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Evaluation of a Method to Measure Respirator Filter Penetration Using the TSI Portacount® Plus

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Abstract

This study evaluated a suggested method of measuring the penetration of submicrometer aerosols through N95 filter media. The proposed method measures the penetration of ambient particles through N95 filters at 31.4 L/min using the Portacount® Plus. Filter penetration measurements were made on two brands of N95 filtering facepiece respirators using both the proposed method and human breathing. Mean penetration values measured on people differed from the proposed method by 3% to 600%. In a separate evaluation, test subjects wore elastomeric half facepieces sealed to their faces to minimize faceseal leakage. Ambient aerosol QNFT were performed with P100 and N95 filters without disturbing the facepiece. Since some penetration of submicrometer aerosols is expected with N95 media, the latter was a total penetration measurement. Penetration of the ambient aerosol through the N95 filters was then measured on a fixture using the proposed method. The measured filter penetration was subtracted from total penetration for the N95 QNFT. The remaining penetration was assumed to be faceseal leakage and was used to calculate a "corrected fit factor" for each subject. Mean corrected N95 fit factors were significantly different than the P100 fit factors. In addition, there was essentially no correlation between corrected N95 fit factors and P100 fit factors. It was concluded that the proposed penetration measurement method should not be used to assess any aspect of respirator performance.

Keywords: fit testing, respirator, fit factor, QNFT, filter penetration, total inward leakage

Introduction

In some situations, it may be desirable to study the performance of N95 filtering facepiece respirators (FFR) in a laboratory environment. For example, it could be useful to perform quantitative fit testing (QNFT) with ambient aerosols. There may also be benefit to studying simulated workplace performance of FFR. In either case, the measurement is often difficult because many ambient particles and typical laboratory generated aerosols lie in the "most penetrating" size range (Bierman *et al.*, 1991). Because N95 respirators are permitted to have up to 5% penetration of these aerosols measured under "worst case" conditions (Federal Register, 1995), filter penetration can contribute to any laboratory performance measurement assessing fit made with submicrometer aerosols.

Zhuang *et al.* (1998) designed a simple clamping device to measure N95 filter penetration to allow QNFT of FFR with

continued. on page 2 >

Evaluation of a Method to Measure Respirator Filter Penetration Using the TSI Portacount® Plus (*continued from page 1)*

the Portacount® Plus Respirator Fit Tester (TSI, Inc., St. Paul, MN). They proposed that filter penetration of a small area of the FFR could be measured with their clamp and the Portacount Plus. They subtracted this penetration from the total inward leakage (TIL) measurements made on test subjects with the Portacount Plus, such that the remaining penetration would represent only faceseal leakage, i.e., allowing a "corrected" fit factor to be determined. Zhuang *et al.* treated the corrected fit factors as fit factors measured in the traditional manner, i.e., on an elastomeric facepiece using class 100 filters. An evaluation of that method demonstrated that the clamp measurements did not accurately represent filter penetration of ambient aerosols (Janssen et al., 2003a). More recently Coffey *et al.* used simulated workplace protection factors (SWPF) measured on N95 FFR to evaluate the performance of five fit tests. The fit tests were judged on their ability to assure 5th percentile SWPF greater than 10. The penetration measured during the SWPF consisted of both filter penetration and faceseal penetration of ambient aerosols. The fit tests Coffey *et al.* evaluated included the generated corn oil and ambient aerosol methods (Coffey *et al.*, 2002). For these two methods, TIL measurements made during the fit test were corrected for filter penetration of the test aerosol to determine a fit factor in a manner similar to that used by Zhuang *et al.* (1998). However, in this study the Portacount Plus was used to measure penetration through the entire FFR as air was drawn through it at a rate of 31.4 L/min. Coffey *et al.* used this procedure again as part of a subsequent study of respirator fitting characteristics (Coffey *et al.*, 2004).

Like the study of Zhuang *et al.* (1998), Coffey *et al.* (2002, 2004) relied on the assumption that filter penetration measured at a fixed flow rate on a test fixture is equal to the filter penetration resulting from human breathing. No data was presented in any of these studies to support that assumption. Since the validity of the filter penetration measurement is critical to the outcome of the fit tests, this study was initiated with the following objectives:

1. To determine if filter penetration measurements made in the manner proposed by Coffey *et al.* reasonably represent the penetration of ambient particles through N95 filters;

2. To determine if these penetration measurements compare favorably with penetration measurements made on the same filters using human breathing;

3. To determine if filter penetration measurements made with the method proposed by Coffey *et al.* can be subtracted from TIL measured on test subjects using the Portacount Plus to yield corrected fit factors that correlate with traditional quantitative fit factors measured with class 100 filters;

4. To determine if measurements made using the method of Coffey *et al.* can lead to valid conclusions regarding respirator fit or fit test performance.

This study was limited to an evaluation of the filter penetration measurement method. It did not attempt to evaluate the specific conclusions of Coffey *et al.* (2002, 2004) regarding fit test performance or respirator fitting characteristics.

Materials and Methods

All ambient aerosol testing was conducted in the same laboratory using the same Portacount Plus. The atmosphere in the laboratory had less than 1,000 particles per cubic centimeter, the minimum necessary for the Portacount Plus to measure fit factors (TSI, 2003). For these situations, the TSI Model 8026 Particle Generator (TSI, St. Paul, MN) was developed to supplement the ambient particle count (TSI, 2002). Two 8026 generators were used simultaneously in this study. The 8026 generators use a 2% sodium chloride solution to produce an aerosol with a nominal count median diameter (CMD) of 0.04 μm and a nominal GSD of approximately 2.2 (TSI, 2002). A small fan was used to direct the aerosol toward the FFR or respirator undergoing testing.

Filtering Facepiece Filter Penetration Testing

The first portion of the study involved measuring the filter penetration of two models of N95 FFR using the method of Coffey *et al.* (2002). Both respirators were approved by the National Institute for Occupational Safety and Health (NIOSH). The Gerson® model 2737 (Louis M. Gerson Co., Middleboro, MA) and 3M model 8210 (3M, St. Paul, MN) were used to represent the approximate range of ambient aerosol penetration values reported by Coffey *et al.* (2002).

continued on page 3 >

Evaluation of a Method to Measure Respirator Filter Penetration Using the TSI Portacount® Plus (*continued from page 2*)

Attempts were made to construct a test fixture identical to that illustrated by Coffey *et al.* (2002) in their Figure 1. Each respirator was sealed to a flat plate with hot-melt glue. A 25mm hole at the back of the plate allowed it to be attached to a house vacuum source with a short length of 25mm Nalgene® tubing (Nalge Nunc International, Rochester, NY). The house vacuum was set to draw 30.7 L/min through the filter media using a calibrated dry gas meter (Singer American Meter Division). When the fixture was connected to the Portacount Plus as illustrated by Coffey *et al.* (2002), the house vacuum caused backflow through the Portacount Plus and rendered it nonfunctional. Therefore, the following modifications to the test fixture were made: A hose barb was inserted into the 25mm tubing approximately 15cm downstream from the back of the plate. The hose barb was perpendicular to the airstream created by the house vacuum and extended to the approximate center of the 25mm tubing. The inside sampling line (C_i) from the Portacount Plus was connected to the hose barb. This modification allowed the Portacount Plus to properly sample from the airstream so aerosols that penetrated the filter media could be counted. The ambient sampling line (C_o) from the Portacount Plus was attached to the flat plate such that the open end was immediately adjacent to the FFR.

The vacuum flow rate was confirmed periodically throughout the testing. The flow rate of the Portacount Plus was confirmed to be 0.7 L/min with a Gilibrator II® system (Sensidyne, Clearwater, FL). Thus, the total airflow through the filter media was 31.4 L/min, the same flow rate used by Coffey *et al.* (2002).

Six samples of the Gerson 2737 and six samples of the 3M 8210 were tested using this apparatus. Six replicates consisting of four penetration measurements were made on one sample of each brand to allow the reproducibility of the method to be examined. Three penetration measurements were made on the remaining five samples of each brand of FFR.

The same samples of each brand of FFR that were subjected to replicate testing were also used in the human breathing penetration measurements. This testing was done to determine if the filter penetration measurements made during human breathing would be the same as those measured on the fixture at 31.4 L/min. The respirator was glued to a flat plate as described above. However, for these measurements the 25mm tubing was attached to a mouthpiece with saliva trap (Medical Graphics Corp., St. Paul, MN) through which the subjects breathed. A noseclip was used to prevent nasal inhalation. Three women and three men participated in this testing. Subjects held the test apparatus to their mouth while seated. Penetration measurements were made during one minute of normal breathing and one minute of deep breathing.

Finally, all six of each brand of FFR glued to a flat plate were tested for penetration in a 14.5m^3 QNFT chamber with a generated sodium chloride aerosol. This testing was done to determine if the filter penetration measurements would be the same in an atmosphere with a controlled particle concentration as in a variable, ambient atmosphere. Three replicate measurements were made on each FFR. Measurements were made with the same Portacount Plus used in the tests described previously, and total flow through the respirators was 31.4 L/min. The aerosol was generated with a Model 9306A Six Jet Atomizer (TSI, St. Paul, MN). The particle size distribution was measured with a TSI Model 3071 Electrostatic Classifier (TSI, St. Paul, MN) used in conjunction with a TSI Model 3022A Condensation Particle Counter (TSI, St. Paul, MN). The count median diameter (CMD) was 0.07 μm and the GSD approximately 2.2.

Corrected Fit Factor Evaluation

This portion of the study was done to examine the validity of subtracting N95 filter penetration measurements made on the test fixture from total penetration measurements made on test subjects wearing half facepiece respirators. Coffey *et al.* (2002, 2004) used this practice to estimate faceseal penetration. It is known that filter penetration is essentially zero when respirators are fitted with P100 filters. Therefore, if the practice of Coffey *et al.* is valid, the N95 "fit factor" corrected for filter penetration should approximately equal the P100 fit factor for a given faceseal penetration.

It was necessary to use elastomeric facepieces for this portion of the study

continued. on page 4 >

Evaluation of a Method to Measure Respirator Filter Penetration Using the TSI Portacount® Plus (*continued from page 3)*

so filters could be changed while holding faceseal penetration constant. Survivair® Series 2000 (Survivair, Santa Ana, CA) and 3M Model 6X00 (3M, St. Paul, MN) elastomeric half-facepiece respirators were used in this portion of the study. Each brand of respirator was available in three sizes. The Survivair respirators were fitted with a part number 420025 fit test adapter between the filter and filter connector. This allowed in-facepiece sampling via a short length of plastic tubing. Survivair part number 1050 P100 filters and part number 1060 N95 filters were used during the testing.

The 3M respirators were fitted with two 3M model 601 QNFT adapters. The adapter used for in-facepiece sampling was mounted on one side of the facepiece as described above for the Survivair respirators. The second 601 adapter was mounted between the filter and filter connector on the other side of the facepiece. It was used to provide a gripping surface so filters could be easily changed without disturbing the position of the facepiece. No tubing was inserted into the facepiece from this adapter. The hose barb on this adapter was permanently capped with a rubber septum. 3M Model 2091 P100 and Model 5N11 N95 filters were used during the testing.

Four women and eight men participated in this portion of the study. Subjects were selected based on their ability to achieve high fit factors. This assured a low "baseline" of faceseal penetration. To further assure faceseal leakage would be minimal, a small amount of Dow Corning® High Vacuum Grease (Dow Corning, Midland, MI) was applied to the respirator's sealing edge. Subjects were assigned an appropriately sized Survivair or 3M respirator equipped with P100 filters based on their past QNFT history or observation of their facial features. The order in which the two brands were assigned was alternated. After the subject performed a user seal check, the Portacount Plus was connected to the fit test adapter. A few minutes were allowed for the facepiece to clear of particles, confirmed by a particle count at or near zero with the Portacount Plus in the count mode. This test also assured that faceseal leakage was negligible.

To assure that faceseal leakage was not induced by excessive facial movements, standard fit test exercises were not used. Instead, subjects repeated a sequence of normal breathing followed by deep breathing twice while seated. Each of the four breathing exercises lasted one minute. After the second deep breathing exercise, the overall fit factor was recorded, and the P100 filters were replaced with N95 filters without disturbing the position of the facepiece. A second "fit test" was conducted using the same breathing exercises. At the end of this test, the subject switched to the other brand of respirator and repeated the test procedure. Finally, the entire test sequence was replicated. A different set of N95 filters was used for the second trial with each brand of respirator.

After the fit tests, each pair of N95 filters was mounted on a T-shaped stainless steel or PVC fixture. The fixture was attached to the same length of 25mm Nalgene tubing used for testing penetration of the FFR. This tubing was then attached to the house vacuum, and penetration measurements were made as described for the FFR. In this case, the Portacount Plus C_o sampling line was attached to the T-shaped fixture between the two filters. Corrected fit factors were calculated by subtracting the filter penetration measurement for each pair of N95 from the TIL measurement using the same pair of N95 filters.

Results

Means and relative standard deviations (RSD) of the FFR filter penetration measurements are shown in Tables I–III. For reference, note that Coffey *et al.* reported a mean penetration of 1.43% for the Gerson 2737 and 0.29% for the 3M 8210, respectively, using the Portacount Plus and an ambient aerosol challenge (Coffey *et al.*, 2002). They did not report RSD or any other measure of variability.

As shown in Table I, the mean of the replicate measurements on a single sample of the 2737 was 1.61%, approximately 1.1 times the value reported by Coffey *et al.* The mean of the remaining five samples was 10% lower than the previously reported value. In the case of the 8210, the mean of the replicate measurements on a single sample agreed exactly with the previously reported value of 0.29%. The mean of the remaining five samples was 1.6 times higher than reported by Coffey *et al.* The RSD values are large for all four sets of measurements: even in the case of best agreement with the penetration measurement reported by Coffey *et al.* (replicate measurements

continued on page 5 >

Evaluation of a Method to Measure Respirator Filter Penetration Using the TSI Portacount® Plus (*continued from page 4*)

on a single 8210), a single penetration measurement could be expected to range from 0.03–0.55%.

Penetration results for human subjects breathing through a single sample of each FFR are shown in Table II. In the case of normal breathing through the 2737, the mean penetration measurements were only 3% higher than those made using the method proposed by Coffey *et al.* The penetration for deep breathing through the 2737 was 2.6 times higher than reported by Coffey *et al.* For the 8210, the penetration measurements were 3.1 times and 7 times higher than reported by Coffey *et al.* for normal and deep breathing, respectively.

As shown in Table III, the mean penetration measurements for the 2737 in the fit test chamber were 52% lower than the replicate measurements using the ambient aerosol method proposed by Coffey *et al.* (Table I). The measurements for the 8210 were 10% lower than reported by Coffey *et al.*

Table IV lists the results of the tests comparing P100 fit factors with TIL measurements using N95 filters corrected for filter penetration (corrected N95 "fit factors"). There was essentially no correlation between the two values: r^2 values were 0.03 and 0.02 for the Survivair and 3M respirators, respectively. In 18 instances the N95 fit factors corrected for filter penetration were negative values, indicating that filter penetration measured using the method of Coffey *et al.* exceeded total penetration. This is obviously not possible.

Discussion

Data presented in Tables I–IV clearly demonstrate the unsuitability of the filter penetration measurement method proposed by Coffey *et al.* for evaluating any aspect of respirator performance. It appears at least five significant sources of variability contribute to the imprecision and inaccuracy of its filter penetration measurements. It was not the objective of this study to determine the contribution of each source to the overall variability seen in the method. Making these determinations would be difficult because of the probable interdependence of the individual sources. The five major sources of error are as follows:

1. **Variability of the instrument.** The Portacount Plus has a stated accuracy of ±10% of the fit factor reading up to fit factors of 10,000 (TSI, 2003). Since filter penetration values are calculated as 100/FF, the accuracy limitation of the instrument likely accounts for some of the measurement variability reflected by the large RSD values. This is most evident in the 24 replicate measurements on sample 1 of each FFR in Table I. Close agreement among the individual measurements would be expected, but RSD values for both FFR are greater than 50%. Instrument error likely interacts with the variability in the ambient aerosol challenge discussed below.

2. **Variability in the challenge atmosphere.** The use of an uncontrolled, ambient test atmosphere allows particle concentrations to fluctuate over a wide range. The average ambient concentrations in this study varied from approximately 2,800 p/cc to approximately 64,000 p/cc (geometric mean=10,246, GSD=2.1). In contrast, the particle concentration in the fit test chamber was held constant at approximately 21,000 p/cc (typical value geometric mean=20,918, GSD=1.03). Examination of Table III suggests a relationship between the challenge atmosphere and penetration measurements. The mean chamber penetration value and RSD for multiple samples of the 2737 was substantially lower than the equivalent measurement made in the ambient atmosphere. While the mean chamber penetration for the 8210 was closer to the ambient value, the RSD was again substantially lower. This indicates the penetration measurement is related to the stability of the challenge atmosphere.

3. **Variability in N95 filter media.** Some variation in penetration is expected among filters from a given manufacturer, even within the same manufacturing lot. In previously reported work (Janssen *et al.*, 2003b), N95 filters from two manufacturers were tested for initial penetration using the "worst case" conditions specified for NIOSH approval (Federal Register, 1995). The mean penetration value for one manufacturer was 0.56% with an RSD of 16%. For the second manufacturer the value was 0.49% with an RSD of 71%. In addition, NIOSH test conditions were used to collect unpublished initial penetration data on ten models of FFR in this laboratory. RSD values ranged from 9.7% to 55%.

continued. on page 6 >

Evaluation of a Method to Measure Respirator Filter Penetration Using the TSI Portacount® Plus (*continued from page 5)*

Since the NIOSH test conditions are carefully controlled, it is reasonable to expect at least this much variability when using the method recommended by Coffey *et al.* In this study, the chamber penetration measurements shown in Table III were collected under controlled test conditions. The RSD values of 37% and 57% for the 2737 and 8210, respectively, are within the expected range of filter media variability.

4. **Variability in flow rate during a fit test.** The total sampling flow rate of 31.4 L/min used by Coffey *et al.* represents a volume-weighted average flow rate for a fit test subject who has an average minute volume of 10.3 liters, a peak flow rate of 40 L/min and a sinusoidal breathing pattern (Zhuang *et al.*, 1998). These assumptions were based on data for subjects at rest reported by Silverman *et al.* (1952). However, the two standard deviation range (± 2 SD) for resting minute volume for Silverman's subjects was 6.9–13.7 L/min. The ± 2 SD range of peak flow rate was 24–56 L/min. As a result, the range of volume-weighted average flow would be 18.9–44.0 L/min. Previous work found a linear increase in penetration of submicrometer particles with increasing flow rate in the range of 8–32 L/min for a single filter normally used in a pair (Janssen *et al.*, 2003a). These flow rates correspond to a range of 16–64 L/min for a pair of filters or an FFR worn by a fit test subject. Further, since fit tests typically require subjects to breath at different rates, e.g., normal and deep breathing, additional error would be introduced. This phenomenon was seen in earlier work (Janssen *et al.*, 2003a). It is also seen in Table II, where the human breathing penetration values are higher than those reported by Coffey *et al.*, and deep breathing measurements exceed normal breathing measurements.

5. **Variability in particles expired by fit test subjects.** Fairchild and Stampfer (1987) reported that individuals exhale up to four particles per cubic centimeter, depending upon the individual and their activity (Fairchild and Stamper, 1987). They noted that the number of particles exhaled was lowest for normal breathing (GM ~0.22 p/cc) and higher for more strenuous activities, including the deep breathing and talking exercises (GM ~0.5 and 0.65 p/cc, respectively). Harrison and Liang (2005) reported exhaled particle counts as high as 10.8 p/cc for deep breathing and 17.4 p/cc when subjects read the rainbow passage. The arithmetic mean particle counts for these exercises, respectively, were 0.16 p/cc and 4.1 p/cc for 10 subjects. The penetration values in Table II are consistent with the findings of these two studies. Except for the normal breathing penetration measurement for the 2737, the mean human breathing values in Table II are substantially higher than the measurements made using the method suggested by Coffey *et al.* The anomaly for the 2737 is likely explained by its relatively higher filter penetration: a small number of exhaled particles contribute relatively less to the overall particle count than in the case of a "cleaner" C_i environment.

It is suggested that it is the interaction of these sources of variability that accounts for much of the error in the filter penetration measurements reported by Coffey *et al.* Because the cumulative effect on the measurement error is quite large, it is inappropriate to report a single "correct" penetration value for any N95 FFR or filter.

It should be noted that the N95 filter penetration measurements listed in Table IV and used to correct the N95 "fit factors" were well within the range of penetration values reported by Coffey *et al.*: 0.24% (RSD 12%) for 3M and 0.62% (RSD 11%) for Survivair. Since faceseal leakage was minimized to the extent feasible in these tests and the facepiece was not disturbed when switching from P100 to N95 filters, the only known source of penetration into the facepiece was the N95 filters. That is, filter penetration should be approximately equal to total penetration measured with the Portacount Plus. Thus, if the method proposed by Coffey *et al.* is valid, subtracting filter penetration from total penetration should result in a penetration value very close to zero. The corrected N95 "fit factor" calculated using this value should be approximately equal to the corresponding P100 fit factor because the faceseal penetration has not changed. As shown in Table IV, this is clearly not the case. Mean corrected N95 fit factors were more than an order of

continued on page 7 >

Evaluation of a Method to Measure Respirator Filter Penetration Using the TSI Portacount® Plus (*continued from page 6*)

magnitude lower than the P100 fit factors for both manufacturers' respirators. This result is similar to previous work (Janssen *et al.*, 2003a). Clearly, correcting TIL for filter penetration using the method proposed by Coffey *et al.* does not yield an accurate estimate of faceseal leakage.

Conclusions

N95 filter penetration is not accurately measured with an ambient aerosol challenge and the Portacount Plus using the method proposed by Coffey *et al.* At least four sources of variability interact to introduce large error in the measurement made on a test fixture. As a result, no single penetration value measured this way is correct for any N95 FFR or N95 filter. Additional error is introduced when the FFR or N95 filters are worn by test subjects because people exhale a variable number of particles. It is clearly not useful to subtract a penetration value measured on a fixture from total penetration measured on a test subject. The remaining penetration cannot be assumed to represent faceseal leakage. Rather, it is a combination of faceseal leakage plus or minus a large amount of measurement error and aerosols exhaled by the test subject.

Data from this study demonstrate that total penetration measurements corrected for N95 filter penetration measured using the method of Coffey *et al.* do not yield meaningful estimates of faceseal penetration. Therefore, this method should not be used to judge respirator fit or fit test accuracy. ■

Table I. N95 filtering facepiece filter penetration measurements-ambient atmosphere.

Respirator (Sample No.)	Penetration 1 (%)	Penetration 2 (%)	Penetration 3 (%)	Penetration 4 (%)	Mean % Penetration
2737 (1)	0.98	0.83	2.22	1.04	1.27
2737 (1)	3.03	4.00	1.59	1.22	2.44
2737 (1)	0.74	1.04	3.23	0.83	1.47
2737 (1)	0.51	2.86	0.96	1.25	1.90
2737 (1)	1.54	1.28	1.09	1.41	1.33
2737 (1)	1.59	2.13	2.27	1.09	1.75
				% Penetration Mean (RSD) of 24 replicates	1.61 (56%)
2737 (2)	0.27	0.22	0.20	—	0.23
2737 (3)	0.85	0.66	1.00	—	0.84
2737 (4)	0.24	0.60	2.33	—	1.02
2737 (5)	0.95	2.94	0.74	—	1.54
2737 (6)	3.57	3.23	1.59	—	2.79
				% Penetration Mean (RSD) of 15 replicates	1.29 (90%)
8210 (1)	0.24	0.26	0.42	0.41	0.33
8210 (1)	0.12	0.21	0.14	0.22	0.17
8210 (1)	0.29	0.31	0.72	0.43	0.44
8210 (1)	0.10	0.24	0.18	0.33	0.22
8210 (1)	0.17	0.28	0.58	0.38	0.35
8210 (1)	0.24	0.20	0.28	0.25	0.24
				% Penetration Mean (RSD) of 24 replicates	0.29 (90%)
8210 (2)	0.19	0.14	0.10	—	0.14
8210 (3)	1.23	0.72	0.36	—	0.77
8210 (4)	0.66	1.30	1.15	—	1.04
8210 (5)	0.11	0.15	0.30	—	0.19
8210 (6)	0.13	0.27	0.29	—	0.23
				% Penetration Mean (RSD) of 15 replicates	0.47 (91%)

continued. on page 8 >

Evaluation of a Method to Measure Respirator Filter Penetration Using the TSI Portacount® Plus (*continued from page 7*)

Table II. Human breathing ambient aerosol penetration measurements (N95 respirators).

Subject (Gender)	Respirator (Sample No.)	NB % Penetration		DB % Penetration		Mean % Penetration
1 (F)	2737-1	1.82		3.33		2.58
2 (F)	2737-1	2.04		3.23		2.63
3 (M)	2737-1	0.98		3.12		2.05
4 (M)	2737-1	2.50		8.33		5.42
5 (M)	2737-1	0.67		5.26		2.96
6 (F)	2737-1	1.96		1.47		1.72
	Mean (RSD)	1.66 (42%)	Mean (RSD)	4.13 (58%)	Mean (RSD)	2.89 (45%)
1 (F)	8210-1	0.93		2.50		1.71
2 (F)	8210-1	0.43		0.87		0.65
3 (M)	8210-1	2.08		2.27		2.18
4 (M)	8210-1	1.59		2.78		2.18
5 (M)	8210-1	0.27		3.70		1.98
6 (F)	8210-1	0.06		0.07		0.06
	Mean (RSD)	0.89 (90%)	Mean (RSD)	2.03 (66%)	Mean (RSD)	1.46 (62%)

Table III. N95 filtering facepiece filter penetration measurements-chamber atmosphere.

Respirator (Sample No.)	Penetration 1 (%)	Penetration 2 (%)	Penetration 3 (%)	Mean % Penetration
2737 (1)	0.56	0.50	0.54	0.53
2737 (2)	0.89	0.90	0.86	0.88
2737 (3)	1.01	1.04	1.12	1.06
2737 (4)	0.41	0.44	0.46	0.44
2737 (5)	0.59	0.56	0.58	0.58
2737 (6)	1.15	1.16	1.20	1.17
			% Penetration Mean (RSD) of 18 replicates	0.78 (37%)
8210 (1)	0.54	0.56	0.56	0.55
8210 (2)	0.15	0.13	0.12	0.13
8210 (3)	0.28	0.29	0.31	0.29
8210 (4)	0.22	0.24	0.24	0.23
8210 (5)	0.15	0.18	0.19	0.17
8210 (6)	0.18	0.16	0.15	0.16
			% Penetration Mean (RSD) of 18 replicates	0.26 (57%)

continued on page 9 >

Evaluation of a Method to Measure Respirator Filter Penetration Using the TSI Portacount® Plus (*continued from page 8*)

Table IV. Fit Factor, N95 "fit factor" and N95 "fit factor" corrected for filter penetration

Subject	Respirator	P100 Fit Factor	N95 "Fit Factor"	Filter Penetration (%)	Corrected N95 "Fit Factor"
1	3M	2410	482	0.233	-3986
		5700	278	0.526	-600
	Survivair	5470	136	1.538	-125
		9330	62	0.463	87
2	3M	15600	452	0.056	605
		10200	447	0.111	889
	Survivair	12200	126	0.216	173
		8500	76	0.633	146
3	3M	1590	184	0.613	-1428
		2810	142	0.233	212
	Survivair	2630	130	0.758	8580
		3550	92	0.424	151
4	3M	13300	282	0.323	3122
		3300	144	0.265	233
	Survivair	10600	107	0.592	292
		7880	193	0.275	412
5	3M	263000	487000	0.431	-232
		267000	261000	0.175	-574
	Survivair	68900	386	0.164	1048
		28400	191	0.259	378
6	3M	38600	659	0.472	-313
		25000	731	0.163	-3836
	Survivair	15600	153	0.350	329
		17300	120	1.176	-291
7	3M	18300	800	0.317	-520
		54100	825	0.164	-2326
	Survivair	24600	395	0.781	-189
		24900	329	0.794	-204
8	3M	10200	177	0.180	260
		18200	247	0.260	692
	Survivair	5130	74	0.457	112
		11100	102	0.641	295
9	3M	377000	469000	0.113	-885
		255000	285000	0.088	-1145
	Survivair	10900	42	0.730	61
		11600	60	0.372	77
10	3M	62600	702	0.281	-722
		35600	616	0.138	4129
	Survivair	47500	449	0.442	-455
		54100	436	0.741	-196
11	3M	20700	150	0.216	222
		21700	172	0.169	242
	Survivair	24300	81	1.136	1018
		18000	55	0.602	82
12	3M	25800	138	0.104	161
		38300	131	0.230	188
	Survivair	18700	39	0.588	51
		24300	56	0.847	107

continued. on page 10 >

Evaluation of a Method to Measure Respirator Filter Penetration Using the TSI Portacount® Plus (*continued from page 9*)

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