

The Effect of Flow Pattern on Collection Efficiency of Respirator Filters

Anbo Wang, Aaron W. Richardson*, Kent C. Hofacre

Battelle Memorial Institute, 505 King Ave., Columbus, OH 43201 USA

* Corresponding author & E-mail: richardsona@battelle.org

ABSTRACT

This study investigated the effect of cyclic flow pattern on the aerosol penetration through selected respirator filters. Two National Institute for Occupational Safety and Health (NIOSH)-approved commercial respirator filters (a P95 and a N95) were challenged with an inert aerosol and the aerosol penetration was measured under four cyclic waveforms: two sinusoidal, a trapezoidal, and an exponential waveforms. The minute ventilation was 50 L/min for each of the waveforms. The measured penetration increased with the peak inhalation flow rate (PIFR), with the highest penetration measured with the exponential waveform. Equivalent penetrations were measured with the two sinusoidal waveforms even though they had different tidal volumes and breathing rates. Similar penetrations, within a factor of two, were measured with the sinusoidal and trapezoidal waveforms, due to their similar PIFRs. A secondary objective was to compare filter performance under constant (32 to 320 L/min) and cyclic flow conditions (minute ventilation ranged from 16 to 130 L/min). The penetrations measured under cyclic flow were generally an order-of-magnitude higher than those measured under constant flow with an equivalent minute ventilation. The primary outcome was the development of a method to estimate filter performance for a range of cyclic flow conditions once the constant flow relationship is established.

Keywords: Filtration, Respirator filters, Aerosol penetration, N95, Constant flow, Cyclic flow, Breathing flow

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) certifies particulate respirator filters for use in industrial and chemical, biological, radiological and nuclear (CBRN) applications. The test methods and pass/fail criteria for industrial respirators are documented in *Title 42 Code of Federal Regulations Part 84* (1995), where particulate filters are tested against a salt or oil aerosol at a constant flow rate of 85 L/min. During actual use, air flow through filters is cyclic due to the nature of human breathing. Minute ventilation, mean inhalation flow rate (MIFR), and peak inhalation flow rate (PIFR) are three parameters commonly used to characterize cyclic breathing flow (ISO/TS 16976-1:2007). Minute ventilation is the total volume of air inhaled (or exhaled) over one minute of breathing, and thus represents a time-averaged flow rate. The MIFR is the average flow rate during the inhalation portion of breathing, which is approximately twice the minute ventilation. The PIFR is the maximum instantaneous flow rate during the inhalation cycle. If the breathing pattern is approximated with a sinusoidal waveform, the PIFR is 3.14 (π) times the minute ventilation.

Several studies have compared the aerosol penetration measured under constant and cyclic flow conditions. Stafford et al. (1973) and Brosseau et al. (1990) reported that the average penetrations

measured under cyclic flow were generally higher than those measured under constant flows equivalent to the minute ventilation. Eshbaugh et al. (2009) observed penetrations measured under a constant flow equivalent to the cyclic MIFR or PIFR better approximated the cyclic flow penetration than testing at equivalent minute ventilation in the regime of the most penetrating particle size (MPPS). Cyclic flow penetrations tended to be between those measured at the constant flow equivalent to the MIFR and PIFR. Haruta et al. (2008) observed that depending on the flow rate, the penetration of ultrafine particles at cyclic flow could be higher or lower than that measured at constant flow with flow rate equivalent to MIFR. The author attributed the reversed trend at higher flow rate to the non-linear relationship between penetration and flow rate based on the filtration mechanisms of diffusion, electrostatic attraction, interception, and impaction.

The above studies used sinusoidal waveforms to simulate breathing flow patterns. The breathing pattern at rest resembles a sinusoidal waveform and transforms to a trapezoidal waveform as the work rate increases (ISO/TS 16976-1:2007). No studies were identified that compared the effect of waveform shape on the measured aerosol penetration. The objectives of this study were: (1) to assess the effect of cyclic flow pattern on the aerosol penetration performance of the respirator filters and (2) to compare performance under constant and cyclic flow conditions. In addition, a method was developed to estimate the performance of a filter under cyclic flow conditions, based on measured penetrations over a range of constant flow conditions. This method provides further insight into the relationship between constant and cyclic flow performance.

METHODS

Test Parameters

Penetration is a function of challenge particle size distribution, filter properties, and flow rate (or velocity) through the filter media (Hinds, 1999). In this study, the challenge particle size distribution and filter properties were held constant such that the results represent the effect of flow rate. Two commercially available NIOSH-approved particulate respirator filters, a P95 and a N95 filter, were tested. These filters were designated A and B, respectively. Both filters were cartridges used with dual-filter, elastomeric half-face masks. The temperature during testing was ambient ($25 \pm 3^\circ\text{C}$) and the relative humidity was $30 \pm 10\%$. The challenge aerosol was monodisperse polystyrene latex spheres (PSL, Cat. No. AP 3300A, Applied Physics Inc., Niwot, CO) with a nominal diameter of $0.3 \mu\text{m}$. The filters were not preconditioned prior to testing (i.e., tested as-received).

The cyclic flow conditions are summarized in Table I. The effect of cyclic flow pattern was tested at constant minute ventilation of 50 L/min. Four waveforms were evaluated, including two sinusoidal waveforms, a trapezoidal waveform, and an exponential waveform. These waveforms are compared in Figure 1. The two sinusoidal waveforms at 50 L/min had different breathing rates and tidal volumes. The trapezoidal waveform was selected to simulate the breathing pattern at a high work load. The exponential waveform was included to simulate the worst case conditions of a cyclic flow with an extremely high peak flow rate.

To assess the effect of flow rate, cyclic flow tests were performed with sinusoidal waveforms with minute ventilations ranging from 16 to 130 L/min. The constant flow rates tested for comparison were 32, 50, 85, 130, 215, and 320 L/min.

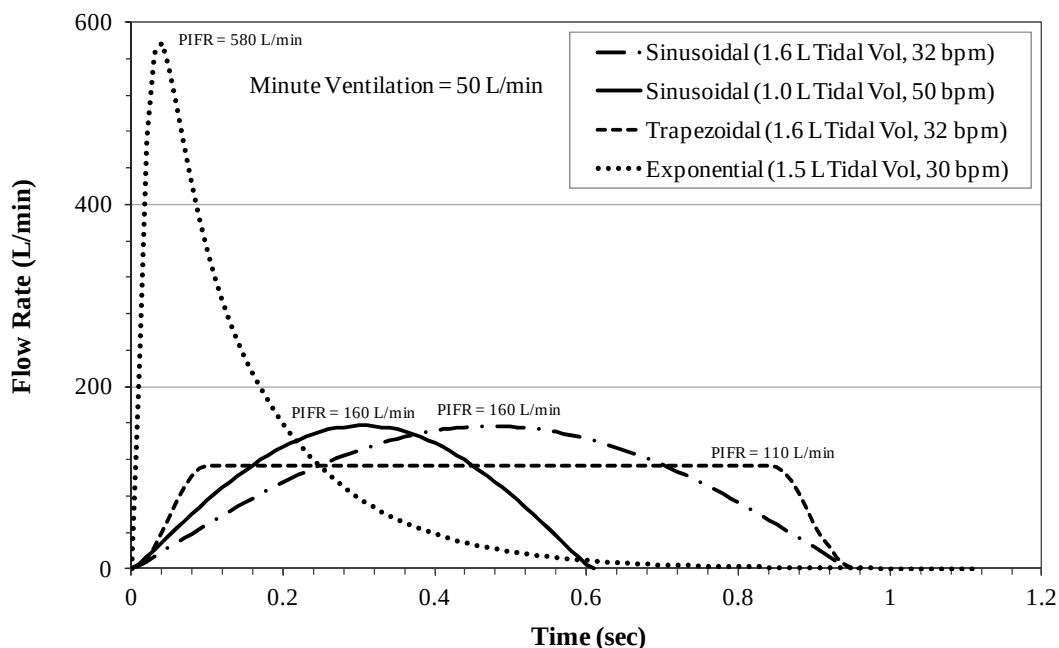
Table I. Cyclic Flow Pattern Used for Testing

Minute Ventilation (L/min)	Waveform	Tidal Volume (L)	Rate (breath/min)	MIFR ^(a) (L/min)	PIFR ^(b) (L/min)
16	Sinusoidal	0.5	32	32	50
32	Sinusoidal	1.0	32	64	100
50	Sinusoidal	1.0	50	100	160
	Sinusoidal	1.6	32		160
	Exponential	1.5	30		580 ^(c)
	Trapezoidal	1.6	32		110
85	Sinusoidal	2.6	33	170	270
130	Sinusoidal	2.6	50	260	410 ^(c)

^(a) Mean inspiratory flow rate.

^(b) Peak inspiratory flow rate.

^(c) PIFR was out of the range of test flow rates at constant flow conditions; therefore, the corresponding PIFR penetration discussed in the paper was extrapolated.

**Figure 1. A Comparison of Test Cyclic Flow Waveforms with Minute Ventilation of 50 L/min.**

Test Apparatus

The test system, as shown in Figure 2, consisted of an aerosol generation system, exposure chamber, filter holder, breathing machine (or vacuum pump for constant flow test), and aerosol sampling/classification system. The PSL particles were suspended in deionized water and aerosolized using an Airlife nebulizer (Cat. No. 002002, Allegiance Healthcare Corp., McGaw Park, IL). The aerosol was mixed with filtered house air prior to passing through a charge neutralizer (Model No. 3012, TSI, Shoreview, MN). The generator continuously delivered aerosol-laden air to the exposure chamber to

ensure a stable aerosol challenge was maintained. The chamber (30 × 30 × 30 cm) housed the filter holder and contained the aerosol challenge. The chamber contained mixing fans to ensure a well-mixed challenge atmosphere was maintained and was equipped with a 0.2 cm I.D. probe for collecting samples of the challenge atmosphere. Chamber pressure was measured using a magnehelic pressure gauge (Dwyer Instruments Inc., Michigan City, IN). Excess challenge was vented through a high-efficiency particulate air (HEPA) filter and exhausted into the fume hood.

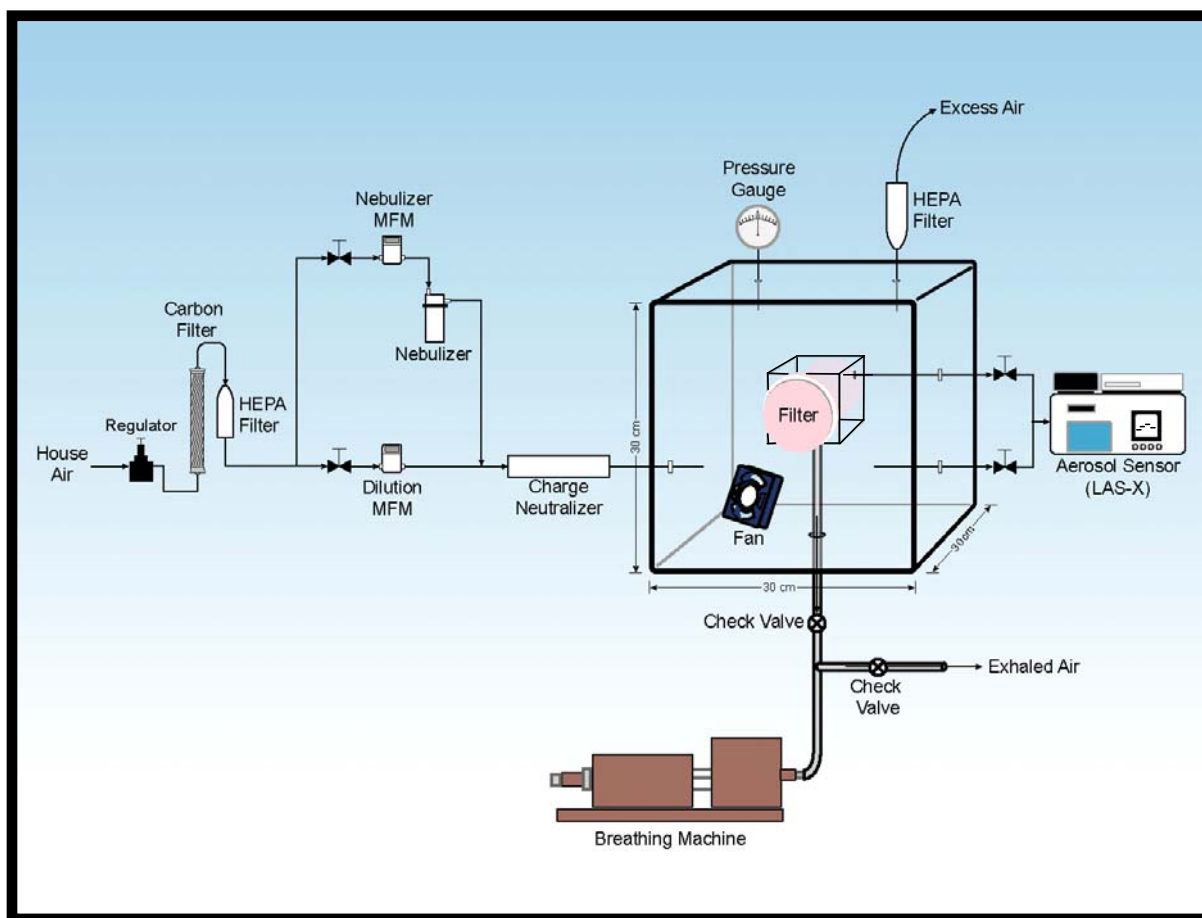


Figure 2. Schematic of Test Apparatus.

The filters were tested in pairs within the exposure chamber and mounted to a small (~250 cm³) sampling chamber that was connected to the breathing machine or vacuum pump. The sampling chamber was equipped with a 0.2-cm I.D. probe for collecting air samples downstream of the filters. The breathing machine was of piston cylinder design and contained a check valve such that air was inhaled through the test filters and exhaled into the hood. Thus, air was not exhaled through the test filters. The challenge and downstream aerosol concentrations were measured using a laser aerosol spectrometer (LAS-X, Particle Measuring Systems, Boulder, CO).

Test Procedure

The filter pair was mounted to the test fixture and the chamber was sealed. The breathing machine (or vacuum pump for constant flow tests) and aerosol generation system were started and permitted to operate for approximately 10 minutes to allow the aerosol to reach a steady state

concentration. When steady state was reached, a sample of the challenge aerosol was collected for two minutes. Next, the sampling line was switched to sample downstream of the filter and adequate time given for the instrument response to stabilize. The downstream sample duration was 15 minutes to provide adequate time to count a sufficient number of particles. A second sample of the challenge aerosol was then recorded. If the two challenge samples (before and after downstream sampling) were not within 20 percent of each other, the test was repeated as the challenge aerosol was not stable. After sampling of the challenge was completed, the aerosol generation system was stopped and the chamber flushed. The filter was removed from the test system and discarded.

Calculation of Aerosol Penetration

The percent aerosol penetration (P) was defined as the ratio of the downstream aerosol concentration (C_{Down}) to the challenge aerosol concentration (C_{Chal}) as shown below:

$$P(\%) = \frac{C_{Down}}{C_{Chal}} \times 100 \quad (1)$$

Filter performance sometimes is characterized by collection efficiency (η). The percent penetration can be converted to collection efficiency as following:

$$\eta(\%) = 100 - P = \left(1 - \frac{C_{Down}}{C_{Chal}}\right) \times 100 \quad (2)$$

The concentrations were the average number concentrations measured by the LAS-X. The challenge concentration was the average of the measurements made before and after the downstream sampling.

Statistical Analysis

Bland Altman plots were created to compare: (1) the constant and cyclic penetration measurements, and (2) the measured and the predicted cyclic penetrations. The data from Filter A and Filter B were combined for the statistical analysis. All percent penetration data were converted to fractional penetration, inverted, and log transformed (base10) for the Bland Altman analysis. This statistical approach is consistent with that used by Eshbaugh et al. (2009).

Two analyses were performed. The first analysis compared the penetration measurements at constant flow equivalent to the cyclic minute ventilation, MIFR, or PIFR rates. The second analysis compared the measured and predicted cyclic penetrations. The difference of the means and the averages were plotted on the y-axis and x-axis, respectively. The overall mean of the differences was indicated by the "mean difference" dash lines marked in the plots. As the differences between two methods (i.e. constant and cyclic measurements or measured and predicted methods) decreased, the mean difference line approached zero. A mean difference line at zero would signify perfect agreement between two methods (i.e. constant and cyclic measurements, or measured and predicted methods). The Bland Altman analysis method included the calculation of the upper limit of agreement (ULOAs) and the lower limit of agreement (LLOAs) (consistent with a 95% confidence interval of the measurement differences), which were included as red dash lines in the plots.

RESULTS AND DISCUSSION

Table II summarizes the average measured penetrations for both filters at the constant and cyclic flow test conditions. The table provides the average $\pm$ one standard deviation of the measurements. Sample size of individual test cells ranged from 2 to 4.

Effect of Breathing Flow Pattern

To assess the effect of breathing flow pattern on filter penetration, the minute ventilation was held constant (i.e., 50 L/min) and tests were performed using two sinusoidal waveforms, one trapezoidal waveform, and one exponential waveform. The measured penetrations are compared in Figure 3 for Filters A and B. The penetrations measured under constant flow are also included in Figure 3 for comparison. Note that the minute ventilation and MIFR are equivalent for all of these flow conditions, while the PIFR varied depending on the waveform. The measured penetration increased with PIFR, with the highest penetrations measured for the exponential waveform that had a PIFR of 580 L/min.

Table II. Measured Aerosol Penetrations under Constant Flow and Cyclic Flow Conditions

Minute Ventilation (L/min)	Waveform	Tidal Volume (L)	Rate (breath/min)	MIFR (L/min)	PIFR (L/min)	Filter A (P95) Penetration (%)	Filter B (N95) Penetration (%)
16	Sinusoidal	0.5	32	32	50	0.047 $\pm$ 0.022	0.008 $\pm$ 0.003
32	Constant flow	-				0.011 $\pm$ 0.002	0.005 $\pm$ 0.004
	Sinusoidal	1.0	32	64	100	0.21 $\pm$ 0.055	0.056 $\pm$ 0.021
50	Constant flow	-				0.043 $\pm$ 0.001	0.017 $\pm$ 0.011
	Sinusoidal	1.0	50	100	160	0.58 $\pm$ 0.075	0.26 $\pm$ 0.066
	Sinusoidal	1.6	32	100	160	0.58 $\pm$ 0.040	0.23 $\pm$ 0.022
	Exponential	1.5	30	100	580	2.9 $\pm$ 0.63	2.2 $\pm$ 1.0
	Trapezoidal	1.6	32	100	110	0.31 $\pm$ 0.069	0.17 $\pm$ 0.003
85	Constant flow	-				0.16 $\pm$ 0.050	0.066 $\pm$ 0.016
	Sinusoidal	2.6	33	170	270	1.4 $\pm$ 0.053	0.84 $\pm$ 0.21
130	Constant flow	-				0.52 $\pm$ 0.009	0.28 $\pm$ 0.006
	Sinusoidal	2.6	50	260	410	2.5 $\pm$ 0.52	4.4 $\pm$ 0.99
215	Constant flow	-				1.5 $\pm$ 0.18	0.87 $\pm$ 0.034
320	Constant flow	-				3.9 $\pm$ 0.80	3.4 $\pm$ 0.13

Equivalent penetrations were measured with the two sinusoidal cyclic flows. These two sinusoidal waveforms had different tidal volumes and breathing rates, but the same minute ventilation and PIFR. These limited results suggest, for a sinusoidal waveform, penetration was sensitive to minute ventilation (or PIFR); therefore, defining the minute ventilation is more important than selection of tidal volume or breathing rate when evaluating filter performance. Further testing is recommended to cover a more extensive range of breathing rates and tidal volumes to confirm this conclusion. The measured

penetration was lower by about a factor of two for the trapezoidal waveform relative to the sinusoidal waveform. This was attributed to the lower PIFR. Thus, testing with a sinusoidal waveform provided a conservative estimate of filter performance relative to a trapezoidal waveform.

The penetrations measured for all cyclic flow patterns were higher than those measured for constant flow for the test conditions evaluated, by at least an order-of-magnitude at equivalent minute ventilations. This is consistent with observations from Stafford et al. and Brosseau et al. The trend is expected as a significant portion of the cyclic flow was in excess of the rated minute ventilation. For example, assuming the sinusoidal flow pattern with a minute ventilation of 50 L used in this study (i.e., 1.6-L tidal volume and 32 breaths/min), approximately 78 percent of the volume was drawn through the filter during inhalation at flow rates in excess of 50 L/min.

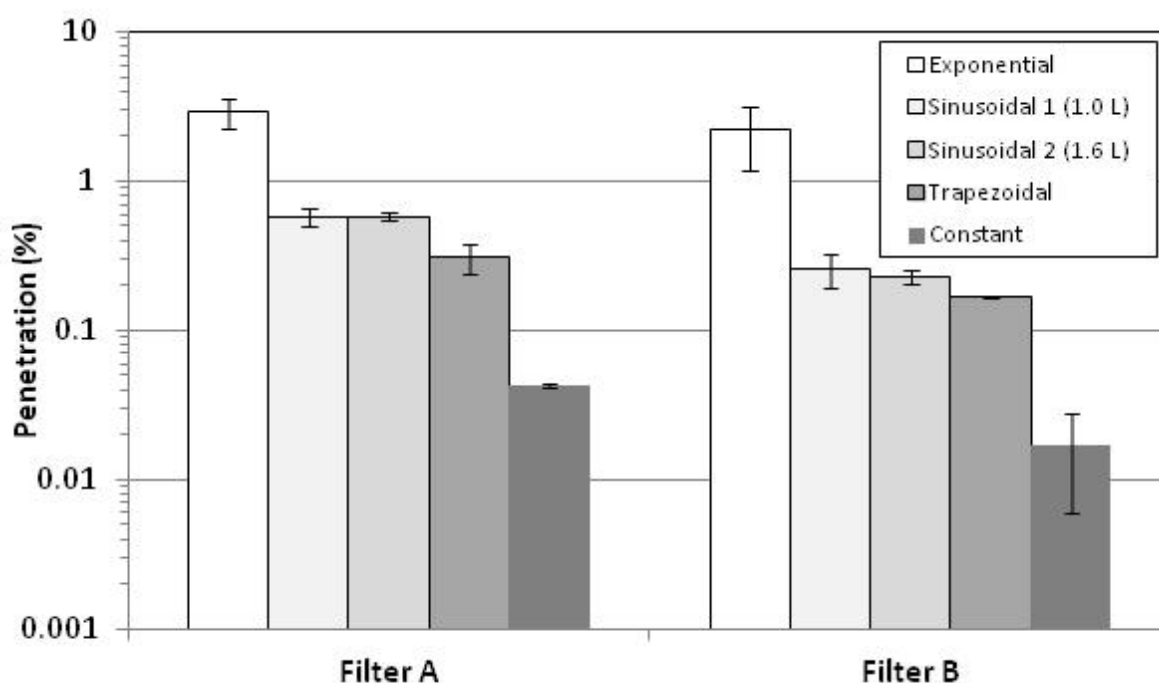


Figure 3. Comparison of Penetrations at Various Cyclic Flow Patterns at Constant Minute Ventilation of 50 L/min.

Comparison of Constant and Cyclic Flow Penetrations

Figures 4 and 5 compare the penetrations measured at constant flow and cyclic sinusoidal flow conditions for Filters A and B, respectively. The average measured penetrations are plotted and the error bars represent one standard deviation about the mean. The penetrations measured with sinusoidal waveforms are plotted based on different flow rates for comparison: (1) minute ventilation, (2) MIFR, and (3) PIFR. The constant flow penetrations were generally an order-of-magnitude lower than those measured under cyclic flow conditions with an equivalent minute ventilation. Similar trends were observed for both filters. The ratio of the cyclic flow (based on minute ventilation) to constant flow penetration averaged 11.5 for Filter A and 12.7 for Filter B.

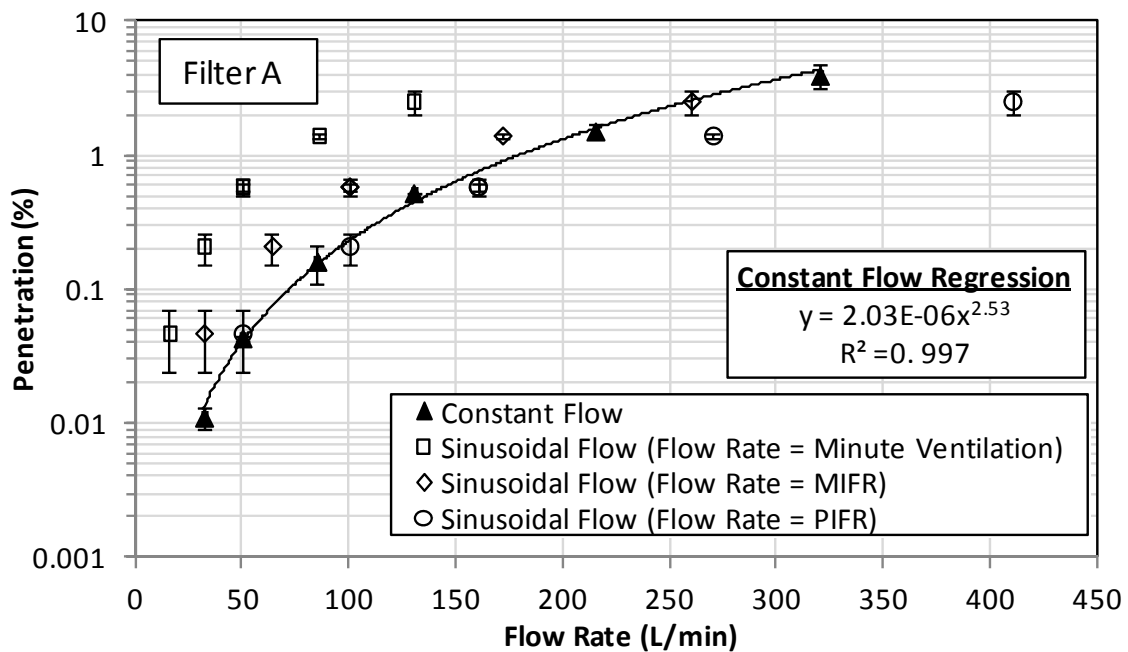


Figure 4. Comparison of Penetrations Measured Under Constant and Cyclic Flows (Sinusoidal Waveform) for Filter A.

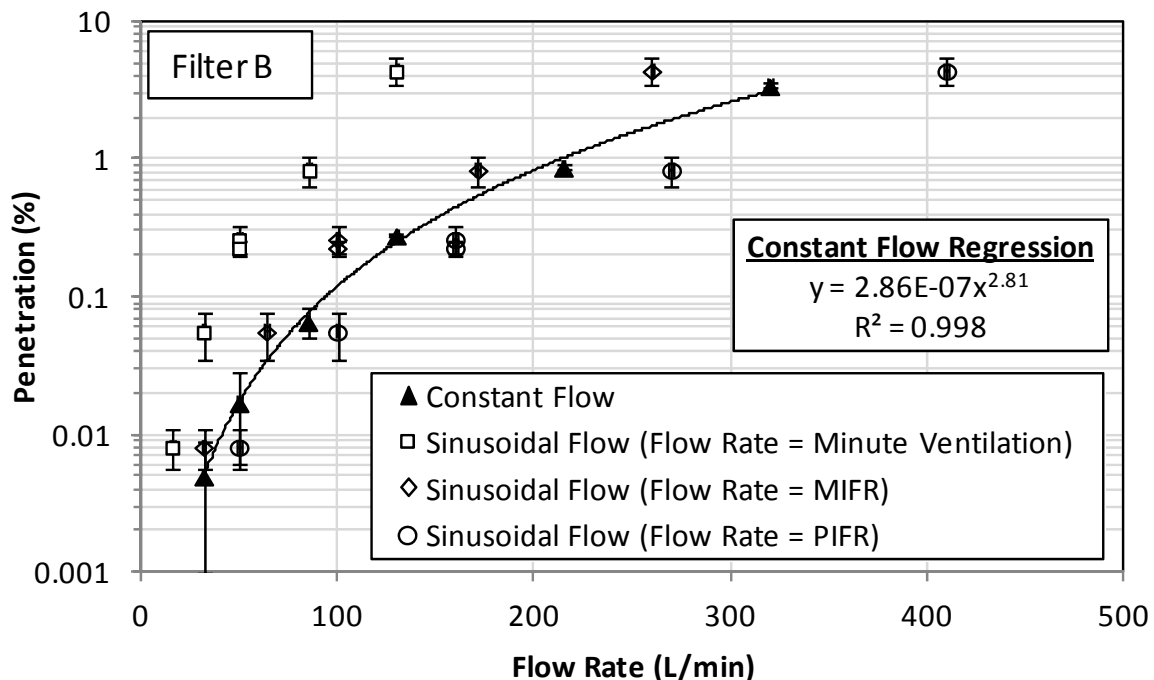


Figure 5. Comparison of Penetrations Measured Under Constant and Cyclic Flows (Sinusoidal Waveform) for Filter B.

The measured penetrations increased with flow rate for both filters. The penetration increased by a factor of nearly two orders-of-magnitude when the minute ventilation increased from 16 to 130 L/min. Several aerosol deposition mechanisms are responsible for capturing the airborne particles on the fibers of filtration media, which include diffusion, interception, electrostatic attraction, and inertial impaction (Hinds, 1999). Flow rate through the filter affects these mechanisms differently. Deposition by diffusion and electrostatic attraction reduces as air flow rate is increased. In contrast, deposition by inertial impaction is enhanced by increased flow rate. The interception deposition mechanism is independent of flow rate. Since penetration was observed to increase with increased flow rate, this suggests that the collection of the 0.3 μm particles by the test filters was predominated by diffusion and electrostatic attraction mechanisms. Note that an opposite trend of penetration versus flow rate may be observed with larger particles, where inertial impaction becomes the primary collection mechanism.

Since constant flow tests were not performed at all MIFR and PIFR conditions, the regression of measured penetration as a function of constant flow rate were used to estimate the constant flow penetrations at the MIFR and PIFR. The best-fit power regressions were shown in Figures 4 and 5. Strong correlations were observed between the measured penetrations and the test flow rate for both filters. It is recognized that the PIFR for the exponential waveform and the 130 L/min sinusoidal waveform are outside of the constant flow range tested. However, the constant flow regressions were extrapolated to provide an estimate for these comparisons.

The Bland Altman plot is shown in Figure 6. Results are shown for both filters and all tested waveforms. The mean differences for the minute ventilation, MIFR, and PIFR comparisons were -1.2, -0.39, and 0.27, respectively. The Bland-Altman plot illustrates that penetration measured at a constant flow equivalent to the minute ventilation significantly underestimated the cyclic flow penetration. The penetrations measured under cyclic flow tended to be between those measured under constant flow equivalent to the MIFR and PIFR. A similar trend was observed by Eshbaugh et al. (2009). The Bland-Altman mean differences were un-inverted and un-transformed to provide averaged ratios of cyclic to constant flow penetration (i.e. $P_{\text{cyclic}}/P_{\text{constant}}$) of 14.3, 2.5, and 0.5 for equivalent minute ventilation, MIFR, and PIFR, respectively.

In Figure 7, the cyclic flow penetrations are again compared to the penetrations measured under constant flow. The dotted line is the one-to-one line and represents perfect agreement between the measured penetrations. This plot again shows that the measured cyclic flow penetrations were intermediate to those measured under a constant flow equivalent to the MIFR and PIFR.

The cyclic penetrations with sinusoidal and trapezoidal waveforms were better approximated by the constant flow penetrations at MIFR and PIFR than that with an exponential waveform. This is reflected in Figure 7, where the data points for the exponential waveform are noted and do not follow the trends observed with the sinusoidal and trapezoidal waveforms. The sharp increase in flow rate and high PIFR associated with an exponential waveform may make the penetrations measured at the MIFR and PIFR less representative.

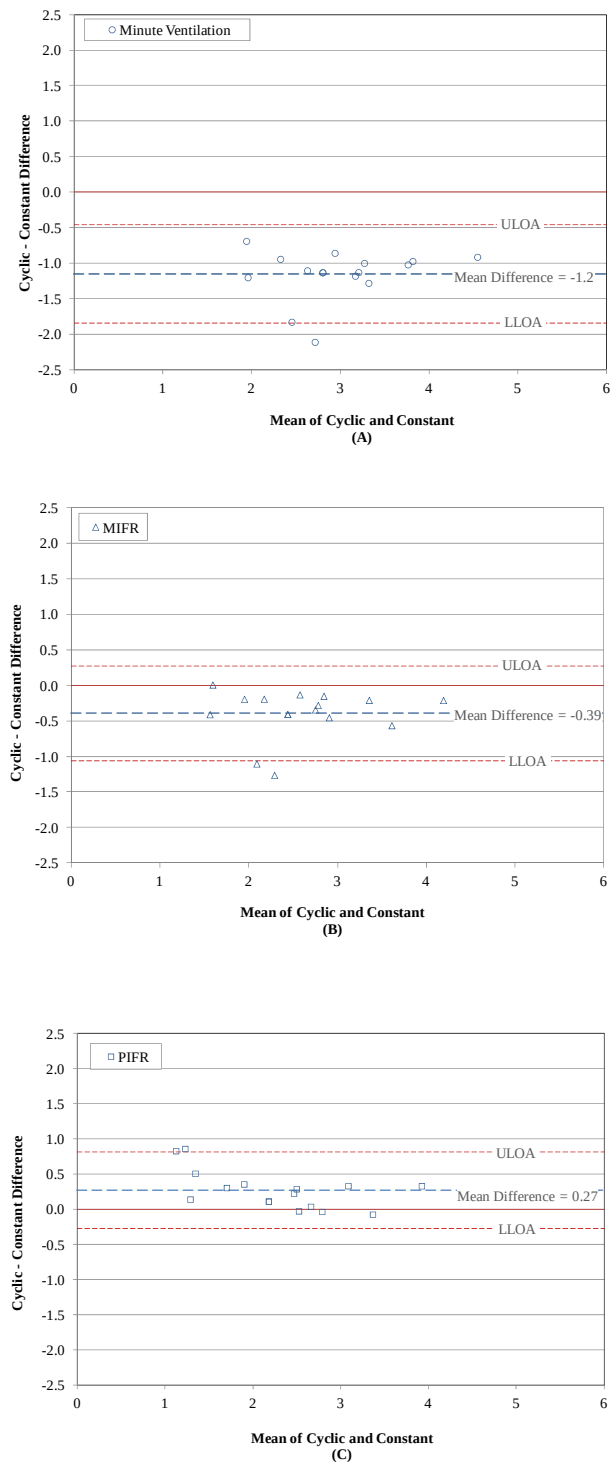


Figure 6. Bland-Altman Plots for (A) Minute Ventilation, (B) MIFR, and (C) PIFR Measurement Comparisons.

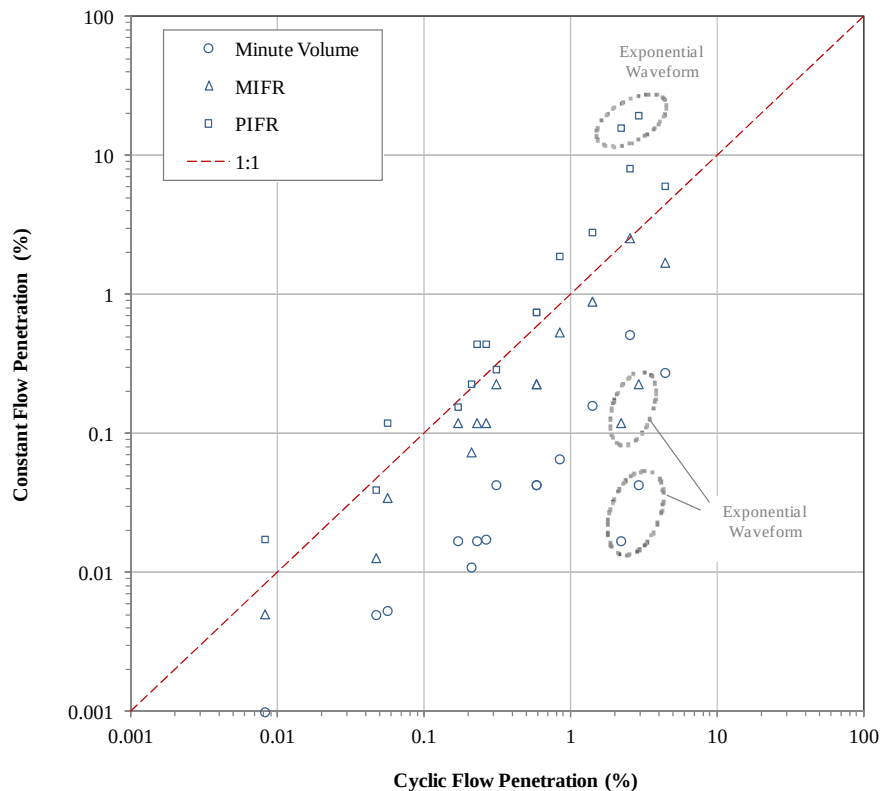


Figure 7. Comparison of Penetration at Cyclic and Constant Flows.

Method to Estimate the Penetration at Cyclic Flow

In an effort to gain further insight into the relationship between aerosol penetration measured under constant and cyclic flow, a method was developed to estimate cyclic flow penetrations based on those measured under constant flow. This technique is useful to estimate filter performance for a range of cyclic flow conditions once the constant flow relationship is established for a particular particle size of interest.

The method is illustrated below using a sinusoidal waveform as an example. Note that the technique could be applied to any waveform including the exponential and trapezoidal waveforms explored in this study. For a sinusoidal waveform, the time dependent flow rate is given by:

$$Q(t) = PIFR \sin\left(\frac{2\pi}{\omega} t\right) \quad (3)$$

where $Q(t)(L/min)$ is the instantaneous inhalation flow, $\omega(sec)$ is the time per breath cycle, and $t(sec)$ is the time.

The regression equations in Figures 4 and 5 for penetration at constant flow provide the expressions for penetration as a function of flow rate for each filter. Substituting the time dependent flow

into these equations provides an expression for the time dependent penetration. For example, the resulting equation for the penetration through the Filter B is:

$$P_{\text{Filter B}}(t) = 2.86 \times 10^{-7} \times \left[\text{PIFR} \sin\left(\frac{2\pi}{\omega}t\right) \right]^{2.81} \quad (4)$$

where $P_{\text{Filter B}}(t)$ represents the instantaneous penetration (%). The average penetration ($P_{\text{Filter B, Avg}}$) over the inhalation cycle is then determined by:

$$P_{\text{Filter B, Avg}} = \frac{2}{\omega} \int_0^{\omega/2} P_{\text{Filter B}}(t) dt \quad (5)$$

Note that the integration is only over the inhalation cycle as it is assumed that there is no inward flow through the filter during exhalation.

This approach was used to predict the aerosol penetrations for each of the cyclic flow conditions. The predicted values are compared with the measured values in the Bland Altman plot shown in Figure 8. The mean difference for measured and predicted comparison was -0.14, which is close to zero, indicating good agreement between the measured and predicted penetrations. The Bland-Altman mean difference was uninverted and untransformed to provide an averaged ratio of measured to predicted penetration (i.e. $P_{\text{measured}}/P_{\text{predicted}}$) as 1.4. Therefore, the predicting method tended to underestimate the penetration at cyclic flow condition. Further investigation is required to determine the cause for this underestimate. Perhaps it can be attributed to differences between the ideal sinusoidal waveform assumed and the actual waveform generated by the breathing machine, or perhaps there are transient, localized flow effects in the filter during the inhalation cycle that are not considered.

All methods explored in this study to approximate filter penetration at cyclic flow conditions (i.e.; testing at constant flow equivalent to the minute ventilation, PIFR or MIFR; or estimation method based on constant flow relationship) are compared in Table 3. The prediction method developed in this study provided the most accurate estimate. As shown in Table 3, the MIFR penetration and PIFR penetration provided estimates at best within a factor of 2 at the test conditions, with the PIFR penetration providing a conservative estimate. Note that the approximation by MIFR and PIFR penetrations may depend on particle sizes and flow rates. In ultrafine particles regime, Haruta's tests (2008) demonstrated that the MIFR penetration could be higher, equivalent, or lower than the cyclic penetration depending on flow rates.

Table III. Comparisons of Methods to Approximate Filter Penetration at Cyclic Flow Conditions

Average Ratio of Penetrations	Measured at Constant Flow			Prediction Method ^(a)
	Minute Ventilation	MIFR	PIFR	
$\frac{P_{\text{measured cyclic}}}{P_{\text{Alternative method}}}$	14.3	2.5	0.5	1.4

^(a) Prediction method based on constant flow data.

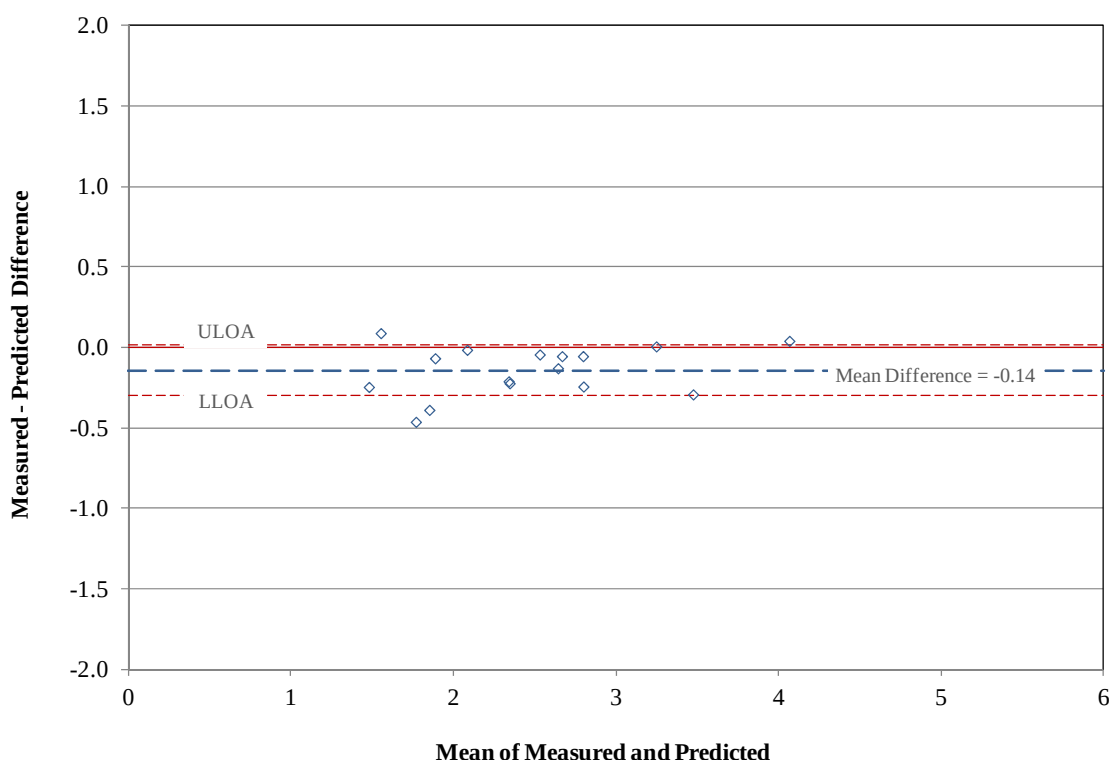


Figure 8. Bland-Altman Plot for Comparison of Measured and Predicted Cyclic Penetrations.

The results described above demonstrate that the shape of the waveform and PIFR should be considered when testing under cyclic flow conditions. The PIFR was usually 2.5 to 3.7 times of the minute ventilation (ISO/TS 16976-1:2007), depending on the shape of a breathing waveform. The NIOSH certification testing is performed at a constant flow rate of 85 L/min. Therefore, conservatively, the NIOSH certification testing can be used to predict actual filter performance at minute ventilation ranging from 23 to 34 L/min, which corresponds to a PIFR around 85 L/min. This minute ventilation corresponds to a moderate work load (ISO/TS 16976-1:2007). Therefore, NIOSH certification test results are most representative of respirator filters performance at moderate work load.

CONCLUSIONS

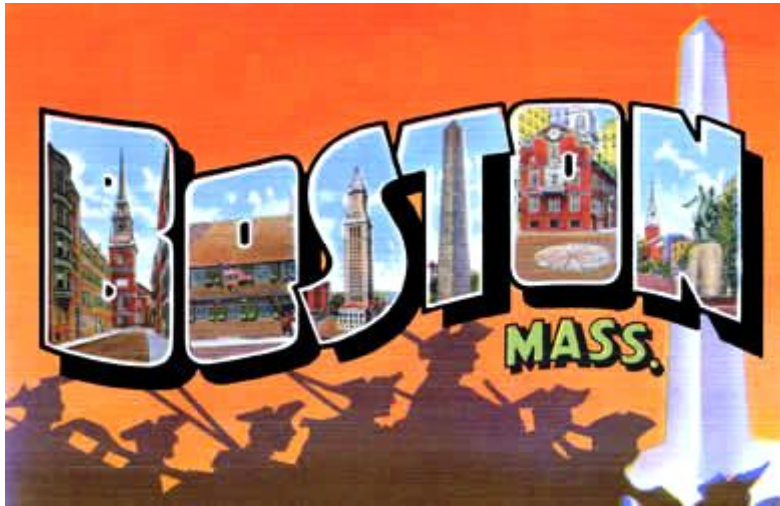
The effect of breathing flow pattern on respirator filter performance was tested in this study using four different cyclic waveforms at the same minute ventilation. The results showed that the measured penetration increased with PIFR at the same minute ventilation, with highest penetration observed with the exponential waveform that had the highest PIFR. Equivalent penetrations were measured for two sinusoidal cyclic flows that had the same minute ventilation but different tidal volumes and breathing rates. As expected, similar penetrations, within a factor of two, were measured with the sinusoidal and trapezoidal waveforms, due to their similar PIFRs. Testing with a sinusoidal waveform provided a conservative estimate of filter performance relative to a trapezoidal waveform, which better approximates the shape of a waveform at higher work rates. The results of this study suggest defining a sinusoidal minute ventilation is more important than specifying the breathing rate and tidal volume.

Filter performance under constant flow and cyclic flow conditions was compared for a N95 and a P95 filter. The penetrations measured at cyclic flow were generally an order of magnitude higher than those measured at constant flow with flow rate equivalent to the minute ventilation of the cyclic flow. For 0.3 μm inert particle, the penetrations at cyclic flow can be conservatively approximated by the penetration measured at constant flow conditions with flow rate equivalent to the PIFR. The NIOSH certification test likely provides a good indication of filter performance up to a moderate workload, which has PIFRs close to 85 L/min.

A method was developed to estimate average penetration under cyclic flow conditions, based on measured penetrations over a range of constant flow conditions and the actual cyclic flow waveform. The technique is useful to estimate filter performance for a range of cyclic flow conditions once the constant flow relationship is established. This method tended to underestimate performance but did typically provide estimates of penetration within a factor of two of those measured experimentally. This testing was conducted on a limited number of respirator filters using a monodisperse challenge aerosol with a nominal size of 0.3 μm . Further research is recommended to assess the accuracy of the prediction method over a range of particle sizes and filter types (e.g., P100).

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Great location — The ISRP conference will take place in the thriving city of Boston, Massachusetts. There's nothing like Boston in the Fall... easy access, spectacular sights and history, shopping, nightlife and much more.

Historic awards banquet venue — The [John F. Kennedy Presidential Library & Museum](#) is lovingly dedicated to our nation's thirty-fifth president. The Library & Museum is located on a ten-acre park overlooking the sea and stands as a tribute to the leadership and legacy of President John F. Kennedy.

Interactive format — Roundtables: share your thoughts, concerns and ideas with experts in the field of Respiratory Protection through roundtable discussions hosted by ISRP board members and interact with presenters of research in the field.

Keynote speakers from NIOSH and OSHA — Experts in various fields of Occupational Safety and Health will be addressing key industry and worker issues in respiratory protection.

Awards/recognition — Numerous prizes and other signs of recognition will be awarded.

Exhibition — Excellent opportunities to showcase new products, services and technologies. Invaluable access to a specialized audience.

Sponsorship — Take advantage of the high visibility, goodwill and benefits associated

with sponsorship.

Ideal conference venue — The [Boston Park Plaza Hotel and Towers](#) is located in historic Back Bay, just blocks from the nation's most historical landmarks. Located just 3 miles from Logan International Airport and steps away from the nation's first public parks, the beautiful Boston Common & The Public Garden. The hotel is easily accessible to world-class shopping along renowned Newbury Street, Faneuil Hall Marketplace, the theatre & financial districts and Boston's best points of interest.

PROGRAM OVERVIEW:



Sunday, September 23

- Welcome cocktail party

Monday, September 24

- Keynote address: John Howard, Director of NIOSH
- Podium presentations
- Keynote address: Richard Fairfax, Deputy Assistant of Labor for OSHA
- Roundtable: "International Standards Organization (ISO) Respiratory Protection Standard: Technical Challenges and Government, Manufacturer, and User Perspectives"

Tuesday, September 25

- Podium presentations
- Exhibition

Wednesday, September 26

- Roundtable: "End of Service Life Indicators (ESLI): Technology and Acceptance"
- Podium presentations
- ISRP annual general meeting
- Banquet dinner and awards ceremony

Thursday, September 27

- Roundtable: "Advances and Experiences in Healthcare Respiratory Protection"
- Podium presentations, with anticipated Healthcare focus

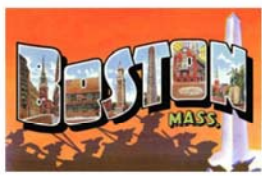
Activities & partners program:

Activities abound in the historic Boston area, from the Historic Harbor, Boston Common to the distinctive neighborhoods of Boston, such as Back Bay, Beacon Hill, Chinatown, Fenway/Kenmore, North End, South End and Harvard Square – there is no shortage of

things to see and do.

The Boston Park Plaza Hotel & Towers concierge will be planning day trips & excursions for guests and partners not attending the technical sessions. Please [contact us](mailto:boston@isrp.com) for more details and to sign up for a historic tour of Boston!

Any questions? Send all queries to boston@isrp.com and we will get back to you.




Registration form

FEE SCHEDULE (US\$)

CATEGORY	Before 01 July	01 July or later
ISRP member	895.00	1,095.00
ISRP member - presenter	795.00	995.00
Non-member	995.00	1,195.00
Non-member - presenter	895.00	1,095.00
Day attendee (per day)	300.00	300.00
Extra person - cocktail party	45.00	45.00
Extra person - banquet dinner	150.00	150.00
Student - conference only	400.00	500.00
Student - conf+cocktails+banquet	500.00	600.00
Student - day attendee (per day)	100.00	125.00
Exhibitor	500.00	500.00
Sponsor level:		
Paul Revere	7,500.00	7,500.00
John Adams	6,000.00	6,000.00
John Hancock	4,500.00	4,500.00
Samuel Adams	3,000.00	3,000.00
Kennedy Honors	2,500.00	2,500.00
Boston Common & Public Garden	5,000.00	5,000.00
Boston Tea Party	Negotiable	Negotiable

BOOKING

Category (see above)	No.	Total US\$

Grand total: US\$

DELEGATE

Mr/Ms/Mrs/Dr/other:

First name(s):

Last (family) name:

Position:

Organization:

Address:
(Full address, including city, state/province, postcode/zip and country)

Email:

Telephone:
(incl. intl & area code)

Names of other delegates included in this registration (if any):

PARTNER/GUESTS

Name(s):

SEND THIS FORM TO:

Attn: Amy Quiring
c/o Scott Safety
4320 Goldmine Road
Monroe, NC 28110, USA
F: +1 (704) 291-8420 (Attn: A. Quiring)
E: boston@isrp.com

PAYMENT

☐ I enclose a US personal/company check*
☐ I enclose an international bank draft*
☐ I enclose an international money order*
☐ I have made an electronic fund transfer*
☐ I wish to pay by credit card (details below)

For complete banking details, see the 'Be a delegate' page on the Boston Conference website (www.isrp.com/boston)

Card type:

☐ 
☐ 
☐ 

Card number:

Name on card: Security code:

Expiry mo/yr: /

Signature (if appl.):

Amount charged to card: **US\$**