Text

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