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Estimating Organic Vapor Cartridge Service Life

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Respirator cartridge change-out schedules depend upon many factors such as the contaminant, airborne concentration, humidity, temperature cartridge, and worker characteristics. End of service life indicator (ESLI) estimator calculators have been created by several cartridge manufacturers including 3M, North, and MSA. This technical report details background information pertaining to cartridge change-out schedules with regard to OSHA and Air Force requirements and manufacturer calculators which may be used to establish cartridge change-out schedules.

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Introduction

The service life of a cartridge is the period of time for which the cartridge provides adequate protection to the user. After a cartridge has absorbed a particular contaminant to its capacity, the contaminant will begin to pass through the cartridge and enter the facepiece of the respirator, a condition commonly referred to as breakthrough. A cartridge change-out schedule allows the respirator wearer to replace the chemical cartridge or canister before breakthrough occurs, instead of relying on the contaminant's warning properties. An appropriate cartridge change schedule is one that is both convenient and assures that the concentration of the chemical downstream does not exceed the exposure limit. Attachment 1 shows a decision matrix flowchart for starting to setup a change-out schedule.

User senses (odor, taste, irritation, etc.) are not acceptable means for determining cartridge service life because warning properties rely upon human senses that are not foolproof. The 1987 NIOSH Respirator Decision Logic described the typical wide variation of odor threshold in the general population (greater than two orders of magnitude). Other problems exist: shift in odor threshold due to extended low exposures, shifts due to simple colds and other illnesses, and failure to recognize odor due to distraction in the workplace competing for worker attention. Given the variability among people with respect to detection of odors and differences in measuring odor thresholds, a better practice is to establish cartridge change-out schedules even for chemicals with adequate warning properties.

Certain cartridges are designed with the capability of warning the user when it is time to change the cartridges. Currently, there are very few cartridges equipped with National Institute for Occupational Safety and Health (NIOSH)-approved end-of-service life indicators (ESLIs). ESLIs are available for exposures to mercury vapor, carbon monoxide, hydrogen sulfide, and ethylene oxide. The small area at the center of the inlet surface of cartridges with ESLIs and the band around the side of the cartridge consists of chemically treated paper. During use, as the paper is exposed to the specific chemical, it changes from one color to another. When the indicator color changes, the cartridge is beginning to lose its effectiveness against vapor or gas and should be replaced. Thus, the wearer has a constant, positive check on the condition of this cartridge.

Regulatory Drivers

The Occupational Safety and Health Administration (OSHA) standard 29 Code of Federal Regulations (CFR) 1910.134(d)(3)(iii) states that for protection against gases and vapors, employers shall provide either a respirator with an ESLI certified by NIOSH for the contaminant or implement a change schedule for canisters and cartridges that is based on objective information or data that will ensure that canisters and cartridges are changed before the end of their service life.

Paragraph 4.2.2.10 of AFOSH Standard 48-137, *Respiratory Protection Program*, states to use air-purifying devices only if the air-purifying respirator has a reliable end of service life indicator that will warn the user prior to contaminant breakthrough, or a cartridge change schedule is implemented based on cartridge service data including desorption studies (unless cartridges are changed daily); expected concentration; pattern of use; duration of exposure have been established; and the chemical does not have a ceiling limit. If the latter is the case, Bioenvironmental Engineering (BE) shall determine that the respirator will provide adequate protection and the change schedule is appropriate.

Also, paragraph 7.3.6. of AFOSH Standard 48-137 requires initial respiratory protection training to include an explanation of how a worker knows when to change the filters or cartridges on an air-purifying respirator. Paragraph 9.3.3.4. requires workplace respiratory protection operating instructions to include the criteria which workers use to determine when respirator filters, cassettes, or cartridges must be changed. Notwithstanding, paragraph 8.4.2. states that the cartridge, filter, or canister of an air-purifying respirator shall be changed:

(a) Whenever the worker detects an increase in breathing resistance;
(b) Whenever the worker smells or tastes the contaminant, or detects the irritant properties of the contaminant;
(c) Whenever the ESLI is triggered;
(d) As required by applicable substance-specific OSHA standards (for instance, formaldehyde); or
(e) As directed by BE.

For gas and vapor contaminants regulated by OSHA's substance-specific standards, minimum cartridges change schedules are already specified (see Attachment 2).

Particulates

Service life determination for particulate filters is not required under 29 CFR 1910.134; it is only required for gases and vapors. Normally, the particulate filtration efficiency will improve during use as the filter loads and a "cake" layer forms on the surface of the filter. Respirators or filters should be changed if they become damaged, soiled, or an increase in breathing resistance becomes noticeable. In addition to these considerations, N series filters should not be used against oily aerosols. The NIOSH 1996 Publication 96-101, *Guide to the Selection and Use of Particulate Respirators*, recommends that R series filters should be changed every 8 hours if used against oily aerosols. Most manufacturers recommend that their P series filters used in environments containing oily aerosols should be limited to 40 hours of use or 30 days, whichever is first.

Chemicals not suited for OV Cartridges

Respirator organic vapor (OV) cartridge performance is particularly poor when removing methanol, dichloromethane, carbon disulfide, methyl chloride, acetone, and methyl acetate. Due to the short breakthrough times for these solvents, other adsorbents or collectors should be used. To make the cartridges more selective for certain chemicals, sorbents can be impregnated with chemical reagents. Impregnated activated carbon removes specific gas and vapor molecules by chemisorption. Chemisorption is the formation of bonds between molecules of the impregnant and the chemical contaminant. These bonds are much stronger than the attractive forces of physical adsorption. The binding is usually irreversible. Reuse of chemical cartridges that work on the principle of chemisorption typically not be a problem. Although counterintuitive, the service life of acid gas, ammonia/methylamine, and other chemical cartridges that work by chemisorption, typically increase with increasing relative humidity.

Rules of Thumb

As part of the overall assessment for determining a change-out schedule, one might look to various "rules of thumb" that have appeared in published literature. Please note that these "rules of thumb" do not work for every chemical in every situation (in particular, these statements do not generally apply to inorganic gases such as sulfur dioxide and hydrogen sulfide):

(a) If a chemical's boiling point is greater than 70°C and the concentration is less than 200 ppm you can expect a service life of eight hours at a normal work rate;
(b) Service life is inversely proportional to work rate;
(c) Reducing concentration by a factor of ten will increase service life by a factor of five;
(d) Humidity above 85% will reduce service life by 50%;
(e) Breakthrough times are diminished from 1-10% with each 10°C rise in temperature; and
(f) Service life is directly proportional to the amount of carbon in the cartridge.

Since the "rules of thumb" are based on a few parameters such as concentration and boiling point, they are considered subjective. To comply with the OSHA standard, objective data must be used. There are three valid ways to estimate a cartridge's service life: conduct experimental tests, use the manufacturer's recommendation, or use a mathematical model.

Use of Analogous Chemical Structures

Appendix A of CPL 2-0.120 states that analogous structures may be used as the basis for estimating cartridge breakthrough where a contaminant with a known service life value has an analogous structure to the contaminant under investigation or where a contaminant with a known migration may be used as a surrogate for a chemical with a less rapid migration. Generally, OSHA suspects that use of analogous chemical structures may be less accurate than other methods and should be used only when better information is not available. However, OSHA believes that use of analogous chemical structures would be infallible so long as objective data or information for lower molecular weight compounds is used to predict the break-through times for higher analogous molecular weight compounds containing only additional methyl or phenyl groups. Analogous chemical structures should not be used to predict break-through of analogous substances that have a lower molecular weight.

Experimental Testing

The ideal cartridge change-out schedule would be based on laboratory test data, which was developed at the same conditions at which the cartridge is to be used. However, it is usually difficult, time-consuming, and expensive to obtain this type of information for the range of workplace variables. A method for conducting field-testing in the workplace is discussed in Attachment 3.

NIOSH certifies organic vapor cartridges using the criteria in 42 CFR 84, *Approval of Respiratory Protective Devices.* Still, there is no widely accepted, standard protocol for performing service life testing. However, both the Environmental Protection Agency (EPA) and OSHA have published recommendations for performing service life testing. These methods can be found at OSHA's website:

(a) http://www.osha-slc.gov/SLTC/etools/respiratory/oshafiles/h049.html
(b) http://www.osha.gov/SLTC/etools/respiratory/testing/testing.html

Manufacturer's Data

Manufacturers are likely to possess the most accurate data for their own respiratory products. However, the manufacturer may not have tested the respirator with the chemicals or environmental conditions that you work with, and therefore may not be able to offer a reliable recommendation. Since their recommendations are based on the characteristics of their cartridges, the recommendation may not be valid for other manufacturer's cartridges due to—for instance—different carbon micropore volumes. Besides respirator manufacturers, objective data for a particular make and model of the respirator cartridges sometimes can be obtained from industry organizations, trade associations, professional societies, chemical manufacturers, or academic institutions.

The September 2001 NIOSH Certified Equipment List (CEL) for respirators includes 78 manufacturers. Not all of these manufacturers have respirators with cartridges, and the ones who do vary in the level of support that they can provide. Attachment 5 contains a list of air-purifying respirator manufacturers (not all inclusive).

Mathematical Models

Mathematical equations have been used to predict the service lives of organic vapor respirator cartridges to varying degrees of accuracy. There are differences in the models, and some are more difficult to solve. Moreover, certain variables of equations are considered proprietary by some respirator cartridge manufacturers and are not released to the general public. Unfortunately, no one physical characteristic (e.g., boiling point, vapor pressure, molecular weight, polarizability, etc.) of the contaminant (gas or vapor) or the sorbent has been identified that consistently correlates with adsorption capacity and service life. Attachment 6 lists some factors known to be important.

Mathematical models may be generally classified into two categories: predictive and descriptive. Predictive models estimate the breakthrough time based on chemical and physical properties of the contaminant whereas descriptive models attempt to fit mathematical equations to existing experimental data. Predictive models can be useful to initially screen whether a cartridge might be appropriate for a new chemical substance. If the model predicts service life at less than 20 minutes for the new chemical substance, then an organic vapor cartridge may not be appropriate for the substance.

Gerry O. Wood, of Los Alamos National Laboratory, has developed a predictive model. Use of the Wood model is demonstrated in Attachment 7. A predictive model uses less data to "predict" cartridge performance than descriptive models, which is why predictive models have a higher percentage of errors associated with them. The model currently only considers dry conditions (relative humidity <50%). Relative humidity is such a complex issue that presently no published predictive models take it into account. The Wood model does not predict breakthrough times for mixtures of materials and cannot be used for inorganic gases. This estimation showed 95% confidence intervals of up to ±50% compared to experimental values.

The preamble to the OSHA respirator standard states "predictive models are probably not likely to present an acceptable alternative for most employers, and their use would require that a considerable margin of safety be incorporated into any change schedule developed from such estimation techniques." Thus, one should not rely on the Wood model without some experimental confirmation of the calculation and/or use of appropriate safety factors (i.e., subtract *at least* a 50% error rate from the calculated result).

The effect of relative humidity on service life of organic vapor cartridges will depend on the relative humidity level, the chemical concentration, volatility of the chemical, and the chemical's miscibility (ability to dissolve) in water. The early work by Gary Nelson of Lawrence Livermore Laboratory in 1976 established a breakthrough time multiplier (correction factor) of about 0.48 for cartridges preconditioned and tested at 90% relative humidity relative to cartridges preconditioned and tested at 50% relative humidity. Based upon relatively few studies, OSHA recommends that a reduction by a factor of two in the cartridge service life originally estimated based upon 50% relative humidity, may be made when the relative humidity reaches 65%. If the relative humidity exceeds 85%, OSHA recommends experimental testing or another method to more specifically determine the service life. Attachment 8 shows what 3M recommends as a correction factor for relative humidity based on volatility.

Two applications of the Wood model are available at OSHA's website. The first is a table (see attachments 9 and 10) of breakthrough times for chemicals at several concentrations. The breakthrough estimates in the table were calculated using "generic" values for the cartridge and workplace input parameters. Therefore, the table does not provide the most accurate breakthrough estimates. OSHA's "Advisor Genius" (see Attachment 11) allows the user to enter specific values for the input parameters to improve the accuracy of the service life estimate. Default values may be used if the actual values are unknown. In addition, the "Advisor Genius" allows calculation of breakthrough times for any organic compound that is a liquid at room temperature and for which certain parameters are known.

Mixtures

Change schedules are very difficult to develop for mixtures using predictive mathematical models. Cartridge breakthrough may occur earlier in the presence of mixtures than would have been predicted from data for a single compound. Cartridge service life for mixtures is best determined using experimental methods. There is no accepted method for estimating the service life of cartridges used in an atmosphere containing a mixture of vapors. However, OSHA's Compliance Directive CPL 2-0.120, *Inspection procedures for the Respiratory Protection Standard*, suggests if the breakthrough times for the individual vapors in a mixture are within one order of magnitude, the individual vapor concentrations should be added together. It can then be assumed that the entire mixture behaves like the contaminant with shortest breakthrough time. If breakthrough times for the individual components vary by two orders of magnitude or more, the service life estimate should be based on the contaminant with the shortest breakthrough time. It is not known how well these simple rules predict cartridge service life in a mixed vapor atmosphere.

Research by Coreen A. Robbins suggests that service time for individual vapors in a mixture is related to their mole fractions in the mixture. The mole fraction for each chemical in a mixture is equal to the concentration of that material (in ppm) divided by the total concentration of the mixture. The service life for each component in the mixture is calculated by multiplying its mole fraction by its predicted "single substance" service time. Simply stated, this method estimates when the first component of a mixture will break through. An example on how to calculate service life for a mixture is in Attachment 12.

Descriptive models use experimental data to calculate parameters that fit the model to the data. Once the model is fit to a set of experimental data, the model is used to calculate values for points where experimental data are not available. The validity of the model is dependant on the accuracy of the experimental data, and some descriptive models may not account for all significant variables (e.g., humidity, temperature, etc.).

The Yoon-Nelson descriptive model assumes each contaminant breakthrough profile (the plot of percentage breakthrough versus time) is a symmetric sigmoidal curve. The experimental data closely follow sigmoidal breakthrough curves in the breakthrough percentage range 0-50%. However, at higher breakthrough percentages, the deviation of experimental data from symmetric breakthrough increases, particularly at high humidity and low concentrations. The confidence level is much higher for the Yoon-Nelson model (±10%) than the Wood model. However, certain parameter values first have to be derived from empirical data for each combination of cartridge type, humidity condition, temperature, and contaminant. For a fee, the Miller-Nelson Research Inc. in Monterey, California (http://www.millernelson.com/, phone number: 831-647-1551) will determine these parameters and the cartridge service life for a particular situation.

Software

Computer software is becoming a major tool to help determine the service life of respirator cartridges used to protect workers against airborne gas and vapor hazards. It's important to know the limitations and understand the results of the software program used. Most of the programs are similar, providing the user with input boxes to select a specific value or enter data on a chemical, its concentration in the workplace, the cartridge type, breakthrough concentration, temperature, humidity, and work rate. The better programs also require the user to input data on atmospheric pressure, select a safety factor, and integrate the specific relative humidity as a parameter. Because these software programs cannot know each workplace situation, they can provide only estimates--not exact predictions. User estimates of work rates and measurements of contaminant concentrations, as well as temperature and humidity, can further affect accuracy. Summaries of software features are in Attachments 13 and 14. Attachment 15 compares the calculated breakthrough times for various cartridges.

The first software program available was 3M's Respirator Service Life Software (based on the Wood Model), released soon after OSHA revised its respirator standard. OSHA's "Advisor Genius" also is based on the Wood model. OSHA's program includes default values for cartridge and carbon characteristics, or users can enter their own values based on information obtained from the respirator manufacturer. Using the manufacturer's data results in a more accurate breakthrough estimate. AO Safety's "Merlin" software program is a spreadsheet. Merlin calculates breakthrough times for either inorganic gases or organic vapors based on the Wood model. Merlin uses a single screen for both data entry and results and provides a list of chemicals. North Safety's "esLife" software has an optional screen to allow the user to enter a job and workplace description, thus providing a printed record of the breakthrough calculation. Willson's service life program (available on CD only) is based on the mathematical model by Nelson. Survivair's "Air Purifying Respirator Cartridge Service Life Program" also uses Nelson's model for the organic vapors. Moldex, US Safety, and Scott do not have calculator programs but do have tables of breakthrough times. The MSA claims it's "Cartridge Life Expectancy Calculator" is accurate to within ±25% of the experimental test values.

Users should be aware of the idiosyncrasies of the program they use. For example, finding a chemical can be a challenge in some of the programs. Methyl ethyl ketone and MEK are common synonyms for 2-butanone. Searching for MEK in certain programs will bring up this material. In the other programs, common names and synonyms are not listed in the search mechanism, making a CAS registry number search a better option. However, not all programs have the capability to search by CAS registry number. Each program may handle specific issues differently, requiring caution on the part of the user. For example, OSHA's standards dictate the frequency of cartridge change depending on the substance, such as benzene. For this reason, most of the programs do not calculate a breakthrough time or alert the user to the presence of a standard. Using a cartridge longer than allowed by an OSHA standard can result in a citation. Only some programs will issue a warning and refuse to calculate a breakthrough time if the user enters a concentration greater than the IDLH. The values for IDLH, PELs, and other standards may or will likely change over time, which means not all the information in the software program should be assumed to be accurate.

Most software programs warn about the potential for desorption or stipulate not to use a cartridge for more than one work shift. When organic materials with a boiling point below 65°C are imbedded in a carbon filter, some may have a tendency to migrate through the sorbent material during periods of storage or when not in use. This can rapidly increase breakthrough and could present an additional exposure to the user. Whenever migration is possible, canisters and cartridges should be changed after every work shift. The American National Standards Institute (ANSI) Z88.2-1992, *Practices for Respiratory Protection*, recommends desorption studies unless cartridges are changed daily. OSHA's CPL 2-0.120 states that where contaminant migration is possible (chemicals with boiling points below 65°C), respirator cartridges should be changed after every work shift where exposure occurs. If the employer has specific objective data (desorption studies) showing the performance of the cartridge under the conditions and schedule of use/nonuse found in the workplace, daily change would not be required.

Limitations

Less volatile chemicals can cause desorption and subsequent early breakthrough of poorly adsorbed, more volatile chemicals. For example, a maintenance worker wears a respirator for exposure to chemical A. The use period is shorter than the service life for chemical A so no breakthrough occurs. The next day the worker goes to a different area with exposure to a different organic chemical, chemical B. Chemical B is less volatile than chemical A. Since the service life was not used up with chemical A, the organic vapor cartridges are reused. Before chemical B breaks through, it displaces the more volatile chemical A. If the change schedule does not consider this effect, chemical A may break through and the worker is exposed to chemical A. Laboratory studies by Yoon and Nelson have shown that a more strongly adsorbed chemical can displace a relatively weakly adsorbed chemical.

Using 65°C as the indicator for migration does not take into account those materials that may migrate after slightly longer periods of nonuse. A case where very nonvolatile chemicals desorb to cause an overexposure might occur when emergency responders store their cartridges for use for another day. For instance, the National Fire Protection Association (NFPA) standard 77, *Standard on Protective Clothing and Equipment for Wildland Fire Fighting*, considers wildfire smoke not immediately dangerous to life and health (IDLH) even though the human health hazards have not been quantified. Under the standard, firefighters are allowed to wear air-purifying respirators with High Efficiency Particulate Air (HEPA) filters by themselves or also with organic vapor/acid vapor cartridges to fight wildland fires.

Some Considerations for Specific AF Jobs

Some Air Force personnel use organic vapor cartridges as an emergency escape mechanism from fuel cells. There are several elements involved in the use of this type of respiratory protection that may fail to adequately support escape. First, this escape mechanism assumes adequate oxygen is available inside the fuel cell. This may not be an adequate assumption. Depending on the procedure in progress and the reason for the loss of breathing air, insufficient oxygen to allow worker escape may exist. For example, if a power outage leads to failure of the breathing air pump, the ventilation system used to air out the cell could also fail. As a result, oxygen levels inside the cell could drop, leading to an oxygen deficiency. Second, even if adequate oxygen is available, the probability of worker escape will depend on the concentration of vapors in the cell, the adsorption capacity of the cartridges, and the position of the worker when the failure occurs. If the cartridge has been in service for a prolonged period of time the adsorption capacity will be greatly diminished. Elevated vapor concentrations inside the cell could overload the cartridge; therefore, the mask would not have enough adsorptive capacity left for safe escape.

Paragraph 3.4.12.1 of AFI 32-1052, *Pest Management Program*, requires all pesticide applicators to be enrolled in the respiratory protection program. The EPA states in the Federal Register, 40 CFR Part 170.240(f)(7), *Worker Protection Standard*, that the employer shall assure that when gas- or vapor-removing respirators are used, the gas- or vapor-removing canisters or cartridges shall be replaced:

(a) At the first indication of odor, taste, or irritation.

(b) According to manufacturer's recommendations or pesticide product labeling, whichever is more frequent.

(c) At the end of each day's work period, in the absence of any other instructions or indications of service life

Contrary to AFOSH Standard 48-137, a June 1999 AFMOA memorandum stated, "Bases are authorized to determine respiratory protection for spraying isocyanate containing paints based on process-evaluation, measured exposure levels, and assigned protection factors (APFs)." Diisocyanates often form condensation aerosols when they are airborne. For this reason, it is generally necessary to use a particulate filter in combination with an organic vapor cartridge. If other organic vapors are present in the same atmosphere as a diisocyanate, those vapors invariably break through first.

Venkatram Dharmarajan of Bayer Corporation studied the breakthrough of hexamethylene diisocyanate (HDI) through MSA GMA type and North N7500-1 cartridges at various relative humidities and solvent saturation. Their results suggest these cartridges provide protection against a challenge concentration of 100 ppb HDI (in a solvent mixture of 60% n-butyl acetate, 30% propylene glycol mono methyl ether acetate, 5% toluene, and 5% methyl ethyl ketone) at relative humidities as high as 80% and as low as 20% at room temperature. No evidence of desorption or migration was seen in cartridges that were repeatedly exposed to HDI atmospheres day-after-day for six days. However, other paint ingredients might lead to breakthrough or desorption in other scenarios.

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http://www.osha.gov/SLTC/respiratoryprotection/changeout.html

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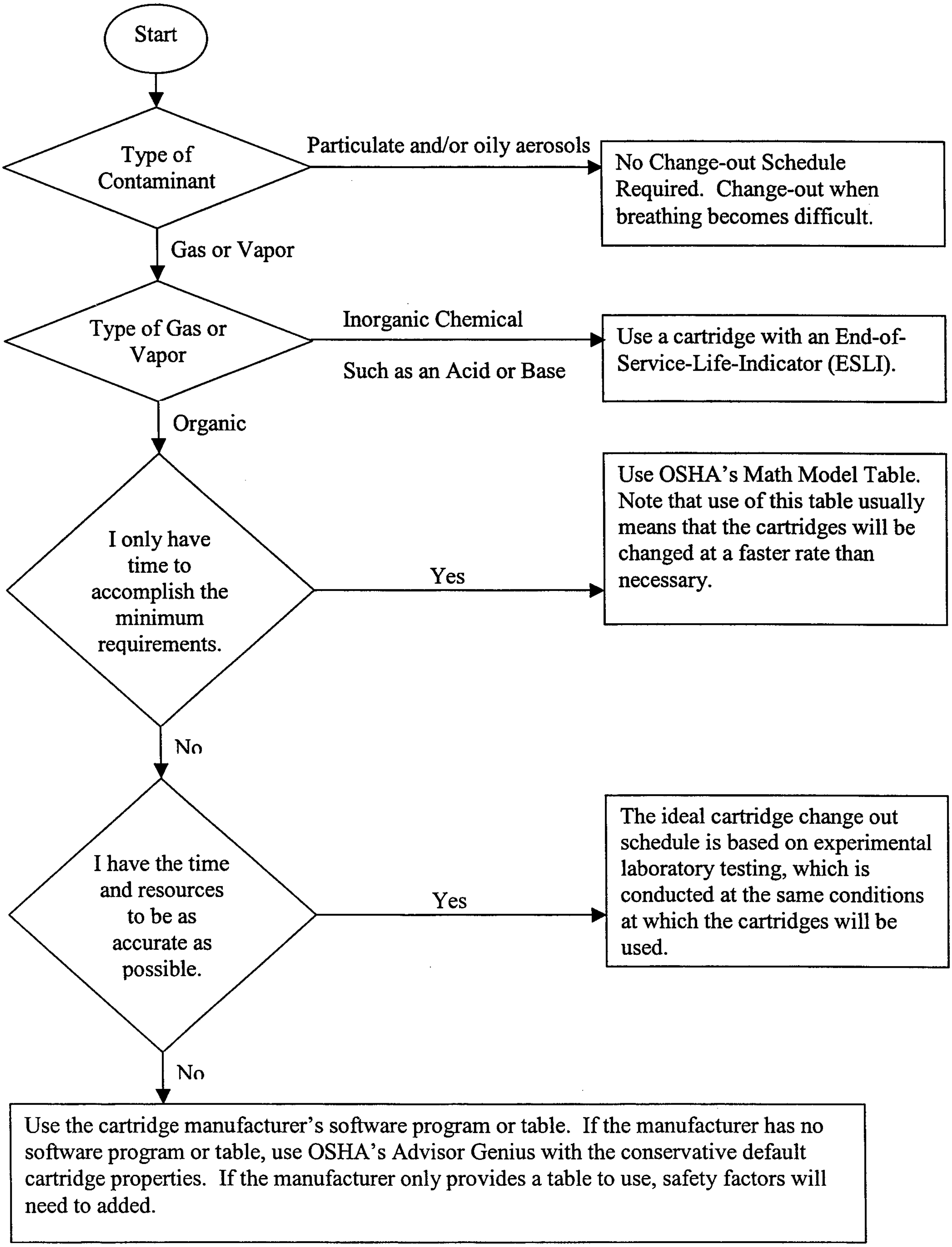
Attachment 1. Estimating Cartridge Service Life Flowchart



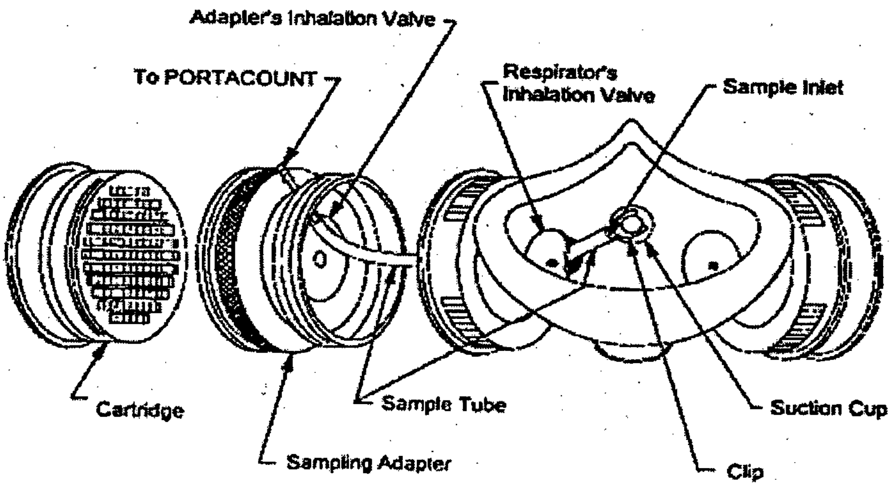
Attachment 2. Cartridge Service Life for OSHA Substance-Specific Standards

OSHA Standard	Change Schedule
Acrylonitrile 29 CFR 1910.1045(h)(2)(ii)	If air-purifying respirators (chemical-cartridge or chemical-canister types) are used: -- The air-purifying canister or cartridge must be replaced prior to the expiration of its service life or at the completion of each shift, whichever occurs first. -- A label must be attached to the cartridge or canister to indicate the date and time at which it is first installed on the respirator
Benzene 29 CFR 1910.1028(g)(2)(ii)	For air-purifying respirators, the employer must replace the air-purifying element at the expiration of its service life or at the beginning of each shift in which such elements are used, whichever comes first. If NIOSH approves an air-purifying element with an ESLI for benzene, such an element may be used until the indicator shows no further useful life.
1,3-Butadiene 29 CFR 1910.1051(h)(2)(ii)	If air-purifying respirators are used, the employer must replace the air-purifying filter elements according to the replacement schedule set for the class of respirators listed in Table 1 of the standard, and at the beginning of each work shift. Instead of using the replacement schedule listed in Table 1 of the standard, the employer may replace cartridges or canisters at 90% of their expiration service life, provided the employer: -- Demonstrates that employees will be adequately protected by this procedure. -- Uses breakthrough data for this purpose that have been derived from tests conducted under worst-case conditions of humidity, temperature, and air-flow rate through the filter element, and the employer also describes the data supporting the cartridge-or canister-change schedule, as well as the basis for using the data in the employer's respirator program. A label must be attached to each filter element to indicate the date and time it is first installed on the respirator. If NIOSH approves an ESLI for an air-purifying filter element, the element may be used until the ESLI shows no further useful service life or until the element is replaced at the beginning of the next work shift, whichever occurs first. Regardless of the air-purifying element used, if an employee detects the odor of BD, the employer must replace the air-purifying element immediately.
Formaldehyde 29 CFR 1910.1048(g)(2)(ii)	If air-purifying chemical-cartridge respirators are used, the employer must: -- Replace the cartridge after three hours of use or at the end of the workshift, whichever occurs first, unless the cartridge contains a NIOSH-approved ESLI to show when breakthrough occurs. -- Unless the canister contains a NIOSH-approved ESLI to show when breakthrough occurs, replace canisters used in atmospheres up to 7.5 ppm (10xPEL) every 4 hours and industrial-sized canisters used in atmospheres up to 75 ppm (100xPEL) every 2 hours, or at the end of the workshift, whichever occurs first.
Methylene chloride 29 CFR 1910.1052(g)(2)(ii)	Employers who provide employees with gas masks with organic-vapor canisters for the purpose of emergency escape must replace the canisters after any emergency use and before the gas masks are returned to service.
Vinyl chloride 29 CFR 1910.1017(g)(3)(ii)	When air-purifying respirators are used: -- Air-purifying canisters or cartridges must be replaced prior to the expiration of their service life or the end of the shift in which they are first used, whichever occurs first. -- A continuous-monitoring and alarm system must be provided when concentrations of vinyl chloride could reasonably exceed the allowable concentrations for the devices in use. Such a system must be used to alert employees when vinyl chloride concentrations exceed the allowable concentrations for the devices in use.

Attachment 3. Field Testing of Cartridge Effectiveness for a Contaminant

In the workplace, collect an air sample behind the cartridge using a Portacount® mask sampling adapter. Collect these samples in the same workplace where the respirator use is required and while the process is ongoing. The sampling method (e.g., flame ionization detector, photoionization detector, hydrocarbon detector tubes, gas chromatograph, charcoal tube, etc) does not have to be specific for each component of the mixture but it should be sensitive enough to detect concentrations at 25 % of the occupational exposure limits of the mixture components. If no organic vapors are detected then the change out schedule is verified. A list of mask sampling adapters available from respirator manufacturers is provided in Attachment 3. Install the Portacount® mask sampling adapter an area free of contaminated air, then return to the worksite to collect the sample behind the cartridge while the respirator is being worn by the worker.

Portacount® mask sampling adapter

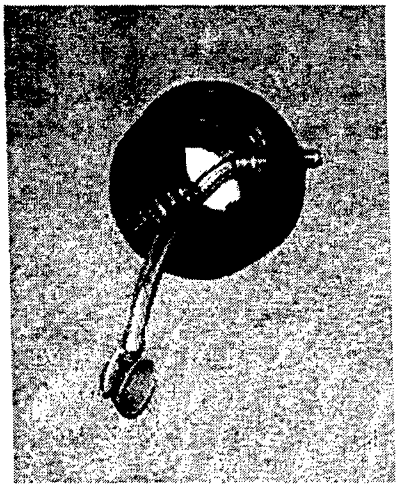


Detach the "Sample Tube" along with the "Suction Cup" and "Clip." Install the Portacount® mask sampling adapter between the facepiece and the cartridge. Attach tubing to the outside fitting of the Portacount® mask sampling adapter. Close off the end of this tubing with a heavy wire paper clip to prevent contaminated air from entering. Have worker redon the respirator. When back in the worksite, remove the clip and attach the sampling device to the end of this tubing. In this arrangement, the air sample will be collected in the chamber between the inhalation valve of the Portacount® mask sampling adapter and the inhalation valve of the facepiece. If there are no organic vapors detected in the samples then significant breakthrough (> 25% occupational exposure limit) has not occurred and the change out schedule is confirmed. Change cartridges according to the estimated (now verified) change out schedule.

It is not necessary for the Air Force to purchase any additional air sampling equipment to collect air samples behind respirator cartridges for verifying cartridge change out schedules. It is acceptable to collect air samples on sorbent tubes behind the cartridges at the highest flow rate allowed by the sampling method. This permits relatively quick collection of the lowest sample volume, for laboratory analysis results that can be reported in concentrations down to the limit of detection. Most air samples can be collected behind cartridges in five to ten minutes.

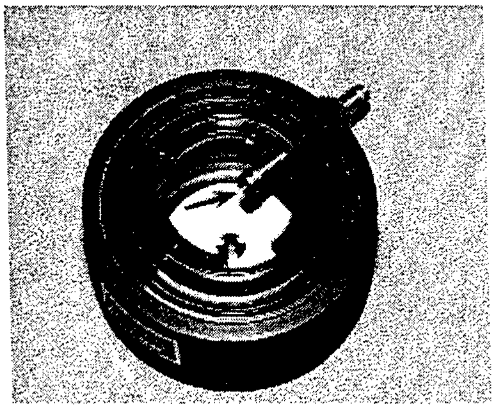
Pictorial Example

The following pictures show a quantitative fit-testing (QNFT) adapter such as the 3M 601 Quantitative Fit Testing Adapter is mounted between the cartridge and the facepiece.



The sample tubing is normally passed through a respirator's inhalation valve for sampling inside the facepiece during quantitative fit testing.

The tubing that is normally passed through the respirator's inhalation valve to draw a sample from inside the facepiece is removed.



The 3M 601 Adapter with the sample tubing removed. The arrow points to the exposed end of the hose connector, which draws samples from the air space between the cartridge and the facepiece.

This allows the space between the inhalation valves on the 3M 601 Adapter and the respirator (i.e. between the cartridge and the respirator) to be sampled. A short piece of tubing is attached to the outer hose connection on the adapter to allow connection of a sampling device. The tubing is held closed with a pinch-style paper clip until the sampling device is connected.

The 3M 601 Adapter positioned for sampling behind the cartridge. The tubing is pinched closed until the air sample is taken.

Any sampling method with sufficient sensitivity to detect the chemical of interest at a concentration below the exposure limit can be used to take the sample.

Sampling behind the cartridge with a colorimetric detector tube.

Since use of the QNFT adapter temporarily voids the respirator's NIOSH approval, it may be put in place for only a short (~30 minute) equilibration period prior to sampling

The U.S. Navy Environmental Health Center (NAVENVIRHLTHCEN) performed an experiment to determine if workers' breathing would interfere with the flow rate of sampling pumps while collecting air samples behind the cartridges. An analysis of variance (ANOVA) test of the experimental results showed that there is no significant difference ($P_{0.05}$) between the average flow rate of pumps collecting air samples in ambient atmosphere and pumps collecting air samples inside Portacount® mask sampling adapters connected to workers' respirators while they breath normally. However, ANOVA indicated that there is a significant difference ($P_{0.05}$) between those two means and the mean flow rate of pumps collecting air samples inside Portacount® mask sampling adapters connected to workers' respirators while they are breathing hard. When an air sample is collected behind a cartridge inside a Portacount® mask sampling adapter, the worker must breath normally so as not to interfere with collection of the sample. Instruct the worker to take a break for five to ten minutes while wearing the respirator in the worksite during air sample collection. The workers' normal breathing will not adversely influence detection of breakthrough. By the time of air sample collection, all of the varying air contaminant concentrations, varying temperature and humidity, and varying breathing rates throughout the day have already had their influence on respirator cartridge breakthrough. In other words, workers breathing normally right before cartridge change out time would not significantly influence breakthrough – breakthrough would have either already occurred or not occurred.

Gary O. Nelson and Charles A. Harder of Lawerence Livermore Laboratory evaluated the service life of organic vapor cartridges using a mechanical breathing simulator for pulsating flow rates. In regards to experimental testing, no significant difference were observed between steady state and pulsating-flow patterns, even at equivalent high work rates and humidity conditions. It is speculated that the equilibrium between the solvent vapor and the charcoal is so rapid that little or no difference exists between the both types of flow.

References:

Industrial Hygiene Directorate of the Navy Environmental Health Center
http://www-nehc.med.navy.mil/ih/Respirator/ChangeSchedule.htm

Nelson, T. J., and Janssen, L. L.: "Developing Cartridge Change Schedules: What are the Options?" *3M Job Health Highlights*, Volume 17(1): 1-5 (1999).

Nelson, G. O. and Harder, C. A.: "Respirator Cartridge Efficiency Studies IV. Effects of Steady-State and Pulsating Flow," *American Industrial Hygiene Association Journal*, Volume 33, 797-805 (1972).

Attachment 4. Mask Sampling Adapters Available from U.S. Respirator Manufacturers

This is a list of adapters available from respirator manufacturers and their distributors. TSI offers many of the same adapters, repackaged with HEPA filters and additional supplies, for direct sale.

Manufacturer	Respirator Model (H=Half, F=Full)	Adapter Kit Part No.	Telephone
MSA	Comfo Series (H)	812022 (QuikChek™ II)	(800)672-2222
	Duo-Twin (F)	812022 (QuikChek™ II)	
	Ultra Twin (F)	812022 (QuikChek™ II)	
	Advantage 100/200/200LS (H)	812022 + 809999	
	Advantage 1000(F) MILLENIUM (F)	10006227	
	Ultra Elite (F) (screw-in version) ADVANTAGE 3000 Series (F)	805078 (QuikChek™ III) + 496081	
	Ultra Elite (F) (1/4 turn version)	805078 (QuikChek™ III) and 817446 (QuikChek™ IV)	
	Ultravue (F) (not for SCBA)	802710 (QuikChek™ I)	
	Phalanx (F)	802710 (QuikChek™ I)	
North	5500 (H)	7700-21	(800)430-4110
	7700 Series (H)	7700-21	
	5400 and 7600 Series (F)	7700-21	
	7800 Series	7700-21	
	85101, 85111, 85201, 85211	7700-21 with 7700-24	
	85400A, 85500A, 800 Series Pressure-Demand (F)	7700-21 with 7700-23 fitting	
3M	6000 Series (H/F)	601	(800)243-4630
	7000 Series (H)(Bayonet)	601	
	7000 Series (H)(Conventional)	7930 (or use 601 with 9286 adapters)	
	7800 Series (F)(Bayonet)	601	
	7800 Series (F)(Conventional)	7930 (or use 601 with 9891 adapters)	
	7900 Series (F)	601	
	F40 Gas Mask (F)	601 with 701	
*Dalloz Safety (Willson)	*Screw Type (3-inch diameter):* 1200(H), 1600(F), 1700(F), 5000(H)	RP98	(800)345-4112
	Bayonet Type: 6100(H), 6200(H), 6400(F), 6500(F), 6800(H), 8100(F), 8600(F)	RP99	

*Glendale Protective Technologies (GPT)	"F" series facepieces with 1-inch diameter screw-on filters	1232	(800)345-4112
	"F" series facepieces with 3-inch screw-on filters	RP98	
	Replacement Tubing (25)	1233	
Scott	Scott-O-Vista (F)	803930-01	(800)247-7257
	AV-2000 (F)	803930-01	
	66 Series (H)	No adapter available. Order probed masks from Scott (803550-??)	
	Scottoramic (F)	No adapter available. Order probe kit from Scott (803119-01)	
	XCEL (H)	7422-FT1	
*Pro-Tech	1490 Series (H)	QNFT Adaptor	(800)375-6020
	1590 Series (H)1694	QNFT Adaptor	
	Series (F)	QNFT Adaptor	
AO Safety (AEARO Company)	All models with screw-on filters	51171-00000 Adapter Kit*	(800)225-9038
	All models with bayonet filters	51172-00000	
Survivair	Air Purifying Masks with Screw-on Filters, including 2000 Blue 1, Low Maintenance, 4000, 20/20, OPTi-Fit	420025 with 105005 Filter	888-277-7222
	Air Purifying Masks with Bayonet Filters, including OPTi-Fit, 7000	760075 with 785000 Filters	
	Positive Pressure/SCBA Masks with Panther-style Mask Mounted Regulator, including Classic, 20/20	962920 and 962900 and Two 105005 Filters	
	Positive Pressure/SCBA (Mk-II) with Hose, including Classic, 20/20	See Appl. Note ITI-029	
Moldex	8000 Series (H)	#8006	(800)267-1611
Interspiro	Spiromatic & Spirolite SCBA (F)	336-890-378	(800)468-7788
	Spiromatic "S"	95991	
Sundstrom	SR90(H)	702.120.99	
ISI	Viking (SCBA) with Airswitch Vanguard (SCBA) with Airswitch	Fit Test Kits: 171066 Small 171065 Medium 171067 Large HEPA Filter: 033003	(888)474-7233
	Ranger (SCBA) - *Not for pre-1986 version*	08925600 *with 03407100 filter*	
	Magnum (SCBA), Magnum Plus (SCBA)	08925600	

Draeger	Panorama (F) cartridge version	4056315	(800)922-5518
	Futura (F) cartridge version		
	Panorama (F) positive pressure		
	Futura (F) positive pressure		
	Combitox Nova (H)		
	Cirrus (H)		
	Picco 20 (H)	4055655	
*U.S. Safety	Kit for all models	79200	(800)252-5002
	Adapter only	79210	
	Refill Kit (for 100 fit tests)	79215	
Respiratory Systems, Inc.	C-Flex	L-1561-75	(800)378-1000
	Lifeair STD Lifeair XL	L-4000-75	

** TSI 800553 Refill Kit can be used with these adapters*
† TSI 800785 Refill Kit can be used with MSA Quik Chek I, II & III

Attachment 5. Respirator Manufacturers

3M Company http://www.3m.com/occsafety/html/cartridgechange.html	1-800-243-4360	651-733-7364
Aearo Corporation http://www.aearo.com/html/products/respirat/respfor.htm	1-800-444-4774	508-764-5787
Draeger Safety http://www.draeger.com/us/ST/productsnservices/protection/filters/filters.jsp	412-787-8383	412-788-5685
Mine Safety Appliance Company http://www.msanet.com/msanorthamerica/msaunitedstates/cartlife/index.html	1-800-MSA-2222	724-776-7775
Moldex-Metrics, Inc http://www.moldex.com/images/PDFs/CARTRIDGE.pdf	1-800-421-0668	310-837-6500
North Safety Products http://www.northsafety.com/feature1.htm	1-800-430-4110 http://www.northsafety.com/train.htm	401-275-2445
Scott Health & Safety http://www.scotthealthsafety.com/hsliterature/product.asp?sku=0899	1-800-633-3915	704-296-4562
Survivair, Inc http://www.survivair.com/cartlife.html	1-888-APR-SCBA	714-850-0299
U.S. Safety http://www.ussafety.com/Cartridge_Service_Life.htm	1-800-821-5218	913-599-5555

Prior Name	Current Name
AG Spiro	Interspiro USA, Inc.
American Optical	Aearo Corporation
Cabot Safety Corporation	Aearo Corporation
Cesco	U.S. Safety
Fastech Corp.	Axis Products, Inc.
Glendale Protective Technologies, Inc.	Willson ® Dalloz Safety Products
H.S. Cover	Pro-Tech Respirators, Inc.
National Draeger, Inc.	Dräger Safety, Inc.
New England Thermoplastics	Better Breathing, Inc.
Norton	North Safety Products
Parmellee	Willson ® Dalloz Safety Products
Pirelli	Dispositivi Protezione Individuale D.P.I. SRL
Protector Technologies Europe	Protector Technologies Limited
Pulmoson	Willson ® Dalloz Safety Products
Racal Health and Safety, Inc. / Racal Panorama	3M Company
Rexnord	Biomarine, Inc.
Robertshaw	International Safety Devices, Inc.
Safety & Supply	Vinatronics, Inc.
Technol	Kimberly-Clark Corporation
Trusafe, Inc.	Vinatronics, Inc.

Attachment 6. Factors to consider when developing a cartridge change-out schedule.

The following is a partial list of factors which may affect the usable cartridge service life and/or the degree of respiratory protection attainable under actual workplace conditions
- Type of contaminant(s) Polarizability, dipole moment, quadrupole moment, etc. all have an effect. In general, activated carbon has a greater affinity for less volatile materials. The weight adsorbed is a decreasing function of the vapor pressure. - Contaminant concentration - Relative humidity - Breathing rate - Temperature - Changes in contaminant concentration, humidity, breathing rate and temperature - Mixtures of contaminants: (1) multiple contaminants present simultaneously versus (2) alternate usage of the same cartridges against different contaminants on different occasions. - Accuracy in the determination of the conditions - Cartridge storage conditions Exposure to trace levels of contaminants and humidity and elevated temperatures. - Storage conditions between multiple uses of the same respirator cartridges. Contaminants adsorbed on a cartridge can migrate through the carbon bed without airflow. - Physical and chemical properties of the sorbent in the cartridge Surface area, porosity, activity of sorbent, capacity of the sorbent all have an effect. - Age of the cartridge - Condition of the cartridge and respirator - Respirator and cartridge selection - Respirator fit - Respirator assembly, operation, and maintenance - User training, experience and medical fitness - Warning properties of the contaminant - Change schedules for contaminants with poor warning properties may require a greater safety factor than a contaminant with good warning properties. - Other conditions specific to the particular user and/or workplace

Properties which sorbents ideally posess are
- Ability to sorb contaminants at a high rate - High capacity (quantity) for contaminant adsorption - High retention for sorbate so as to minimize desorption - Ability of sorbent granules to retain their shape and size so that they do not crush - Stability and retention of these properties under normal storage conditions and use conditions.

Attachment 7. Calculating the Wood Equation

The following calculation will estimate the contaminant breakthrough time for an activated carbon respirator cartridge using physical and environmental parameters specific to the contaminant and the workplace. It only applies to contaminants that are liquids at the workplace temperature.

A hexane (CAS # 110-54-3) challenge concentration of 500 ppm in 50% relative humidity air at 20°C flowing through a pair of cartridges at a total of 53.3 L/min is assumed. What is an estimate of the 50 ppm (10%) breakthrough time?

First, obtain the following cartridge specific information from the manufacturer. The cartridge properties for this example are as follows:

W_o = carbon micropore volume = 0.454 cm^3/g (maximum volume of the adsorption space)
ρ_B = bulk density of the packed bed = 0.441 g/cm^3
n = number of cartridges = 2 (respirators generally use two cartridges)
W = weight of sorbent in cartridge = (carbon volume) ρ_B n = (80 cm^3)(0.441 g/cm^3)(2) = 70.6 g
A = cross sectional area of the adsorbent bed = $\pi(\text{diameter})^2/4 = \pi(7.1\ cm)^2/4 = 39.6\ cm^2$ (assuming a round cartridge)

The carbon micropore volume is a measure of the air spaces within the sorbent and is determined experimentally for each type of sorbent. If not available, you may use a conservative value of 0.4 cm^3/gram. If the weight of sorbent (activated charcoal) in a single cartridge is not available, you can disassemble a respirator cartridge and weigh the sorbent. There can be a significant variation in the amount of sorbent between cartridges (±30% or more). If an average value is not available, you should adjust the weight toward the low end of the expected range. The bulk density of the backed bed in units of grams per cubic centimeter. You can measure this by disassembling a respirator cartridge and determining the total volume (cubic centimeters) of the bed, then dividing this number into the sorbent weight. A typical value is about 0.4 grams/cm^3.

Some chemical and physical property information can be found for chemicals online. The Defense Occupational and Environmental Health Readiness System (DOEHRS) office has negotiated a Department of Defense wide site license for the Micromedex TOMES CPS™ database, accessible to anyone with a valid .mil Internet address (username and password required). The address is https://doehrswww.apgea.army.mil/. At the DOEHRS homepage click on the DOEHRSNet link and apply for an account.

Next, the molar polarization, Pe, can be calculated from the liquid density, d_L, molecular weight, M_w, and refractive index, n_D. These properties can be found in the CRC Handbook of Chemistry and Physics.

$$Pe = \left(\frac{n_D^2 - 1}{n_D^2 + 2}\right)\frac{Mw}{d_L} = \left(\frac{1.3751^2 - 1}{1.3751^2 + 2}\right)\frac{86.18\ \text{g/mol}}{0.6603\ \text{g/cm}^3} = 29.88\frac{\text{cm}^3}{\text{mol}}$$

Antoine's equation is a simple 3-parameter fit to experimental vapor pressure measured over a restricted temperature range:

$$\text{Saturation vapor pressure} = \rho_{sat} = 10^{A - \frac{B}{T+C}} = 10^{6.87601 - \frac{1171.17}{20+224.408}} = 121.4\ \text{torr}$$

where A, B, C are Antoine coefficients that vary from substance to substance and the temperature, T, is in degrees Celisius. Another form of the Antoine equation is found in the Handbook of Chemistry and Physics, which gives similar results.

$$\rho_{sat} = -\frac{0.05223a}{T} + b = -\frac{0.05223(31{,}679)}{20 + 273.15} + 7.724 = 120.2\ \text{torr}$$

where a and b are Antoine coefficients and T is in degrees Kelvin. The concentration of hexane is in units of parts per million, which means it is a volume fraction multiplied by 1,000,000. The ideal gas law tells us that the volume of a gas is simply proportional to the number of moles, so the volume fraction of any gas is just equal to its mole fraction.

$$\text{Partial pressure of solvent vapor corresponding to inlet concentration} = \rho = \frac{(500\ \text{ppm})(760\ \text{torr})}{1{,}000{,}000} = 0.38\ \text{torr}$$ (assuming atmospheric pressure is 1 atm)

$$\text{Molar volume} = \frac{RT}{P_{atmosphere}} = \frac{\left(0.08206\frac{\text{L atm}}{\text{mol K}}\right)(293.15\ \text{K})}{1\ \text{atm}} = 24.056\frac{\text{L}}{\text{mol}}$$

where T is the absolute temperature (°K = °C + 273.15) and R is the ideal gas constant.

$$C_o = \text{inlet concentration} = \frac{\left(\frac{500\,\text{ppm}}{1{,}000{,}000}\right) M_W}{\text{molar volume}} = \frac{\left(\frac{500\,\text{ppm}}{1{,}000{,}000}\right)\left(\frac{86.18\text{g}}{\text{mol}}\right)}{\left(24.056\frac{\text{L}}{\text{mol}}\right)} = 0.00179\frac{\text{g}}{\text{L}}$$

The equilibrium adsorption capacity, W_e, is estimated by

$W_e = W_o d_L \exp\left[-b' W_o P_e^{-1.8} R^2 T^2 \left(\ln(\rho/\rho_{sat})\right)^2\right]$ where b' is an empirical coefficient.

$$W_e = \left(0.454\frac{\text{cm}^3}{\text{g}}\right)\left(0.6603\frac{\text{g}}{\text{cm}^3}\right)\exp\left[-\frac{\left(3.56\text{x}10^{-5}\frac{\text{mol}^2\text{g}}{\text{cm}_o^3\text{cal}^2}\left(\frac{\text{cm}_L^3}{\text{mol}}\right)^{1.8}\right)\left(0.454\frac{\text{cm}^3}{\text{g}}\right)\left(1.987\frac{\text{cal}}{\text{mol K}}\right)^2(293.15\,\text{K})^2}{\left(29.877\frac{\text{cm}^3}{\text{mol}}\right)^{1.8}}\left(\ln\left(\frac{0.38\,\text{torr}}{121\,\text{torr}}\right)\right)^2\right]$$

$W_e = 0.199$ g/g

Note that if you reference this equation from the 1994 article, "Estimating Service Lives of Organic Vapor Cartridges" in the *American Industrial Hygiene Association Journal* (Volume 55, Number 1, pages 11-15), the units for the empirical coefficient, b, do not match the above equation. This coefficient for this equation has different units in the 1992 article, "Activated Carbon Adsorption Capacities for Vapors" (Volume 30, Number 4, pages 593-599) in the journal *Carbon*.

The linear flow velocity, V_L, for the cartridge is calculated by the following equation:

$V_L = \frac{Q}{An} = \frac{(53.3\,\text{L/min})(1000\,\text{cm}^3/\text{L})}{(39.6\,\text{cm}^2)(2)(60\,\text{sec/min})} = 11.22\,\text{cm/sec}$ where Q is the volumetric flow rate (i.e., average breathing rate)

The linear flow rate through the cartridge(s) varies directly with the worker breathing rate. If you calculate this value, be sure and account for the number of cartridges. A typical value for a moderate workrate of 60 LPM with two cartridges is about 13 cm/second.

The exit concentration, C_x, does not need to be calculated as long as the desired percentage breakthrough is known. The empirical coefficient, S_b, is dependent on the percentage breakthrough.

$$S_b = 0.063\frac{\text{min cm}^4}{\text{sec mol}} - \left(0.0058\frac{\text{min cm}^4}{\text{sec mol}}\right)\ln\left[\frac{C_o - C_x}{C_x}\right] = 0.063\frac{\text{min cm}^4}{\text{sec mol}} - \left(0.0058\frac{\text{min cm}^4}{\text{sec mol}}\right)\ln\left[\frac{100 - \text{Percentage}_{\text{breakthrough}}}{\text{Percentage}_{\text{breakthrough}}}\right]$$

$S_b = 0.036\ \frac{\text{min cm}^4}{\text{sec mol}}$ for 1% breakthrough and $0.05\ \frac{\text{min cm}^4}{\text{sec mol}}$ for 10% breakthrough

The adsorption rate coefficient, k_v, for 10% breakthrough is found by

$$k_{v10\%} = \frac{1}{\left(\frac{1}{V_L} + 0.027\frac{\text{sec}}{\text{cm}}\right)\left(0.000825\frac{\text{min cm}}{\text{sec}} + \frac{S_b}{Pe}\right)} = \frac{1}{\left(\frac{1}{11.22\frac{\text{cm}}{\text{sec}}} + 0.027\frac{\text{sec}}{\text{cm}}\right)\left(0.000825\frac{\text{min cm}}{\text{sec}} + \frac{0.05\frac{\text{min cm}^4}{\text{sec mol}}}{29.88\frac{\text{cm}^3}{\text{mol}}}\right)} = \frac{3447}{\text{min}}$$

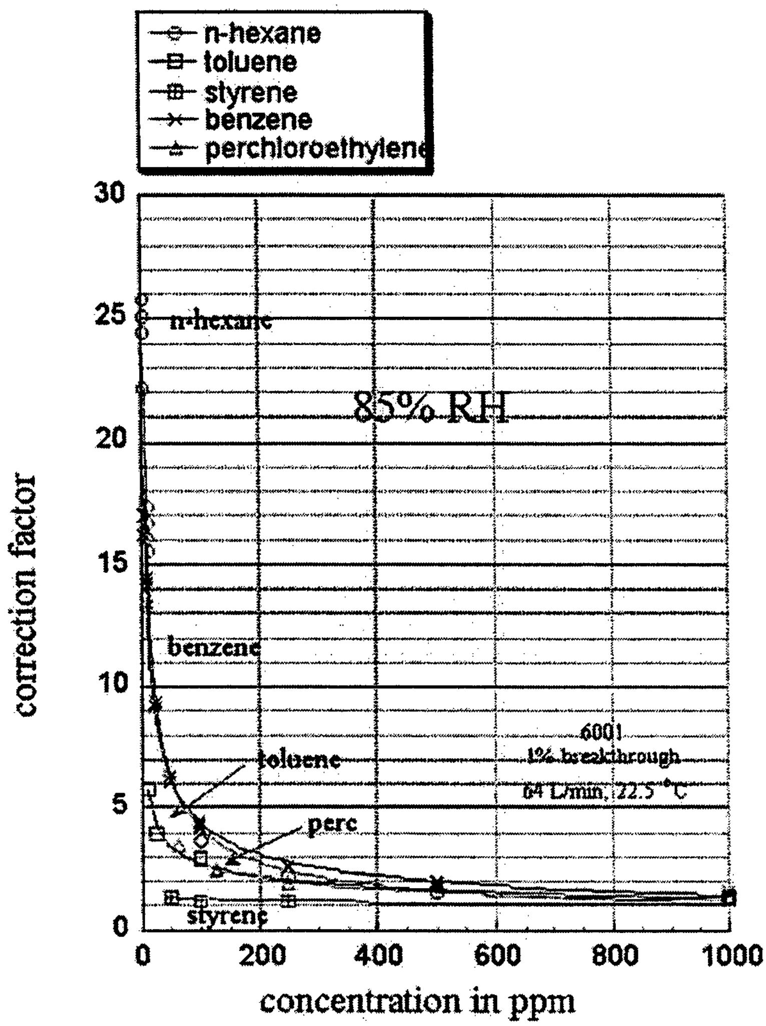
The breakthrough time is calculated by using the following equation:

$$t_{b10\%} = \frac{W_e W}{C_o Q} - \frac{W_e \rho_\beta}{k_v C_o} \ln\left(\frac{C_o - C_x}{C_x}\right) = \frac{W_e W}{C_o Q} - \frac{W_e \rho_\beta}{k_v C_o} \ln\left(\frac{100 - \text{Percentage}_{\text{breakthrough}}}{\text{Percentage}_{\text{breakthrough}}}\right)$$

$$t_{b10\%} = \frac{(0.199)(70.6\,\text{g})}{\left(0.00179\,\frac{\text{g}}{\text{L}}\right)\left(53.3\,\frac{\text{L}}{\text{min}}\right)} - \frac{(0.199)\left(0.441\,\frac{\text{g}}{\text{cm}^3}\right)}{\left(\frac{3447}{\text{min}}\right)\left(0.00179\,\frac{\text{g}}{\text{L}}\right)\left(\frac{1\,\text{L}}{1000\,\text{cm}^3}\right)} \ln\left(\frac{100\% - 10\%}{10\%}\right) = 117\,\text{min}$$

$t_{b10\%}$ = breakthrough time = 117 minutes

Attachment 8. Correction Factor versus Solvent Concentration at 85% Relative Humidity and for 1% Breakthrough



These measurements were taken by 3M with 3M (model 6001) organic vapor cartridges. For chemicals with low volatility such as styrene, the effect of high relative humidity is small. At 85% relative humidity, a correction factor of about 1.5 seems appropriate through the styrene concentration range tested. For the more volatile chemicals tested, the most significant relative humidity effect is at low concentrations. Using n-hexane as an example, at high concentrations (~ 400 ppm) the necessary correction factor for 85 % RH is about 2, whereas at low concentrations (~ 10 ppm) the service life estimate should be reduced by a factor of about 16.

Solvent Vapor Pressure	mmHg Boiling point	degrees C
n-hexane	124	69
Benzene	75	80
Toluene	21	110.6
Perchloroethylene	14	121
Styrene	5	145-146

Attachment 9. The Wood Math Model Table

The table below provides breakthrough times for chemicals at various concentrations. OSHA derived these breakthrough times from the Gerry O. Wood math model (Wood, G.O., "Estimating Service Lives of Organic Vapor Cartridges", *American Industrial Hygiene Association Journal*, 55:11-15, 1994).

OSHA used the following standard conditions:

- Relative humidity: less than or equal to 50%
- Sorbent mass per cartridge: 26 g
- Flow rate: 53.3 liters per minute
- Breakthrough: 10%
- Number of Respirator Cartridges: 2
- Temperature: 22 degrees Celsius (72 degrees Fahrenheit)
- Sorbent: Activated Charcoal

If the conditions in your case are significantly different than these, in particular relative humidity greater than 65%, you will need to make appropriate corrections to the times in the table. This table is at the following website:

http://www.osha.gov/SLTC/etools/respiratory/wood_table/wood_table.html

Name	CAS #	Contaminant Concentration (ppm)				
		50	100	200	500	1000
Aromatics						
Benzene	71-43-2	Work Shift	Limited to a maximum concentration of 50 ppm for negative pressure APR			
		See the Benzene Standard 29 CFR 1910.1028(g)				
Toluene	108-88-3	1018	562	307	135	72
Ethylbenzene	100-41-4	1133	604	319	135	70
m-Xylene	108-38-3	1143	608	321	136	70
Cumene	98-82-8	1122	586	304	126	64
Mesitylene	108-67-8	1159	603	311	128	65
p-Cymene	99-87-6	1104	566	289	117	59
Alcohols						
Methanol	67-56-1	This calculation is not applicable to this compund				
Ethanol	64-17-5	123	105	85	60	43
Isopropanol	67-63-0	425	286	186	101	61
Allyl alcohol	107-18-6	789	495	303	152	87
Propanol	71-23-8	551	364	233	123	73
sec-Butanol	78-92-2	773	464	272	130	72
Butanol	71-36-3	1073	615	345	156	84
2-Pentanol	6032-29-7	1091	601	327	143	75
3-Methyl-1-butanol	123-41-3	1242	672	358	152	78
4-Methyl-2-pentanol	108-11-2	1076	578	307	130	67
Pentanol	71-41-0	1281	690	366	155	79

2-Ethyl-1-butanol	97-95-0	1246	657	342	142	72
Monochlorides						
Methyl chloride	74-87-3	Not applicable, boiling point below ambient temperatures				
Vinyl chloride	75-01-4	Not applicable, boiling point below ambient temperatures See the Vinyl Chloride Standard 29 CFR 1910.1017(g)				
Ethyl chloride	75-00-3	Not applicable, boiling point below ambient temperatures				
2-Chloropropane	75-29-6	224	150	99	54	34
Allyl chloride	107-05-1	264	177	116	64	40
1-Chloropropane	540-54-5	492	301	181	90	52
2-Chloro-2-methylpropane	507-20-0	655	374	212	98	54
1-Chlorobutane	109-69-3	733	422	239	111	61
2-Chloro-2-methylbutane	594-36-5	705	398	222	101	55
1-Chloropentane	543-59-9	852	474	260	116	62
Chlorobenzene	108-90-7	1327	709	376	160	83
1-Chlorohexane	544-10-5	993	530	281	119	62
o-Chlorotoluene	95-49-8	1297	682	356	148	76
1-Chloroheptane	629-06-1	930	492	258	109	56
3-(Chloromethyl) heptane	123-04-6	771	410	216	92	48
Dichlorides						
Dichloromethane	75-09-2	See the Methylene Chloride Standard 29 CFR 1910.1052(g)				
trans-1,2-Dichloroethylene	156-60-5	296	198	129	71	44
1,1-Dichloroethane	75-35-4	234	157	103	57	35
cis-1,2-Dichloroethylene	156-59-2	356	236	152	82	50
1,2-Dichloroethane	107-06-2	482	310	194	101	60
1,2-Dichloropropane	78-87-5	776	452	259	121	67
1,4-Dichlorobutane	110-56-5	846	475	263	118	64
Trichlorides						
Chloroform	67-66-3	409	263	166	87	52
Methyl chloroform	71-55-6	618	366	214	102	57
Trichloroethylene	79-01-6	749	441	256	122	68
1,1,2-Trichloroethane	79-00-5	976	558	314	143	77
Tetrachlorides						
Carbon tetrachloride	56-23-5	677	398	231	109	61
Perchloroethylene	127-18-4	1106	609	331	145	77
Acetates						
Methyl acetate	79-20-9	182	131	92	55	36
Vinyl acetate	108-05-4	389	251	158	82	49
Ethyl acetate	141-78-6	483	299	182	91	53

Isopropyl acetate	108-21-4	668	386	219	102	56
Propyl acetate	109-60-4	768	438	246	112	61
Butyl acetate	123-86-4	935	508	273	118	62
Isopentyl acetate	123-92-2	1007	530	277	116	59
Pentyl acetate	628-63-7	1023	537	280	117	59
Ketones						
Acetone	67-64-1	118	92	69	44	30
2-Butanone	78-93-3	423	271	170	88	52
2-Pentanone	107-87-9	729	424	243	113	62
3-Pentanone	96-22-0	744	433	248	115	63
4-Methyl-2-pentanone	108-10-1	884	488	266	117	62
Mesityl oxide	141-79-7	1063	581	314	136	71
Cyclopentanone	120-92-3	1020	589	333	153	83
2,4-Pentanedione	123-54-6	1103	612	335	147	78
3-Heptanone	106-35-4	1061	561	294	123	63
2-Heptanone	110-43-0	791	432	234	102	54
Cyclohexanone	108-94-1	1257	683	366	157	81
Diisobutyl ketone	108-83-8	963	496	254	103	52
Alkanes						
Pentane	109-66-0	332	205	124	63	37
2,3-Dimethylbutane	79-29-8	533	307	175	82	45
Hexane	110-54-3	585	334	189	87	48
Methylcyclopentane	96-37-7	613	357	205	96	53
2,2,4-Trimethylpentane	540-84-1	747	401	214	92	48
Heptane	142-82-5	769	420	227	99	52
Methylcyclohexane	108-87-2	842	463	252	111	59
2,2,5-Trimethylhexane	3522-94-9	817	429	224	93	48
Cyclooctane	292-64-8	747	410	224	99	53
Nonane	111-84-2	907	470	242	100	51
Decane	124-18-5	902	461	234	95	48
Amines						
Methylamine	74-89-5	Not applicable, boiling point below ambient temperatures				
Dimethylamine	124-40-3	Not applicable, boiling point below ambient temperatures				
Ethylamine	75-04-7	Not applicable, boiling point below ambient temperatures				
Isopropylamine	75-31-0	167	117	80	46	30
Propylamine	107-10-8	226	155	104	59	37
Diethylamine	109-89-7	498	299	177	86	49
Butylamine	109-73-9	580	349	207	100	57
Triethylamine	121-44-8	747	412	225	100	53
Dipropylamine	142-84-7	871	474	255	111	58

Diisopropylamine	108-18-9	716	395	216	96	51
Cyclohexylamine	108-91-8	1065	575	308	132	69
Dibutylamine	111-92-2	980	507	261	107	54
Miscellaneous						
Methyl iodide	74-88-4	This calculation is not applicable to this compund				
Acrylonitrile	107-13-1	Work Shift	465	Limited to a maximum concentration of 100 ppm		
		See the Acrylonitrile Standard 29 CFR 1910.1045(h)				
Dibromomethane	74-95-3	947	565	331	158	89
Pyridine	110-86-1	1031	599	342	158	87
Epichlorohydrin	106-89-8	866	525	310	150	84
1,2-Dibromoethane	106-93-4	1252	699	384	170	90
1-Nitropropane	108-03-2	933	548	315	147	80
2-Ethoxyethanol	110-80-5	1105	624	345	154	81
Acetic anhydride	108-24-7	1095	623	348	156	83
2-Methoxyethyl acetate	32718-56-2	1092	594	319	137	71
Bromobenzene	108-86-1	1448	761	397	165	84
2-Ethoxyethyl acetate	111-15-9	1143	600	312	129	65

Attachment 10. OSHA's Example on how to use a Math Model Table

The Wood model table can be found in Attachment 7. The math models are usually only directly applicable for single contaminant exposures. If you have a multiple contaminant situation, you may need to use other methods to derive a schedule or increase the safety factors. Since the Wood model is not a descriptive model, it is suggested that you reduce the service life estimate by some safety factor to give a change schedule that you should document in your written respiratory program.

Steps	Example
1. Determine the concentration level of airborne contaminants in the work area	Grant owns a mid-size furniture company that paints with lacquers. They use a volatile solvent, toluene to quickly dry the lacquer. His several measurements of the toluene vapor reveal a worst case exposure of 200 ppm over an eight-hour day.
2. Obtain access to a predictive table that is based on research	Grant surfs to the web page on this Advisor site called Wood Model Table, which lists cartridge service lives for 120 chemicals at varying concentrations.
3. Use the table to come up with a cartridge service life estimate	Grant looks across the top of the table and finds the column for 200 ppm — the concentration equal to or above the level of toluene at his work place. Then he scrolls down the table and finds toluene in the aromatic group. He discovers that the service life estimate is 307 minutes. He writes down the number.
4. Account for differences in the real work environment and those assumptions used by the math model • humidity and temperature • breathing rate	Grant looks at the standard conditions given at the top of the table. He sees that the assumed relative humidity is 50% — much lower than the 75% humidity found in his work area. Grant is aware that such a high humidity will seriously affect organic vapor cartridge performance, so he applies a safety factor of two by cutting the estimate in half, giving him 154 minutes. The other standard conditions assumed by the table match his work environment.
5. Create a written change schedule for the cartridges	Grant applies a further safety factor to the estimate and creates a change schedule requiring his employees to turn in their used cartridges for new ones every 2 hours. He also prints a copy of the Wood Model Table and circles the 307 minute value and notes the factor applied for humidity and the safety factor reduction to 2 hours, and includes them in his written respiratory program.

Attachment 11. OSHA's Example on how to use a Math Model Equation

Mathematical equations have been used to predict the service lives of organic vapor respirator cartridges when used for protection against single contaminants. The Wood Math Model is just one equation you can use. Also, because it is a predictive type of model (as opposed to a descriptive type), you should not rely on it without some experimental confirmation of the calculation or use of appropriate safety factors.

OSHA's Advisor Genius web program will estimate the contaminant breakthrough time for an activated carbon respirator cartridge using physical and environmental parameters specific to the contaminant and the workplace. It only applies to contaminants that are liquids at the workplace temperature.

http://www.osha.gov/SLTC/respiratory_advisor/advisor_genius_wood/advisor_genius.html

Steps	Example
1. Determine the following: • Number of cartridges used by the respirator • Weight of sorbent in each cartridge in grams • Carbon micropore volume in cubic centimeters per gram • Density of the packed bed in units of grams per cubic centimeter • The maximum temperature expected in the workplace • The maximum humidity expected in the workplace • The maximum concentration of contaminants in the workplace in units of parts per million • The work-rate (volumetric flow rate) in units of liters per minute (LPM).	The lacquer-drying technique has been modified at Grant's shop, which has lowered the amount of airborne toluene to 125 ppm. While this is below the OSHA PEL, Grant still wants his painters to wear respirators. When Grant looks to the Wood table for this concentration to figure a service life estimate, he finds there is no column for 125. It gives data for 100 ppm and then jumps right up to 200 ppm. Grant understands that he must go with the 200 ppm estimate of 154 minutes to be safe, yet he thinks the cartridges should last longer than that. He determines to use the Wood calculation for his exact concentration of 125 ppm. So, Grant does a little research to come up with the required data. He calls the manufacturer to get data on its respirator cartridges.
2. Put the information from Step 1 into a mathematical equation and calculate for the unknown service life	Grant hears that the OSHA Advisor will perform the calculation for him. All he has to do is provide his information to the Advisor Genius, which asks for the data one step at a time. Grant is delighted with how easy it is, and at the end, the Genius gives him the service life estimate of 224 — 70 minutes longer than if he had used the table.
3. Apply a safety reduction to the service life estimate, create a written change schedule for the cartridges and include in written respiratory protection program.	Grant applies a safety reduction to the service life estimate and sets his change schedule at 3 hours. The Advisor Genius also offers to print out a report for Grant that can serve as the basis for written change schedule as part of the respirator program. Grant prints out the form, notes the adjustment factors and is done!

Attachment 12. How to Calculate Service Life for Mixtures

Employees in a coating line have 8-hour time-weighted average exposures to an atmosphere containing the following mixture of solvents: 100 ppm for toluene, 75 ppm for MIBK, and 100 ppm for ethyl acetate. The job is classified as light work and relative humidity in the plant is 50%. 3M 6001 organic vapor cartridges are used. What is an appropriate cartridge change schedule?

Answer:
3M Service Life software predicts the following "single substance" service times: 3,770 minutes for toluene, 3,290 minutes for MIBK, and 2,480 minutes for ethyl acetate. These values represent the times to reach 10% of the inlet concentration if the cartridges were exposed to each contaminant individually.

OSHA method (see OSHA's Compliance Directive CPL 2-0.120):
Since breakthrough times are within one order of magnitude, the concentrations of the individual contaminants are added and the total concentration is used to predict the breakthrough time:

100 ppm + 100 ppm + 75 ppm = 275 ppm

Since ethyl acetate has the shortest breakthrough time, it is assumed that the entire mixture behaves like ethyl acetate. 3M Service Life Software predicts a service time of 989 minutes (16.5 hours) for 275 ppm ethyl acetate. Changing cartridges after each normal shift appears to be appropriate.

Mole fraction method:
The mole fractions for the components of the mixture are calculated as follows:
Total ppm of mixture = 275 ppm.

- Toluene mole fraction = 100 ppm / 275 ppm = 0.36
- MIBK mole fraction = 100 ppm / 275 ppm = 0.36
- Ethyl acetate mole fraction = 75 ppm / 275 ppm = 0.27

Breakthrough times for the components as they exist in the mixture are then calculated:

Chemical	**Mole fraction**	**Single substance breakthrough time**	**Break- through time in mixture**
Toluene	0.36	3,770 min	1,360 min
MIBK	0.36	3,290 min	1,180 min
Ethyl acetate	0.27	2,480 min	670 min

This method predicts earlier breakthrough than OSHA's method (670 minutes vs. 989 minutes). Changing cartridges after each 8-hour shift still appears to be appropriate, but the margin of safety is smaller. Since there is presently little data to support either of the methods used for mixtures, sampling behind the cartridge near the end of the predicted use period is advisable to confirm that the change schedule is correct.

Attachment 13. Summary of Software Features

Company	3M	OSHA	North	AO Safety	MSA	Willson	Survivair
Availability	Run on the Web or Download to your PC	Run on the Web	Download to your PC or view table online	Download to your PC	Run on the Web	Order CD	Download to your PC
Synonyms	Yes	No	No	No	No	Yes	No
Add Additional Chemcials	Yes	Yes	Yes	No	No	No	No
Work Rate	Light = 20 lpm Moderate = 40 lpm Heavy = 60 lpm PAPR tight fitting = 185 lpm PAPR loose fitting = 250 lpm	Low = 30 lpm Moderate = 60 lpm High = 85 lpm	Slow = 30 lpm Moderate = 50 lpm Heavy =70 lpm	Light = 20 lpm Medium = 40 lpm Heavy = 60 lpm	Low = 30 lpm Moderate 60 lpm High = 85 lpm May input any value	Light = 40 lpm Moderate = 60 lpm Heavy = 90 lpm Very Heavy = 120 lpm	Slow = 30 lpm Moderate = 50 lpm Heavy = 70 lpm
Mixtures	Yes (Organics and Inorganics can be mixed)	No, user must calculate	No	No	Up to 3 chemicals	Up to 3 chemicals	No, User told how to calculate
Humidity Levels	< 65% or recommended input of correction factors available for >65%	1% to 64% 65% to 84% divide by 2 85% to 100% divide by 4	<65%, 65% to 80% divide by 1.11, >85% divide by 1.25, Correction Factor of 0%, 20%, 50%, or your input	<50%, 50% to 65% divide by 1.06, 65% to 80% divide by 1.39, 80% to 90% divide by 2	Enter any value (humidity value part of equation) No place to input correction factor	Enter any value (humidity value part of equation only for values >65%) Input any correction factor	0-65% 66% to 80% divide by 1.11 81% to 100% divide by 1.25 Input any correction factor
Temperature	Either <0, 0, 10, 20, 30, 40, 50, >50 °C (web version has less choice)	Enter a value	Enter a value	Enter a value	Enter a value	Enter a value	Enter a value
Input Atmospheric Pressure	Yes	No	No	No	Yes	No	No
Desorption (i.e., boiling point <65°C)	Warns for each material	No	Warns for each material	Warns for each material	Warns for each material	Warns for each material	Warns for each material
Estimates for Inorganic Gases	Yes	No	Yes	Yes	From table on website	Yes	Yes
OSHA Regulated Substances	Warning to see standard, no calculation	Calculation allowed, warned to see standard	Calculation allowed, no warning to see standard	Warning to see standard, no calculation	Warning to see standard, no calculation	Warning to see standard, no calculation	Calculation allowed, warned to see standard

Attachment 14. Chemical Selection per Manufacturer for Cartridge Service Life

Chemical	CAS	3M	AOSafety	Survivair	Scott	USSafety	North	MSA	OSHA	Willson	Moldex
2-Dietylaminoethanol	100-37-8	X	X	X			X	X		X	
4-Ethenyl -1-1-cyclohexene	100-40-3	X	X								
Ethylbenzene	100-41-4	X	X	X	X	X	X	X	X	X	X
Styrene Monomer	100-42-5	X	X	X			X	X		X	
Benzyl Chloride	100-44-7	X	X	X			X				
Chlorine Dioxide	10049-04-4		X	X			X			X	
Benzyl Alcohol	100-51-6	X	X					X			
Benzaldehyde	100-52-7	X	X					X			
Monomethyl Aniline	100-61-8	X	X	X			X				
Phenylhydrazine	100-63-0	X	X	X			X				
n-Ethylmorpholine	100-74-3			X			X				
Methylene Bisphenyl Isocyanate	101-68-8	X	X	X				X		X	
Phenyl Ether	101-84-8		X								
Daltogen	102-71-6	X									
sec-Butyl Acetate	105-46-4	X	X	X	X	X	X		X	X	
Ethyl Butyl Ketone	106-35-4	X	X	X	X	X	X	X	X	X	X
p-Xylene	106-42-3			X			X	X		X	
p-Cresol	106-44-5			X			X				
p-Dichlorobenzene	106-46-7			X			X	X			
o-Toluidine	106-49-0							X			
1,2-Butene Oxide	106-88-7	X	X								
1,2 Epoxybutane	106-88-8	X									
Epichlorohydrin	106-89-8	X	X	X	X	X	X		X		
Allyl Glycidyl Ether	106-92-3							X			
Ethylene Dibromide	106-93-4	X	X	X	X	X	X		X		
1,3-Butadiene	106-99-0	X	X	X			X	X			
Acrolein	107-02-8	X	X	X			X	X			
1-Propanethiol	107-03-9		X								
Allyl Chloride	107-05-1	X	X	X	X	X	X	X	X		
Ethylene Dichloride	107-06-2	X	X	X	X	X	X	X	X		
Ethylene Chlorohydrin	107-07-3	X	X	X			X	X			
Propylamine	107-10-8				X	X			X		
Acrylonitrile	107-13-1	X	X	X	X	X	X	X	X		X
Ethylenediamine	107-15-3	X	X	X			X	X		X	
Allyl Alcohol	107-18-6	X	X	X	X	X	X	X	X	X	
Propargyl Alcohol	107-19-7	X	X					X			
Chloroacetaldehyde	107-20-0	X		X				X			
Ethylene Glycol	107-21-1		X					X			
Methyl Formate	107-31-3	X	X	X			X	X			
Diisobutene	107-39-1	X	X								

Attachment 14. Chemical Selection per Manufacturer for Cartridge Service Life

Chemical	CAS	3M	AOSafety	Survivair	Scott	USSafety	North	MSA	OSHA	Willson	Moldex
Hexylene Glycol	107-41-5	X	X					X			
Methyl Propyl Ketone	107-87-9	X	X	X	X	X	X	X	X	X	
Propylene Glycol Monomethyl Ether	107-98-2	X	X					X		X	
1-Nitropropane	108-03-2	X	X	X	X	X			X		
Vinyl Acetate	108-05-4	X	X		X	X		X	X	X	
Methyl Isobutyl Ketone	108-10-1	X	X	X	X	X	X	X	X	X	
Methyl Isobutyl Carbinol	108-11-2	X	X	X	X	X		X	X	X	
Diisopropylamine	108-18-9	X	X	X	X	X	X	X	X	X	
Isopropyl Ether	108-20-3	X	X	X			X	X		X	
Isopropyl Acetate	108-21-4	X	X	X	X	X	X	X	X	X	
Isopropenyl Acetate	108-22-5				X	X			X		
Acetic Anhydride	108-24-7	X	X	X	X	X	X	X	X	X	
m-Xylene	108-38-3			X	X	X	X	X	X		X
m-Cresol	108-39-4			X			X				
m-Aminotoluene	108-44-1	X	X								
1-Methoxy-2-propylacetate	108-65-6	X									
1,3,5-Trimethylbenzene	108-67-8		X		X	X		X	X	X	
Diisobutyl Ketone	108-83-8	X	X	X	X	X	X	X	X	X	
sec-Hexyl Acetate	108-84-9			X			X			X	
Bromobenzene	108-86-1				X	X			X		
Methylcyclohexane	108-87-2	X	X	X	X	X	X	X	X		
Toluene	108-88-3	X	X	X	X	X	X	X	X	X	X
4+A176-Methyl-pyridine	108-89-4	X	X								
Chlorobenzene	108-90-7	X	X	X	X	X	X	X	X	X	X
Cyclohexylamine	108-91-8	X	X		X	X		X			
Cyclohexanol	108-93-0	X	X	X			X	X		X	
Cyclohexanone	108-94-1	X	X	X	X	X	X	X		X	X
Phenol	108-95-2							X		X	
Phenyl Mercaptan	108-96-5							X		X	
Benzenethiol	108-98-5	X	X								
3-Methyl-pyridine	108-99-6	X	X								
2-Methyl-pyridine	109-06-8	X	X								
n-Propyl Acetate	109-60-4	X	X	X	X	X	X	X	X	X	
Pentane	109-66-0	X	X	X	X	X	X	X	X		
1-Chlorobutane	109-69-3				X	X					
n-Butylamine	109-73-9	X	X	X	X	X		X	X	X	X
Butyl Mercaptan	109-79-5	X	X	X			X	X		X	
2-Methoxyethanol	109-86-4	X	X	X	X	X	X	X	X		X
Methylal	109-87-5	X	X	X			X				
Diethylamine	109-89-7	X	X	X	X	X		X	X	X	

Attachment 14. Chemical Selection per Manufacturer for Cartridge Service Life

Chemical	CAS	3M	AOSafety	Survivair	Scott	USSafety	North	MSA	OSHA	Willson	Moldex
Ethyl Formate	109-94-4	X	X	X			X	X			
Tetrahydrofuran	109-99-9	X	X	X			X	X		X	
Methyl Isoamyl Ketone	110-12-3	X	X	X			X	X		X	
Isobutyl Acetate	110-19-0	X	X	X			X			X	
Methyl n-Amyl Ketone	110-43-0	X	X	X	X	X	X	X	X	X	X
2-Methoxyethylacetate	110-49-6				X	X					X
Hexane (n-hexane)	110-54-3	X	X	X	X	X	X	X	X	X	
1,4-Dichlorobutane	110-56-5				X	X			X		
n-Valeraldehyde	110-62-3	X	X					X			
1-Pentanethiol	110-66-7		X								
2-Ethoxyethanol	110-80-5	X	X	X	X	X	X	X	X		X
Cyclohexane	110-82-7	X	X	X	X	X	X	X	X	X	
Cyclohexene	110-83-8	X	X	X	X	X	X	X		X	X
Pyridine	110-86-1	X	X	X	X	X	X	X	X	X	
Hexahydropyridine	110-89-4	X	X								
Morpholine	110-91-8	X	X	X			X	X		X	
Chlorodiphenyl (54% Chlorine)	11097-69-1			X			X				
2-Ethoxyethyl Acetate	111-15-9	X	X	X	X	X		X	X	X	X
Glutaraldehyde	111-30-8	X	X					X			
hexanethiol	111-31-9		X								
Diethylene Triamine	111-40-0	X	X								
Diethanolamine	111-42-2							X			
Dichloroethyl Ether	111-44-4							X			
Diethylene Glycol	111-46-6	X	X					X			
Octane	111-65-9	X	X	X			X	X		X	
Addipic Acid Dinitrile	111-69-3	X	X								
2-Butoxyethanol	111-76-2	X	X	X			X	X		X	
Nonane	111-84-2	X	X		X	X		X	X		X
1-Octanol	111-87-5	X	X					X			
Diethylene Glycol Monoethyl Ether	111-90-0	X	X					X			
Dibutylamine	111-92-2	X	X		X	X		X	X		
N, N'-bis(2-aminoethyl)-1,2,ethane diamine	112-24-3	X									
1-Dodecanethiol	112-55-0		X								
1,2,4-Trichlorobenzene	120-82-1	X	X					X			
Cyclopentanone	120-92-3				X	X			X		
Triethylamine	121-44-8	X	X	X	X	X	X	X	X		
Dimethylaniline	121-69-7	X	X	X			X	X		X	
Phenyl Glycidyl Ether	122-60-1			X			X				
3-(Chloromethyl) heptane	123-04-6				X	X			X		
Butyrane	123-19-3	X	X								

Attachment 14. Chemical Selection per Manufacturer for Cartridge Service Life

Chemical	CAS	3M	AOSafety	Survivair	Scott	USSafety	North	MSA	OSHA	Willson	Moldex
3-Methyl-1-butanol	123-41-3								X		
Diacetone Alcohol	123-42-2	X	X	X			X	X		X	
Isoamyl Alcohol	123-51-3	X	X	X	X	X	X	X		X	
2,4-Pentanedione	123-54-6				X	X			X		
Butylaldehyde	123-72-8	X	X					X			
n-Butyl Acetate	123-86-4	X	X	X	X	X	X	X	X	X	
Dioxane	123-91-1	X	X	X			X	X			
Isoamyl Acetate	123-92-2	X	X	X	X	X	X	X	X	X	
Di-2-propenylamine	124-02-7	X									
Decane	124-18-5				X	X			X		
Dimethylamine	124-40-3				X	X			X	X	X
Isoprene Cyanide	126-98-7	X	X								
beta-Chloropicrin	126-99-8	X	X	X			X	X			
Tetrachloroethylene	127-18-4	X	X	X	X	X	X	X	X	X	
Dimethyl Acetamide	127-19-5	X	X	X			X	X			
Xylidene	1300-73-8			X			X			X	
Dimethylphthalate	131-11-3	X	X	X			X				
Cresol, all isomers	1319-77-3	X	X					X		X	
Divinyl Benzene	1321-74-0	X	X								
Dimethylbenzene (o-, m-, p-isomers)	1330-20-7	X	X								
Hexachloronaphthale	1335-87-1			X			X				
Acetic Acid Benzyl Ester	140-11-4	X	X								
Ethyl Acrylate	140-88-5	X	X	X			X	X		X	
Butyl Acrylate	141-32-2	X	X					X			
Ethanolamine	141-43-5	X	X	X			X	X		X	
Ethyl Acetate	141-78-6	X	X	X	X	X	X	X	X	X	
Mesityl Oxide	141-79-7	X	X	X	X	X	X	X	X	X	
Heptane	142-82-5	X	X	X	X	X	X	X	X	X	X
Dipropylamine	142-84-7				X	X			X		
Hexyl Acetate	142-92-7				X	X			X		
1-Decanethiol	143-10-2		X								
Ethyleneimine	151-56-4	X						X			
2-Bromo-2-chloro-1,1,1-trifluoroethane	151-67-7	X	X								
cis-1,2-Dichloroethylene	156-59-2				X	X			X		
trans-1,2-Dichloroethylene	156-60-5				X	X			X		
5-Ethylidene-2-norbornene	16219-75-3				X	X			X		
Methyl tert-Butyl Ether	1634-04-4	X	X					X			
1,1-Dichloro-1-fluoroethane	1717-00-6	X									
n-Butyl Glycidyl Ether	2426-08-6			X			X				
Vinyl Toluene	25013-15-4	X		X			X	X			

Attachment 14. Chemical Selection per Manufacturer for Cartridge Service Life

Chemical	CAS	3M	AOSafety	Survivair	Scott	USSafety	North	MSA	OSHA	Willson	Moldex
Trimethyl Benzene,Mixed Isomers	25551-13-7	X	X					X			
Methylcyclohexanol	25639-42-3			X			X				
Cyclopentane	287-92-3	X	X					X			
Cyclooctane	292-64-8				X	X			X		
2,2-dichloro-1,1,1-trifluoroethane	306-83-2	X									
2-Methyoxyethyl acetate	32718-56-2								X		
Diazomethane	334-88-3			X			X				
2,2,5-Trimethylhexane	3522-94-9				X	X			X		
Isopropyl Glycidyl Ether	4016-14-12			X			X				
Isophorone Diisocyanate	4098-71-9	X									
Crotonaldehyde	4170-30-3	X	X					X			
Formaldehyde	50-00-0	X	X	X			X	X			
2-Chloro-2-methylpropane	507-20-0				X	X			X		
Tetranitromethane	509-14-8	X	X	X			X				
alpha-Chloroacetophenone	532-27-4			X			X				
Chlorodiphenyl (42% Chlorine)	53469-21-9			X			X				
1-Chloropropane	540-54-5				X	X			X		
1,2-Dichloroethylene	540-59-0	X	X	X				X		X	
2,2,4-Trimethylpentane	540-84-1				X	X			X		
tert-Butyl Acetate	540-88-5	X	X					X	X		
Nicotine	54-11-5						X				
5-Methyl-3-Heptanone	541-85-5			X	X	X			X	X	
1,3-cis, trans Dichloropropene	542-75-6				X	X					
bis-Chloromethyl Ether	542-88-1	X	X					X			
Cyclopentadiene	542-92-7	X	X	X			X	X			
1-Chloropentane	543-59-9				X	X			X		
1-Chlorohexane	544-10-5				X	X			X		
1,3,5-Cycloheptatriene	544-25-2				X	X			X		
Glyceryl Trinitrate	55-63-0	X	X	X							
Glycidol	556-52-5	X	X	X			X	X			
Carbon Tetrachloride	56-23-5	X	X	X	X	X	X	X	X	X	
Methyl Isopropyl Ketone	563-80-4	X	X					X			
1,2-Propylene Glycol	57-55-6	X	X					X			
beta-Propiolactone	57-57-8	X	X					X			
o-Methylcyclohexanone	583-60-8			X							
Toluene-2,4-Diisocyanate	584-84-9	X	X	X				X		X	
4-Methylcychexanone	589-92-4				X	X			X		
Methyl-3-cyclohexanone	591-24-2				X	X					
Methyl Butyl Ketone	591-78-6	X	X	X			X	X		X	
Allyl Chloride	591-87-7				X	X			X		

Attachment 14. Chemical Selection per Manufacturer for Cartridge Service Life

Chemical	CAS	3M	AOSafety	Survivair	Scott	USSafety	North	MSA	OSHA	Willson	Moldex
Butyl Ethylene	592-41-6	X									
1,5-Hexadiene	592-42-7							X			
1,4-Hexadiene	592-45-0	X	X								
2-Chloro-2-methylbutane	594-36-5				X	X			X		
Perchloromethyl Mercaptan	594-42-3			X			X				
Cajeputene	5989-27-5	X									
1-Chloro-1-Nitropropane	600-25-9			X							
2-Hydroxy-1-ethanethiol	60-24-2	X	X								
Ethyl Ether	60-29-7	X	X	X			X	X		X	
2-Pentanol	6032-29-7				X	X			X	X	
Methyl Isocyanate	624-83-9	X	X	X			X	X			
Aniline	62-53-3	X	X	X			X	X			
3-Methylcyclohexanone	625-96-7								X		
sec-Amyl Acetate	626-38-0			X			X			X	
n-Amyl Acetate	628-63-7	X	X	X	X	X	X	X	X	X	
1-Chloroheptane	629-06-1				X	X			X		
Ethyl Alcohol	64-17-5	X	X	X	X	X	X		X		
Formic Acid	64-18-6	X	X	X			X	X			
Acetic Acid	64-19-7	X	X	X			X	X		X	
Methyl Alcohol	67-56-1	X	X	X	X	X	X		X	X	
Isopropyl Alcohol	67-63-0	X	X	X	X	X	X	X	X	X	
Acetone	67-64-1	X	X	X	X	X	X	X	X	X	X
Chloroform	67-66-3	X	X	X	X	X		X	X	X	
Dimethylformamide	68-12-2	X	X	X			X	X			
cis-1,2-Dichloropropene	6923-20-2								X		
trans-1,2-Dichloropropene	7069-38-7								X		
n-Propyl Alcohol	71-23-8	X	X	X	X	X	X	X	X	X	
n-Butyl Alcohol	71-36-3	X	X	X	X	X	X	X	X	X	
Pentanol	71-41-0				X	X			X		
Benzene	71-43-2	X	X	X	X	X	X	X	X		X
1,1,1-Trichloroethane	71-55-6	X		X	X	X	X	X	X		
Sulfur Dioxide	7446-09-5	X	X	X			X			X	
Methyl Chloride	74-87-3				X	X			X	X	
Methyl Iodide	74-88-4		X	X	X	X	X		X		
Methyamine	74-89-5	X	X	X	X	X	X		X	X	X
Dibromomethane	74-95-3				X	X			X		
Ethyl Bromide	74-96-4	X	X	X			X	X			
Chlorobromomethane	74-97-5	X	X	X			X	X			
Methyl Acetylene	74-99-7						X				
Ethyl Chloride	75-00-3			X	X	X	X		X		

Attachment 14. Chemical Selection per Manufacturer for Cartridge Service Life

Chemical	CAS	3M	AOSafety	Survivair	Scott	USSafety	North	MSA	OSHA	Willson	Moldex
Vinyl Chloride	75-01-4	X	X	X	X	X	X		X		
Ethylamine	75-04-7				X	X			X		
Acetonitrile	75-05-8	X	X	X			X	X			
Acetaldehyde	75-07-0	X	X	X			X	X		X	
Ethyl Mercaptan	75-08-1	X	X	X				X			
Methylene Chloride	75-09-2	X	X	X	X	X	X	X	X		
Formamide	75-12-7	X	X								
Carbon Disulfide	75-15-0	X	X	X			X	X		X	
Ethylene Oxide	75-21-8	X	X	X			X				
Bromoform	75-25-2	X	X	X							
2-Chloropropane	75-29-6				X	X			X		
Isopropylamine	75-31-0	X	X	X	X	X	X	X	X	X	
1,1-Dichloroethane	75-34-3	X	X	X	X	X	X	X			
Vinylidene Chloride	75-35-4	X	X					X	X		
Dichloromonofluoromethane	75-43-4							X			
Nitromethane	75-52-5	X	X	X			X				
Propylene Imine	75-55-8	X		X			X				
Propylene Oxide	75-56-9	X	X	X			X				
Difluorodibromomethane	75-61-6	X	X	X			X	X			
tert-Butyl Alcohol	75-65-0	X	X	X				X		X	
Trichlorofluoromethane	75-69-4			X			X				
Acetone Cyanohydrin	75-86-5	X	X					X			
Pentachloroethane	76-01-7				X	X			X		
Chlorpicrin	76-06-2	X	X	X			X	X		X	
1,1,1,2-Tetrachloro-2,2-Difluoroethane	76-11-9			X			X				
1,1,2,2-Tetrachloro-1,2-Difluoroethane	76-12-0	X	X	X			X	X			
Trifluoroethane (Refrig. 113)	76-13-1	X	X	X			X				
2-Butylenedichloride	764-41-0	X									
Hydrogen Chloride	7647-01-0		X	X			X			X	
Hydrogen Fluoride	7664-39-3	X	X	X			X			X	
Ammonia	7664-41-7	X	X	X			X			X	
Hexachlorocyclopentadiene	77-47-4	X	X								
Dimethylsulfate	77-78-1	X	X	X			X				
Chlorine	7782-50-5		X	X			X			X	
Hydrogen Sulfide	7783-06-4	X	X	X			X				
Lead tetraethyl	78-00-2	X	X	X							
Ethyl Silicate	78-10-4			X			X	X			
Isophorone	78-59-1	X	X	X			X	X		X	
Isoprene	78-79-5	X	X								
Isobutyronitrile	78-82-0		X								

Attachment 14. Chemical Selection per Manufacturer for Cartridge Service Life

Chemical	CAS	3M	AOSafety	Survivair	Scott	USSafety	North	MSA	OSHA	Willson	Moldex
Isobutyl Alcohol	78-83-1	X	X	X			X			X	
1,2-Dichloropropane	78-87-5	X	X	X	X	X	X	X	X	X	
sec-Butyl Alcohol	78-92-2	X	X	X	X	X		X	X	X	
Methyl Ethyl Ketone	78-93-3	X	X	X	X	X	X	X	X	X	
1,1,2-Trichloroethane	79-00-5	X	X	X	X	X	X	X	X		
Trichloroethylene	79-01-6	X	X	X	X	X	X	X	X		
Chloracetylchloride	79-04-9	X	X								
Acrylamide	79-06-1			X			X				
Propionic Acid	79-09-4	X	X					X			
Acrylic Acid	79-10-7	X	X					X			
Methyl Acetate	79-20-9	X	X	X	X	X	X	X	X	X	X
Nitroethane	79-24-3	X	X	X			X				
Acetylene Tetrabromide	79-27-6	X	X	X			X	X			
2,3-Dimethylbutane	79-29-8				X	X			X		
1,1,2,2-Tetrachloroethane	79-34-5	X	X	X	X	X	X	X	X		
a-Methacrylic Acid	79-41-4	X	X								
2-Nitropropane	79-46-9	X	X	X			X				
Petroleum Distillates (Naphtha)	8002-05-9			X			X				
Turpentine	8006-64-2			X			X				
Cumene Hydroperoxide	80-15-9	X									
Naphtha, Coal Tar	8030-30-6			X			X			X	
V, M & P Naphtha	8032-32-4									X	
Stoddard Solvent	8052-41-3									X	
Methyl Methacrylate	80-62-6	X	X	X			X	X		X	
Hexamethylene diisocyanate	822-06-0	X	X							X	
Dibutyl Phthalate	84-74-2	X	X	X			X				
n-Methyl Pyrrolidone	872-50-4	X									
Hexachloro-1,3-butadiene	87-68-3	X	X								
o-Nitrotoluene	88-72-2	X	X	X			X	X			
o-Anisidine	90-04-0			X			X				
Naphthalene	91-20-3							X		X	
1-Azana-phtalene	91-22-5	X	X								
Chlorocyclopentane	930-28-9				X	X			X		
Benzoyl Peroxide	94-36-0			X			X				
Indene	95-13-6	X	X					X			
o-Xylene	95-47-6			X			X	X		X	
o-Cresol	95-48-7						X				
o-Chlorotoluene	95-49-8	X	X	X				X	X		
o-Dichlorobenzene	95-50-1	X	X	X	X	X		X	X	X	
o-Toluidine	95-53-4	X	X	X			X				

Attachment 14. Chemical Selection per Manufacturer for Cartridge Service Life

Chemical	CAS	3M	AOSafety	Survivair	Scott	USSafety	North	MSA	OSHA	Willson	Moldex
1,2,4-Trimethylbenzene	95-63-6		X								
Dibromochloropropane	96-12-8	X	X	X			X				
1,2,3-Trichloropropane	96-18-4	X	X	X	X	X	X	X	X		
Diethyl Ketone	96-22-0	X	X		X	X		X	X		
Methyl Acrylate	96-33-3	X	X	X			X	X		X	
Methylcyclopentane	96-37-7				X	X			X		
2-Ethyl-1-butanol	97-95-0				X	X			X		
Tetrahydro-2-furancarbinol	97-99-4	X									
Furfuryl Alcohol	98-00-0	X	X	X			X	X		X	
Furfural	98-01-1	X	X	X			X	X			
Benzenylchloride	98-07-7	X									
p-tert-Butyltoluene	98-51-1			X			X	X			
Cumene	98-82-8	X	X	X	X	X	X	X	X	X	X
alpha-Methyl Styrene	98-83-9	X	X	X				X			
Acetophenone	98-86-2		X					X			
Benzene Carbonyl Chloride	98-88-4	X	X		X	X					
Nitrobenzene	98-95-3	X	X	X			X	X		X	
Nitrotoluene (m-isomer)	99-08-1		X								
p-Cylene	99-87-6				X	X			X		
Total		**226**	**222**	**188**	**120**	**120**	**169**	**168**	**118**	**103**	**22**

Attachment 15. Comparision of Software Programs Breakthrough Times

Chemical	CAS	2 x OEL	3M	AOSafety	Willson	Survivair	MSA	North	OSHA
Acetone	67-64-1	1000	1.9	1.5	2.3	2.5	2.6	1	1
n-Butyl Acetate	123-86-4	300	10.7	10.1	11.7	14.4	12	6.9	5.3
Cumene	98-82-8	100	32.5	30.9	25.5	38	36.7	18.1	16.3
Cyclohexane	110-82-7	600	5.1	4.6	6.2	6.2	5.9	2.8	2.7
Ethyl Acetate	141-78-6	800	3.7	3.2	5.3	5	4.2	2.2	1.9
Ethylbenzene	100-41-4	200	17.8	16.7	16.8	22.4	20	10.7	8.9
Ethyl Butyl Ketone	106-35-4	100	31.1	29.3	27.4	40.9	33.3	19.8	15.7
Hexane	110-54-3	100	18.4	16.1	20.1	24.7	23.9	11.2	10.1
Isoamyl Acetate	123-92-2	200	15.2	29.4	14.1	20.6	17.1	10.1	7.7
Isopropyl Acetate	108-21-4	500	5.8	5.2	7	17.1	6.7	3.7	3
Methyl Ethyl Ketone	78-93-3	400	6.1	5.2	9.8	7.7	7.7	3.1	3.3
Methyl n-Amyl Ketone	110-43-0	100	31.2	29.5	30.4	44.7	84.1	20.7	12.5
Methyl Isobutyl Ketone	108-10-1	100	27.4	25.1	29.2	35.8	29.8	16.7	14.1
n-Propyl Acetate	109-60-4	400	7.8	7.1	9.8	10.4	6.8	4.9	4
Toluene	108-88-3	100	31.4	28.6	29.5	33.4	29.2	15.1	16.3

The above breakthrough times are in units of hours.

Model of Organic Vapor Cartridge	6001	8051	T01	100100	Comfo GMA	N-7500-1	Default
Relative Humidity	<65%	<50%	0%	0% to 65%	0%	<65%	1%
Breathing Rate (lpm)	40	40	40	30	30	30	30

Temperature: 68°F (20°C)

Atmospheric Pressure: 1 atm

The Occupational Exposure Limit (OEL) in the table is the smaller value of either the ACGIH TLVs or OSHA PELs.

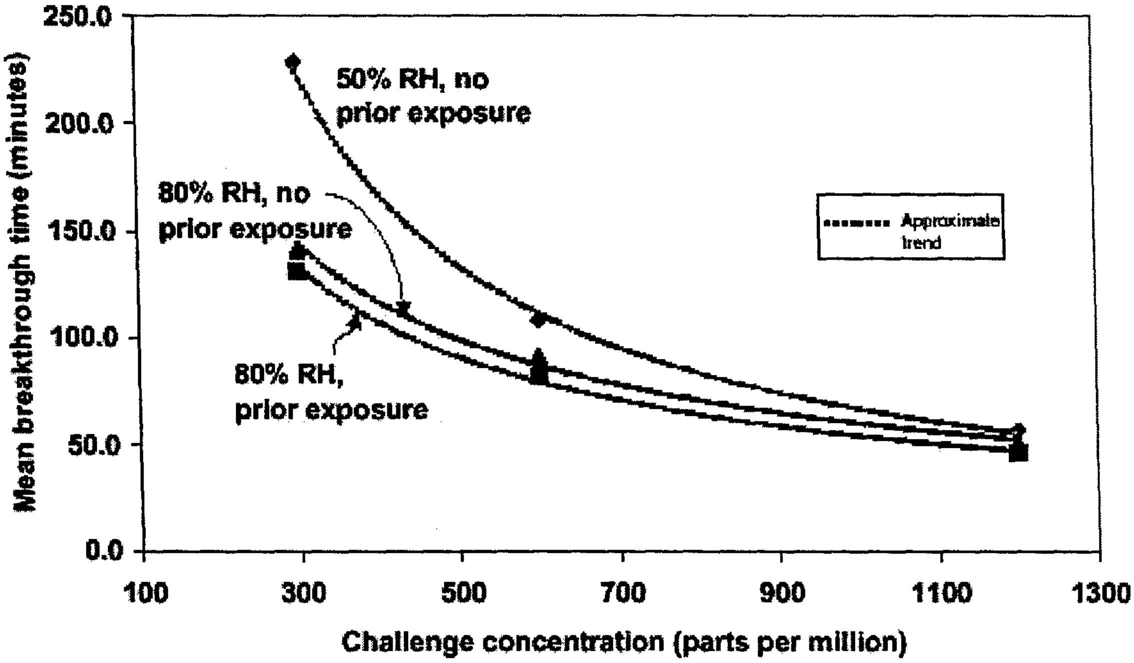
Breakthrough: 10% of input concentration (Some programs only allow selection of a percentage of the exposure limit. In these cases the percentage of the exposure limit inputed was computed to be equivalent to 10% of input concentration.)

No correction factors were selected for the above results.

The default values of cartridge properties in OSHA's "Advisor Genius" were selected.

Caution: From this table alone, do not draw the conclusion that one cartridge is better than another. The purpose of the table to show the variability of breakthrough times among the programs for similar conditions. Only comparision to experimental results can show the accuracy and precision of the calculated results.

Attachment 16. Estimated Service Life for Cartridges Exposed to JP-8



(a) Vapor concentration less than 300 ppm	Breakthrough time		
Desired change-out concentration	Below 50% relative humidity	50-80% relative humidity	Above 80% relative humidity or temp above 85 °F
7 ppm (1/2 of proposed TLV®)	2 ½ hrs	1 hr	45 min.
25 ppm (1/2 of USAF OEL)	3 ¼ hrs	2 hrs	1 ½ hrs.

(b) Vapor concentration 300 to 600 ppm	Breakthrough time		
Desired change-out concentration	Below 50% relative humidity	50-80% relative humidity	Above 80% relative humidity or temp above 85 °F
7 ppm (1/2 of proposed TLV®)	1 hr	35 min.	20 min.
25 ppm (1/2 of USAF OEL)	1 ¼ hrs	1 hr	45 min.

(c) Vapor concentration 600 to 1200 ppm	Breakthrough time		
Desired change-out concentration	Below 50% relative humidity	50-80% relative humidity	Above 80% relative humidity or temp above 85 °F
7 ppm (1/2 of proposed TLV®)	35 min.	30 min.	20 min.
25 ppm (1/2 of USAF OEL)	40 min.	30 min.	20 min.

Estimates are based upon the service life tested under laboratory conditions with 32 lpm through each cartridge (equivalent to 64 lpm airflow through each set of cartridges). All cartridges were preconditioned at 80% relative humidity and 25°C for six hours. (Note that these tests were conducted when the OEL for JP-8 was 52 ppm).

Reference: Culp, K. W.: *Determining Organic Vapor Cartridge Breakthrough Characteristics of JP-8 During Aircraft Fuel Tank Entry Operations*, thesis at West Virginia University, Morgantown, West Virginia, (2000).

Attachment 17. Cartridge Properties

	Carbon Micropore Volume (cm^3/gm)	Weight of Sorbent in Cartridge (gm)	Sorbent Bulk Density (gm/cm^3)	Diameter of Sorbent Bed (cm)
MSA Comfo GMA	0.75	37	0.4	7.4
MSA Comfo GMC	0.55	48	0.51	7.4
MSA Comfo GME	0.35	72	0.62	7.4
MSA Advantage GMA	0.75	41	0.4	8.0
MSA Advantage GMC	0.55	52	0.51	8.0
MSA Advantage GME	0.35	75	0.62	8.0
North N7500-1	0.604	83.4	0.444	7.52
North N7500-3	0.49	93.8	0.5	7.52
North 75SC	0.346	140.6	0.59	7.52
Moldex 8100	?	36.7	?	7.85
Moldex 8600	?	28	?	7.85
Scott Organic Vapor Cartridges*	0.78	110	0.87	7.95
OSHA Default Values**	0.4	26	0.4	7

* The values for the Scott Cartridges apply to all the models listed below:
- TC-23C-219 organic vapor only, full facepiece,air-purifying respirator
- TC-84A-2711 organic vapor / P100, full facepiece, air-purifying respirator
- TC-84A-2858 organic vapor / N95, full facepiece, air-purifying respirator
- TC-23C-780 organic vapor only, half facepiece, air-purifying respirator
- TC-84A-2712 organic vapor / P100, half facepiece, air-purifying respirator
- TC-84A-2855 organic vapor / N95, half facepiece, air-purifying respirator

** The OSHA Default value of 7 cm for the diameter was calculated based on its default value of 13 cm/sec for the linear flow rate at a breathing rate of 60 lpm.

References:

http://www.moldex.com/images/PDFs/CARTRIDGE.pdf
http://www-nehc.med.navy.mil/ih/Respirator/ChangeSchedule.htm
http://warranty.msanet.com/safetyproducts/resptest/index.html
http://www.osha.gov/SLTC/respiratory_advisor/advisor_genius_wood/calcframe.html