Technical Data Bulletin

OH&ESD

#180–Determination of Service Life for NIOSH CBRN approved 3M™ Cartridges and Canisters

Published: September, 2007

Background
In April 2000, NIOSH entered into a Memorandum of Understanding with the National Institute for Standards and Technology (NIST), the Occupational Safety and Health Administration (OSHA), and the National Fire Protection Association (NFPA) to work on the development of standards for all types of counter-terrorism respiratory protective equipment. NIOSH and NIST initiated Interagency Agreements with U.S. Army Research Development and Engineering Command (RDECOM) for development of respiratory protection standards, test procedures and laboratory support. As of July 2007 NIOSH has developed voluntary CBRN respirator standards for air purifying respirators (APR), air purifying escape respirators (APER), powered air purifying respirators (PAPR), and self contained breathing apparatus (SCBA). The most recent standard is the CBRN PAPR standard which was released in October of 2006.

NIOSH initiates these voluntary approval programs pursuant to Title 42, Code of Federal Regulations, 84.60(b), 84.63(c), and 84.110(c). These sections provide NIOSH with the authority to issue approvals for respirators not specifically addressed in Part 84 and to develop additional requirements that the agency determines are "necessary to establish the quality, effectiveness and safety of any respirator used as protection against hazardous atmospheres."

Canister versus Cartridge
NIOSH set test criteria for CBRN approvals of cartridges and canisters in the APR and PAPR CBRN standards. Cartridge approval (23C) is given to loose fitting PAPRs and may be used for escape from *up to* IDLH concentrations assuming >19.5% oxygen is present.

Canister (14G) approval is given to CBRN APRs and tight fitting PAPRs and may be used for escape from *greater than* IDLH concentrations assuming >19.5% oxygen is present.

NIOSH approves CBRN PAPR cartridges and canisters by challenging them with CBRN Standard test agent concentrations at a pre-selected time of 15, 30, 45 or 60 minutes. These selected times are classified as CAP 1 (15 minutes), CAP 2 (30 minutes), CAP 3 (45 minutes) and CAP 4 (60 minutes). In order to receive a CAP 1 approval on a canister or cartridge it must not exceed breakthrough concentrations when challenged for a minimum of 15 minutes.

CAP 1 versus CAP 2 versus CAP 3 etc…
CAP 1 approved canisters/cartridges must provide at least 15 minutes of capacity while challenged with the NIOSH test agents. CAP 2 must provide 30 minutes, CAP 3 must provide 45 minutes and CAP 4 must provide 60 minutes. With regard to selection of canisters/ cartridges, CAP 3 offers more capacity than CAP 2 which offers more capacity than CAP 1. However, more capacity generally means a heavier cartridge. It is important to understand that laboratory gas challenges do not correlate to real world use conditions, for example the challenge concentrations of the NIOSH test agents are often 2–3 times IDLH concentrations. Therefore, a cartridge or canisters that provides 15 minutes of capacity at very high concentrations may provide more than enough capacity for real world exposures which are typically exposures to lower concentrations for longer periods of time.

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Cartridge and Canister Test Conditions
CBRN APR Canister gas life tests are performed at room temperature, 25 ± 5°C (77 ± 9°F) and two relative humidity's: 25 ± 5 percent relative humidity and 80 ± 5 percent relative humidity. Canisters are tested at each specified humidity with a flow rate of 64 liters per minute (lpm) continuous flow. In addition, canisters must provide a service life of 5 minutes when tested at a flow rate of 100 liters per minute, 50 ± 5 percent relative humidity and 25 ± 5°C (77 ± 9°F) for each of the test agents at the Canister Test Challenge and Test Breakthrough Concentrations.

CBRN PAPR Cartridges and Canisters capacity tests are performed at room temperature, 25°C ± 2.5°C; and at 25% ± 2.5% relative humidity and 80% ± 2.5% relative humidity. Three canisters are tested at each specified humidity. Canister test times shall be identified in 15-minute intervals (15 minutes, 30 minutes, 45 minutes). For a service life of 60 minutes or greater, applications shall be identified in 30-minute intervals (60 minutes, 90 minutes, 120 minutes). Canister capacity testing is tested at a flow rate of 115 lpm and cartridge capacity testing is tested at a flow rate of 170 lpm. The flow rates are divided by the least number of canisters/cartridges used on any configuration of the system for which approval is sought. Cartridge and canister capacity testing is performed following the durability conditioning.

Canister and Cartridge Test Challenge and Test Breakthrough Concentrations

	Canister		Cartridge	
Test Chemical	Test Concentration (ppm)	Breakthrough Concentration (ppm)	Test Concentration (ppm)	Breakthrough Concentration (ppm)
Ammonia	2,500	12.5	1,250	12.5
Cyanogen chloride	300	2	150	2
Cyclohexane	2,600	10	1,300	10
Formaldehyde	500	1	250	1
Hydrogen cyanide	940	4.7*	470	4.7*
Hydrogen sulfide	1,000	5.0	500	5.0
Nitrogen dioxide	200	1 ppm NO_2 or 25 ppm NO†	100	1 ppm NO_2 or 25 ppm NO†
Phosgene	250	1.25	125	1.25
Phosphine	300	0.3	150	0.3
Sulfur dioxide	1,500	5	750	5

* Sum of HCN and C_2N_2

† Nitrogen Dioxide breakthrough is monitored for both NO_2 and NO. The breakthrough is determined by which quantity, NO_2 or NO, reaches breakthrough first.

How did NIOSH determine the 10 test chemicals?
One of the challenges NIOSH faced in developing the CBRN respiratory protection standards was determining test chemicals to challenge the cartridge/canister. NIOSH approached this challenge by deriving a list of toxic industrial chemicals (TICs) and toxic industrial materials (TIMs) and chemical warfare agents from a comprehensive review of available technical data and government agencies. This review established 151 TICs and TIMs that included chemical warfare agents. The initial list was reduced from 151 to 139 substances. In an effort to reduce the number of certification tests necessary for the CBRN standard, 139 respiratory hazards were categorized into families. Test representative agent(s) (TRA) were then determined for each family. TRAs are, in essence, surrogates representing the family of compounds.

Toxic Industrial Chemicals/Materials (TIC/TIM) Breakdown and Test Representative Agents (TRA) by Family

Family	Number of Compounds	TRA
Organic vapor family with vapor pressures less than that of cyclohexane	61	Cyclohexane
Acid gas family	32	SO2, H2S, CNCl, $COCl_2$, HCN
Base gas family	4	Ammonia
Hydride family	4	Phosphine
Nitrogen oxide family	5	Nitrogen dioxide
Formaldehyde family (only member of family)	1	Formaldehyde
Particulate family	32	DOP

Biological and radiological agents were addressed as part of the particulate agent family and require P-100 (PAPR High Efficiency Filter) media.

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Determination of CBRN Cartridge and Canister Service Life for Organic Vapors

One of the many challenges facing first responders and first receivers is estimating the service life of their respiratory canisters/cartridges. By using the NIOSH CBRN Test Representative Agents as surrogates for service life calculations, it is possible to estimate service life of cartridges and canisters for various concentrations of hazardous compound families.

The best method for estimating service life is to use Service Life Software that is based on actual chemical breakthrough data for the specific cartridge/ canister. Unfortunately, this data is not always available and the following methods may be used as a service life estimate: OSHA Advisor Genius and NIOSH MultiVapor Calculator.

3M™ Service Life Software

Service Life Software may be used directly on our web site http://www.3Mrespirators.com or downloaded free of charge.

- **3M™ Canister FR-15-CBRN:** Use 3M Service Life Software and select the 3M cartridge FR-64. 3M FR-64 and FR-15-CBRN gas and vapor capabilities are identical.
- **3M™ Cartridge RBE-57 and 3M™ Canister RBE-40:** 3M Service Life Software does not yet have the 3M RBE-57 or RBE-40 included. We hope to have these available soon. There are some other options for calculating service life for organic vapors described below.

OSHA's Advisor Genius

OSHA Salt Lake Technical Center has a service life program called the "Advisor Genius" which may be helpful for calculating organic vapor service life for the 3M cartridges RBE-57 and 3M canisters RBE-40. For the 3M FR-15-CBRN, 3M Service Life Software should be used selecting the 3M cartridge FR-64.

The Advisor Genius program is found on the OSHA-SLTC web site:

http://www.osha.gov/SLTC/etools/respiratory/advisor_genius_wood/calcframe.html

Calculations are based on cartridges approved for organic vapors only. Therefore, service life may be shorter for cartridges that are approved for both organic vapors and other contaminants (e.g. organic vapor/ acid gas).

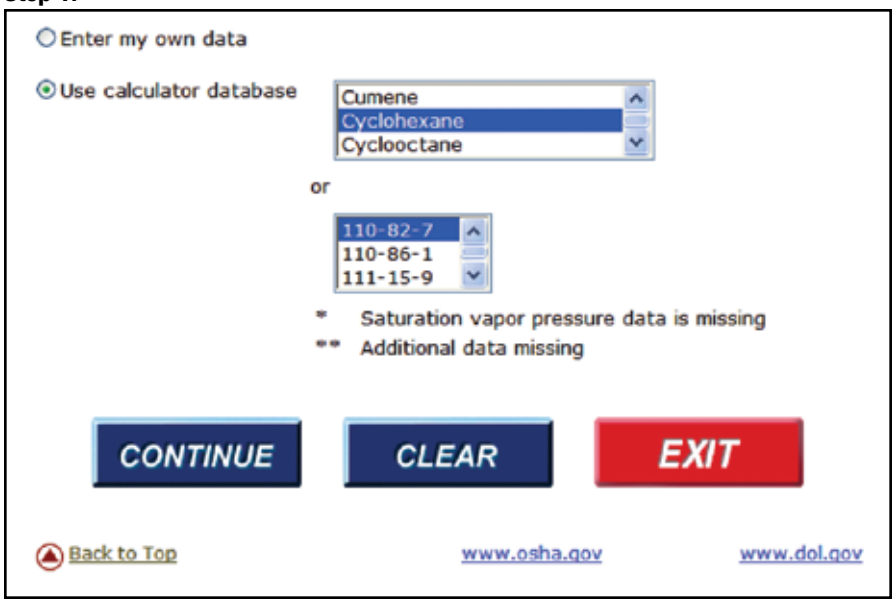
The following parameters for the 3M cartridges RBE-57 or 3M canisters RBE-40 are needed:

Carbon mass per cartridge = 149 g
Packing density = 0.43 g/cc
W0 (micropore volume) = 0.4 cc/g
Bed cross section per system = 243 cm^2

Maximum flow rates for the Breathe Easy systems range from 160–180 liters/min for tight fitting facepieces and 220–250 liters/min for loose fitting facepieces, helmets and hoods. Flow rate depends on the status of the battery, type of cartridge/ canister, and age of motor blower. The user is also asked to enter linear airflow velocity (cm/sec). This is calculated by dividing the PAPR flow rate by the entire bed cross section of the system. For example, linear airflow velocity for one of the above cartridges with a loose fitting hood would be:

$$\frac{220\text{liters}}{\text{min}} \times \frac{1000\text{cm}^3}{\text{liter}} \times \frac{1\text{min}}{60\text{sec}} \times \frac{1}{243\text{cm}^2} = 15.1 \frac{\text{cm}}{\text{sec}}$$

Step 1.



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Step 2.

Worker breathing rate: This is the breathing (work) rate of the worker and is measured in units of liters of air per minute. You should estimate the average breathing rate for the worker during the work period that the respirator is worn.

- ○  Low (e.g., sitting or standing to control machines, performing light hand or arm work) - assume 30 liters per minute
- ○  Moderate (e.g., walking about with moderate lifting and pushing) - assume 60 liters per minute
- ○  High (e.g., pick and shovel work) - assume 85 liters per minute
- ⊙ Other: 220 liters/minute

Workplace Temperature: Enter the maximum temperature expected in the workplace. Fahrenheit is normally used in the United States. Celsius is used in countries which use the metric system. Room temperature is about 22 °C or 72 °F.

75 ° ○ Celsius ⊙ Fahrenheit 

Relative Humidity: Enter the maximum relative humidity expected in the workplace.

50 %

Contaminant Concentration: This is the highest concentration of contaminant expected in the workplace. You should calculate this as an 8-hour time-weighted average (TWA).

2600 ⊙ ppm ○ mg/m^3

CONTINUE CLEAR EXIT

Step 3.

0.4 $cm^3/gram$

The weight of sorbent (activated charcoal) in a single cartridge. If not available, you can disassemble a respirator cartridge and weigh the sorbent. Note that 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.

149 grams 

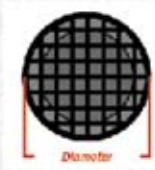
The bulk density of the backed bed in units of grams per cubic centimeter. You can measure this by disassembling a respirator cartridge and determining the total volume (cubic centimeters) of the bed, then dividing this number into the sorbent weight (previous value). A typical value is about 0.4 $grams/cm^3$.

0.43 $grams/cm^3$ ☐ estimate from cartridge diameter or area and depth

You must provide the following information if you want the calculator to estimate the above values. The cartridge diameter assumes a round cartridge. If it is not round, you will need to determine the bed area and enter that value.

Diameter/area of cartridge bed

243
○ diameter (cm)
⊙ area (cm^2)



Depth of cartridge bed (needed to calculate bulk density)

2.6 cm

CONTINUE CLEAR EXIT

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Step 4.

Breakthrough Time Calculator Report

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using calculator version J1.0.

Chemical Name: Cyclohexane
CAS Number: 110-82-7
Breakthrough time: 52 minutes for a maximum concentration of 2600 parts per million (ppm) and a breakthrough of 10% of the workplace concentration.

The breakthrough time assumes that the relative humidity in the workplace is less than 65%.

The following values were used to calculate the breakthrough time.

- Highest workplace temperature expected: 75 degrees Fahrenheit
- The worker breathing rate is estimated to be

The following parameters are associated with the chemical:

- Molecular weight: 84.16 (table)
- Density: 0.7785 (table)
- Refractive Index: 1.4266 (table)
- Saturation vapor pressure: 77.01 torr (table)
- Molar polarization: 27.733 cm^3/mole (table)

The following parameters are associated with the respirator cartridge:

- Weight of sorbent in the cartridge: 149 grams (entered)
- Linear airflow velocity: 15.1 centimeters per second (entered)
- Bulk density of the packed bed: 0.43 g/cm^3 (entered)
- Carbon micropore volume: 0.4 cm^3/g (assumed)
- Equilibrium absorption capacity: 0.2632 g/g carbon (calculated)
- Absorption rate: 4082 per minute (calculated)
- Number of cartridges: 3

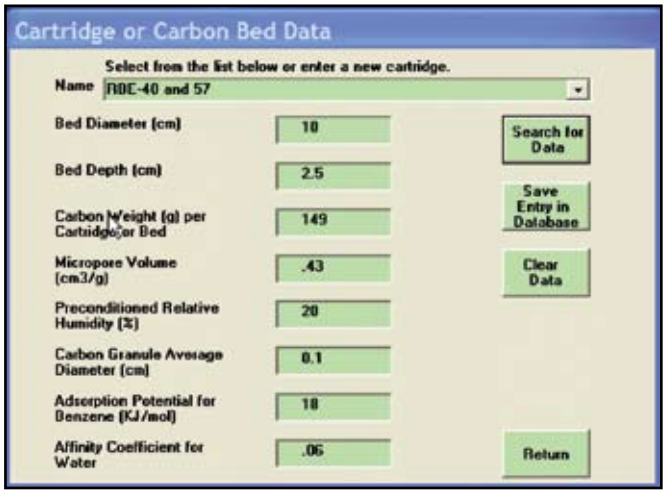
END OF REPORT

Summary — Breakthrough time calculator report shows an estimated breakthrough time of 52 minutes with a breakthrough concentration of 260ppm (10% of workplace concentration).

MultiVapor Calculator from NIOSH
NIOSH has developed a program to estimate service life for organic vapors on cartridges and canisters. It can be found online at: http://www.cdc.gov/niosh/npptl/multivapor/multivapor.html.

In order to use the MultiVapor Calculator for estimating organic vapor service life for the RBE-57 and RBE-40 the following parameters are required.

Maximum flow rate for the Breathe Easy systems range from 160–180 liters/min for tight fitting face pieces and 220–250 liters/min for loose fitting face pieces, helmets and hood.



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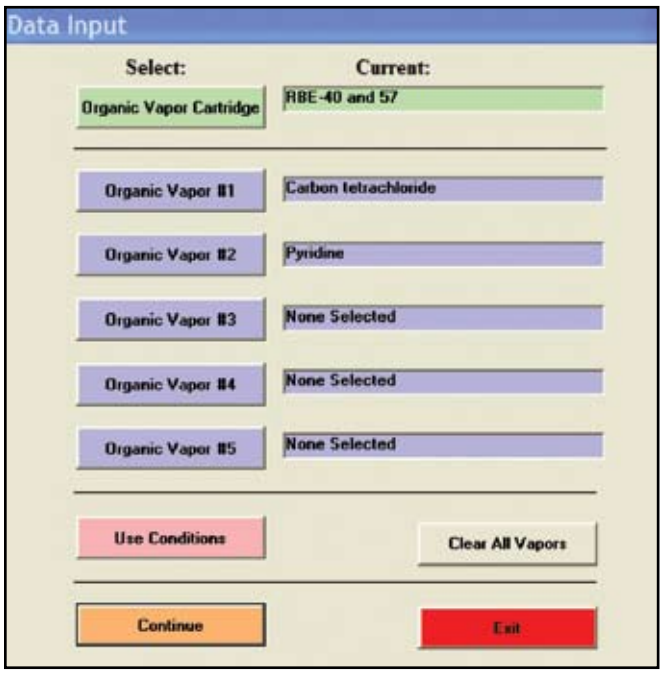
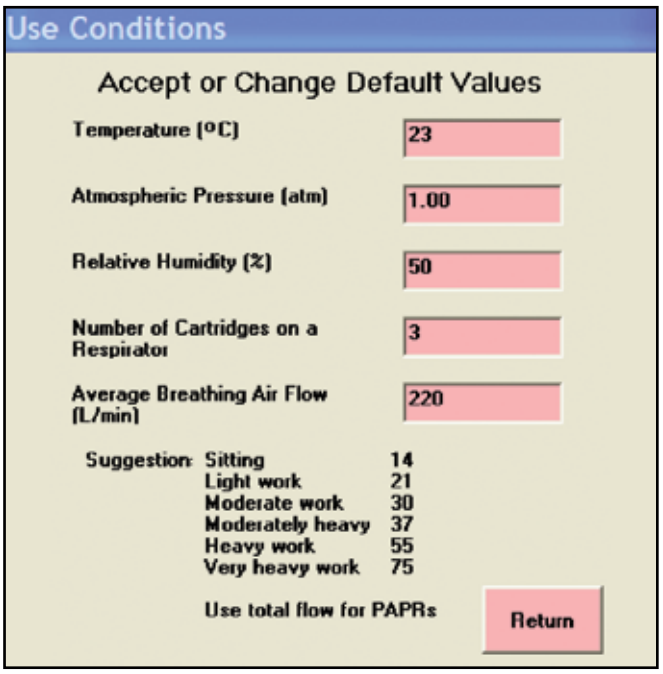
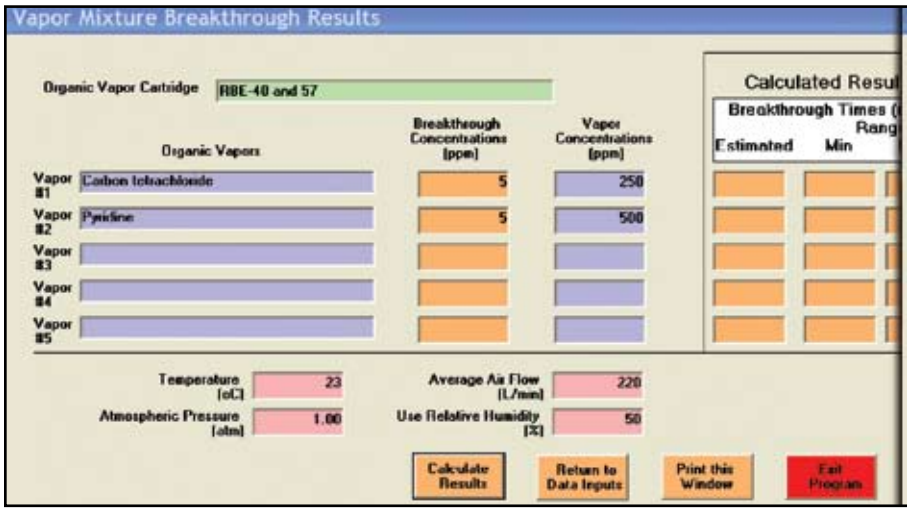
Sample Calculation

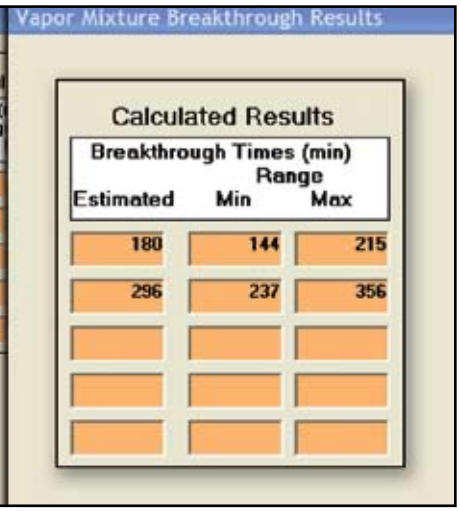
Chemical of concern — pyridine and carbon tetrachloride

Measured or estimated concentrations — carbon tetrachloride = 250ppm; pyridine = 500ppm









Summary — Breakthrough results show estimated breakthrough time ranges for both chemicals. Generally, a conservative approach would be to select the lower breakthrough time which in this case is 144 minutes.

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Determination of CBRN Cartridge and Canister Service Life for Acid Gases and other Compounds

3M™ Respirator Service Life Software
3M Service Life Software does not yet have inorganic test data available for the 3M™ Canister FR-15-CBRN, 3M™ Cartridge RBE-57 or 3M™ Canister RBE-40. Therefore, manual service life estimates must be performed.

Calculating Service Life using 3M Test Data
Technical data bulletins on the 3M FR-15-CBRN, 3M RBE-57 and 3M RBE-40 can be downloaded from our website at http://www.mmm.com/occsafety/html/techdata.html. These Technical Data Bulletins contain NIOSH Gas and Vapor test requirements.

Concentrations
Service life is generally inversely proportionate to concentration (will be longer at lower concentrations), but it is difficult to predict. Extrapolation may give a rough approximation, but may underestimate or overestimate the actual performance, especially at concentrations that are much less than the test concentration.

Flow Rate
Service life is, for the most part, inversely proportionate to flow rate. NIOSH tests loose fitting CBRN PAPR cartridges at a nominal flow rate of 170 liters per minute and tight fitting CBRN PAPR canisters at a nominal flow rate of 115 liters/min and CBRN APR Canisters at 64 l/min.

Since the maximum flow rate for the Breathe Easy systems are 160–180 liters/min for tight fitting face pieces and 220–250 liters/min for loose fitting face pieces, helmets and hoods, corrections would need to be made for flow rate relative to the test conditions.

Safety Factor
Service life information is often modified by a safety factor before determining a change schedule. Since the data provided in the technical data bulletins is set at the minimum test criteria time of 15 minutes, a safety factor may not be needed since the actual test results are generally longer than the minimum time of 15 minutes for CAP 1 approval. Warning properties and the acute toxicity of the contaminant may also be considered. It should be noted that the breakthrough concentration in these experiments is often at or above the exposure limit. Users may want to estimate service life at a breakthrough concentration that is less than these levels.

Sample Calculation
Service life for the cartridge RBE-57 used with the 3M™ Breathe Easy™ for Responders PAPR Respirator and 3M™ Hood BE-10BR, loose fitting, against 10 ppm sulfur dioxide (20 times OSHA PEL) to 1 ppm breakthrough and 3 ppm phosphine (10 times OSHA PEL) to a 0.1 ppm breakthrough, at 25°C, 50% RH.

Information from 3M RBE-57 Tech Data Bulletin #177
- NIOSH test criteria for SO2 is 750 ppm
- NIOSH maximum allowed SO2 break through concentration: 5 ppm
- NIOSH test criteria for phosphine is 150 ppm
- NIOSH maximum allowed phosphine break through concentration: 0.3ppm

Other information
- Cartridge tested at a nominal flow of 170 lpm.
- Maximum flow of Breath Easy PAPR with loose fitting respiratory inlet cover (hood, helmet) is 220–250 lpm.

Estimated Break through Calculation for 10 ppm of SO2 to a break through concentration of 1ppm

$$15\text{min} \times \frac{750\text{ppm}}{10\text{ppm}} \times \frac{1\text{ppm}}{5\text{ppm}} \times \frac{170\text{liters/min}}{220\text{liters/min}} = 173.8\text{min}$$

Estimated Break through Calculation for 3 ppm phosphine to a break through concentration of 0.1ppm

$$15\text{min} \times \frac{150\text{ppm}}{3\text{ppm}} \times \frac{0.1\text{ppm}}{0.3\text{ppm}} \times \frac{170\text{liters/min}}{220\text{liters/min}} = 191.1\text{min}$$

Cartridges should also be replaced earlier if smell, taste or irritation from contaminants is detected.

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Environmental Conditions
High relative humidity will shorten service life for organic vapor cartridges. For more information, please see the help information under the environment section of Service Life Software. However, high relative humidity often improves the service life of cartridges designed to filter acid gases, ammonia and amines.

- Formaldehyde cartridges show a decrease in service life in very dry environments.
- An increase in temperature will lead to a decrease in service life for the organic vapor cartridges.
- Temperature does not have a large effect on service life for acid gases, ammonia and amines under the normal range of workplace temperatures.
- Formaldehyde cartridges show a decrease in service life in very hot environments.

Other Compounds
Service Life Software allows users to enter chemical parameters for organic vapors not found in the software. Service life may also be estimated using analogous chemicals. For acid gases, sulfur dioxide may often be used to give a conservative estimate of service life for the other acid gases listed on the approval label.

Migration
Organic vapors adsorbed on an organic vapor cartridge can migrate through the carbon bed during storage. For organic vapors with a boiling point less than 65°C (149 F°), the cartridge should never be used longer than one shift. More research needs to be done on migration of less volatile chemicals. For more information, please see the help information under the results section of Service Life Software, or Technical Data Bulletin 142, "Reuse of Organic Vapor Chemical Cartridges." Migration is not as much of a concern with the non-organic vapor cartridges. With regard to CBRN cartridges and canisters, NIOSH has issued the following special precautions in the PAPR and APR CBRN standards.

- Direct contact with CBRN agents requires proper handling of the respirator after each use and between multiple entries during the same use. Decontamination and disposal procedures must be followed. If contaminated with liquid chemical warfare agents, dispose of the respirator after decontamination.
- The respirator should not be used beyond eight (8) hours after initial exposure to chemical warfare agents to avoid possibility of agent permeation. If liquid exposure is encountered, the respirator should not be used for more than two (2) hours.

For More Information, Please Call:

In the U.S., contact:
Customer Service
1-800-328-1667
Technical Assistance
1-800-243-4630
Fax On Demand
1-800-646-1655
Website
www.3M.com/OccSafety
For other 3M products
1-800-3M HELPS

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London, Ontario N6A 4T1
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Fax On Demand
1-800-646-1655
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www.3M.com/CA/OccSafety

Technical Assistance In Mexico
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5270-2255, 5270-2119 (Mexico City only)
Technical Assistance In Brazil
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