

# #180 - Determination of Service Life for 3M™ and 3M™ Scott CBRN and First Responder Cartridges and Canisters

## Background

In April 2000, the National Institute for Occupational Safety and Health (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. NIOSH developed several standards for respirators for Chemical, Biological, Radiological and Nuclear (CBRN) applications. These included air-purifying respirators (APR) and powered air-purifying respirators (PAPR) with cartridges or canisters.

## Canister versus Cartridge

NIOSH has separate approvals for cartridge and canister style respirators. Respirators with "cartridge" approval (23C) such as many industrial APR, industrial PAPR and loose fitting CBRN PAPR, may be used for escape from contaminant concentrations up to immediately dangerous to life or health (IDLH), assuming >19.5% oxygen is present.

Respirators with "canister" approval (14G) including certain tight fitting industrial APR, CBRN APR and CBRN PAPR, may be used for escape from *greater than* IDLH concentrations assuming >19.5% oxygen is present.

## CBRN CAP 1 versus CAP 2 versus CAP 3 etc...

CBRN 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.

## Cartridge and Canister Test Conditions

CBRN APR Canister gas life tests are performed at room temperature,  $25 \pm 5^\circ\text{C}$  ( $77 \pm 9^\circ\text{F}$ ) and two relative humidity's:  $25 \pm 5$  percent relative humidity and  $80 \pm 5$  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,  $50 \pm 5$  percent relative humidity and  $25 \pm 5^\circ\text{C}$  ( $77 \pm 9^\circ\text{F}$ ) for each of the test agents at the Canister Test Challenge and Test Breakthrough Concentrations.

CBRN PAPR Cartridges (used with loose fitting headgear) and Canisters (used with tight fitting facepieces) capacity tests are performed at room temperature,  $25^\circ\text{C} \pm 2.5^\circ\text{C}$ ; and at  $25\% \pm 2.5\%$  relative humidity and  $80\% \pm 2.5\%$  relative humidity. Three canisters/cartridges are tested at each specified humidity. 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.

**Table 1: Canister and Cartridge Test Challenge and Test Breakthrough Concentrations**

Test Chemical	Canister		Cartridge	
	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 <sub>2</sub> or 25 ppm NO <sup>†</sup>	100	1 ppm NO <sub>2</sub> or 25 ppm NO <sup>†</sup>
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<sub>2</sub>N<sub>2</sub>

† Nitrogen Dioxide breakthrough is monitored for both NO<sub>2</sub> and NO. The breakthrough is determined by which quantity, NO<sub>2</sub> 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.

**Table 2: 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	SO <sub>2</sub> , H <sub>2</sub> S, CNCl, COCl <sub>2</sub> , 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.

## Determination of 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 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: 3M™ Service Life Software and NIOSH MultiVapor Calculator.

### 3M™ Service Life Software

Service Life Software may be used directly on our web site [www.3M.com/sls](http://www.3M.com/sls).

- **3M™ Canister FR-15-CBRN:** Use 3M Service Life Software and select the 3M cartridge FR-64 for estimating organic vapor service life. 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. There are some other options for calculating service life for organic vapors described below.

### 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: <https://www.cdc.gov/niosh/docs/2010-124c/default.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.

Cartridge or Carbon Bed Data

Select from the list below or enter a new cartridge.

Name: RBE-40 and RBE-57

Bed Diameter (cm)	10	Search for Data
Bed Depth (cm)	2.5	
Carbon Weight (g) per Cartridge or Bed	149	Save Entry in Database
Micropore Volume (cm <sup>3</sup> /g)	0.43	
Preconditioned Relative Humidity (%)	20	Clear Data
Carbon Granule Average Diameter (cm)	0.1	
Adsorption Potential for Benzene (KJ/mol)	18	Return
Affinity Coefficient for Water	0.06	

### Sample Calculation

Chemical of concern — pyridine and carbon tetrachloride

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

Data Input

Select: Organic Vapor Cartridge  
Current: RBE-40 and RBE-57

Organic Vapor #1: Carbon tetrachloride

Organic Vapor #2: Pyridine

Organic Vapor #3: None Selected

Organic Vapor #4: None Selected

Organic Vapor #5: None Selected

Use Conditions      Clear All Vapors

Continue      Exit

Use Conditions

Accept or Change Default Values

Temperature (o C)      23

Atmospheric Pressure (atm)      1.00

Relative Humidity (%)      50

Number of Cartridges on a Respirator      3

Average Breathing Air Flow (L/min)      220

Suggestion: Sitting      14  
Light work      21  
Moderate work      30  
Moderately heavy      37  
Heavy work      55  
Very heavy work      75

Use total flow for PAPRs      Return

Vapor Mixture Breakthrough Results

Organic Vapor Cartridge: RBE-40 and RBE-57

Organic Vapors	Breakthrough Concentrations (ppm)	Vapor Concentrations (ppm)	Calculated Results		
			Breakthrough Times (min) Range		
			Estimated	Min	Max
Vapor #1: Carbon tetrachloride	5	250	180	144	215
Vapor #2: Pyridine	5	500	296	237	356
Vapor #3:					
Vapor #4:					
Vapor #5:					

Temperature (oC)      23      Average Air Flow (L/min)      220

Atmospheric Pressure (atm)      1.00      Use Relative Humidity (%)      50

Calculate Results      Return to Data Inputs      Print this Window      Exit Program

**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.

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

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. The following technical data bulletins contain gas-vapor testing conditions from NIOSH and other organizations. This can serve as a starting point for a rough approximation of service life at lower exposure concentrations.

- [#153 - Test Criteria for the 3M™ Cartridge FR-64 Against Various Military and Industrial Chemical Agents](#)
- [#155 - Test Criteria for the 3M™ Cartridge FR-57 Against Various Military and Industrial Chemical Agents](#)
- [#162 - Recommended use of the 3M™ Canister FR-15-CBRN Against Various Military and Industrial Chemical Agents](#)
- [#177-Recommended use of the 3M™ Cartridge RBE-57 CBRN against Various Military and Industrial Chemical Agents](#)
- [#181-Recommended use of the 3M™ CBRN CAP 1 Canister RBE-40 against Various Military and Industrial Chemical Agents](#)
- [3M™ Scott™ CBRN CAP-1](#)
- [3M™ Scott™ Enforcement Cartridge](#)

- 3M™ Scott™ MPC40PF Powered Air Purifying Cartridge
- Scott MPC Plus
- 3M™ Scott™ TAC 1

### 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. NIOSH tests CBRN APR cartridges at 64 liters/min. This is similar to a breathing rate of 60 liters/min, so adjustments for flow rate may not be needed. 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 SO<sub>2</sub> is 750 ppm
- NIOSH maximum allowed SO<sub>2</sub> 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 SO<sub>2</sub> to a break through concentration of 1 ppm

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

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

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

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

## 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 vapors. 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.

### Personal Safety Division

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