Collection of Silica and Asbestos Aerosols by Respirators at Steady and Cyclic Flow

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Air-purifying dust/mist respirators are presently tested using a silica aerosol under conditions of steady flow. In the experiments described here, the predictive validity of such tests was evaluated by testing respirators using silica and asbestos aerosols under conditions of both steady and cyclic flow. Although measurements of silica penetration at steady flow were reasonably predictive of silica penetration under cyclic flow, they were not for asbestos penetration under either steady or cyclic flow. Furthermore, the potential for exhalation valve failure under cyclic flow was identified. These results indicate that current NIOSH protocols for evaluating respirator performance should be re-evaluated.

Introduction

Tests used by the National Institute for Occupational Safety and Health (NIOSH) and the Mine Safety and Health Administration (MSHA) to certify respiratory protective equipment[1] were originally developed by the Bureau of Mines in the early 1900's. The test procedures have changed little, but equipment design has advanced rapidly. There is general agreement among respirator users and manufacturers that the current certification tests are in many cases inappropriate for modern respirator designs.[2]

NIOSH has recognized the need for updating respiratory protection certification tests,[2,3,4] and the research reported here was designed to address certain aspects of the certification program for particle-filtering respirators. Such tests now employ a limited number of aerosols--none of which is fibrous in nature. Air purifying respirators equipped with dust/mist filters are tested using continuous flow, while only disposable respirators (those which until recently had no exhalation valve) are tested under more characteristic cyclic flow conditions.

Even though respirators using dust/mist filters were previously certified for use against asbestos,[1] NIOSH has recommended against their use in such atmospheres[5] and the Occupational Safety and Health Administration (OSHA) asbestos standard prohibits use of these respirators in asbestos-containing atmospheres.[6] These actions were taken with little or no knowledge of the asbestos collection efficiency of dust/mist filters.

The particular issues addressed by this research are:

What is the penetration of silica and asbestos aerosols through electrostatically-charged dust/mist respirator filters when challenged with silica and asbestos under conditions similar to those of NIOSH approval tests, i.e., continuous flow of 0.032 m^3/min?

2. What is the relationship between penetration measured by the continuous flow and that measured using a more representative cyclic flow?

3. Is it possible to predict, within acceptable limits of error, the observed performance by either purely theoretical models or by semi-empirical models based on measured performance with monodisperse aerosols?

The first two points are addressed in this paper; the third point is addressed elsewhere.[7] The answers to these questions will help to determine if the NIOSH certification results can be used to predict the behavior of a respirator under actual use conditions (i.e., cyclic flow with a significantly different aerosol from that used in the approval tests).

Methods and Materials

Four combinations of aerosol and flow were tested (in the order listed):

1. silica aerosol at steady flow,
2. asbestos aerosol at steady flow,
3. asbestos aerosol at cyclic flow, and
4. Silica aerosol at cyclic flow.

Filter/facepiece combinations were randomized within each of the four sets of experiments.

Three manufacturers' dust/mist filters were selected from a group of ten manufacturers included in a previous set of experiments in which their collection of monodisperse aerosols was measured.[8] These three manufacturers were chosen to represent the range of filter performance exhibited in these previous experiments. Preliminary calculations suggested that ten replicate tests would give sufficient statistical power for data analysis. Thus, ten replications of each respirator of three manufacturers at each of the four aerosol/flow conditions (a total of 120 filter pairs) were tested.

All respirators and parts were purchased through normal distribution channels. The filter pairs were drawn from two lots for two of the manufacturers and from a single lot for the third. Two half-mask silicone/rubber facepieces were included in each set of tests; thus, 8 facepieces per manufacturer and a total of 24 facepieces were included in the entire set of experiments. The filter pairs were randomly assigned to a facepiece; where two separate lots of filters were included care was taken to assure that each received an approximately equal number of filter pairs from each lot. Filters, facepiece, and facepiece elements were only tested in their approved configurations for these experiments, i.e., within manufacturer.

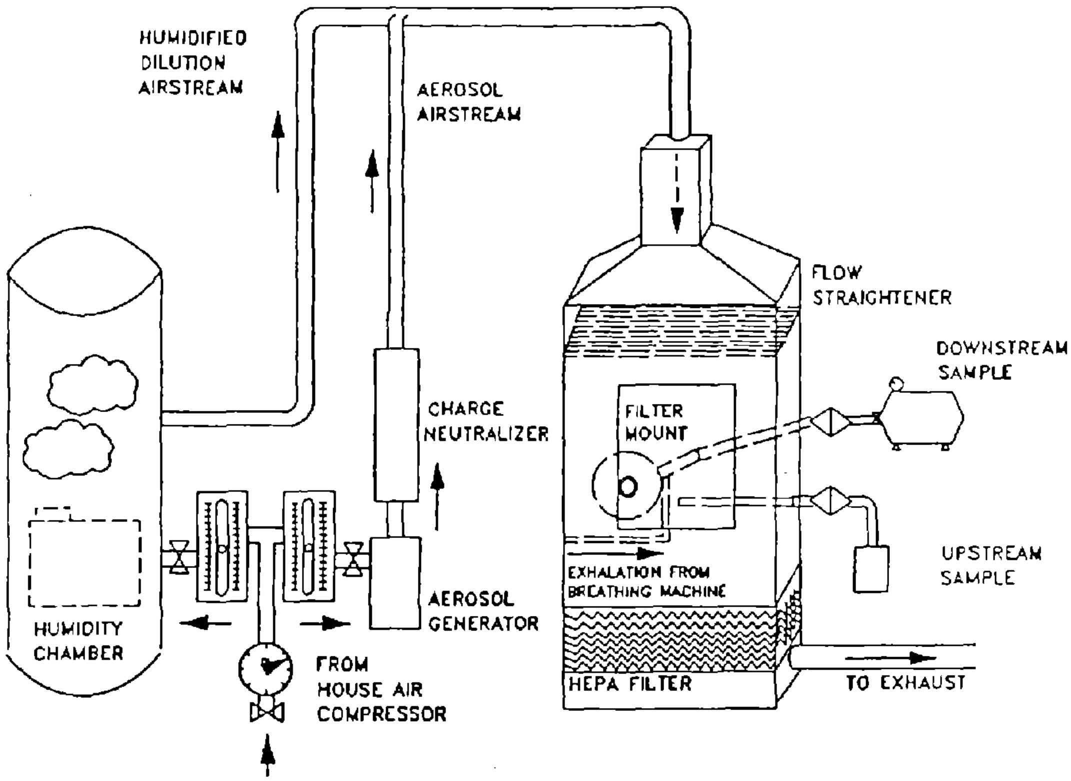
Exhalation and inhalation valves were not replaced during the steady flow experiments. Preliminary tests showed that the exhalation valves of at least one manufacturer (#2) were unfavorably influenced by the 90-min breathing pattern of the cyclic tests; therefore, all valves were replaced before each cyclic flow test. The valves were drawn from one lot for each manufacturer, and were matched to the appropriate manufacturer's facepiece.

Variables critical to the design of these experiments included:

1. Relative humidity and temperature within the test chamber,
2. Generation of test aerosol within the chamber,
3. Sampling from the chamber,
4. Creation of cyclic airflow similar to the human breathing pattern,
5. Mounting and sealing of the experimental filters/facepieces, and
6. Safety of personnel during the course of the experiments.

The approach used to minimize problems associated with each of these factors is described below.

The experimental apparatus (Figure 1) was designed to reproduce the conditions of the NIOSH certification tests for dust/mist[9] (steady flow) and disposable (cyclic flow) respirators.[10] The NIOSH approval protocols require that disposable respirators be tested with a cyclic flow breathing pattern, because they usually lack exhalation valves. The filters of disposable respirators experience both inward and outward airflow during normal use, while the filters attached to a half-mask air purifying respirator will normally experience only an inhalation airflow.


HUMIDIFIED
DILUTION
AIRSTREAM
AEROSOL
AIRSTREAM
FLOW
STRAIGHTENER
DOWNSTREAM
SAMPLE
CHARGE
NEUTRALIZER
FILTER
MOUNT
UPSTREAM
SAMPLE
EXHALATION FROM
BREATHING MACHINE
AEROSOL
GENERATOR
HUMIDITY
CHAMBER
FROM
HOUSE AIR
COMPRESSOR
HEPA FILTER
TO EXHAUST

A 0.4 m^3 exposure chamber constructed of galvanized steel was placed on and sealed to a high efficiency (HEPA) filter. The test aerosol entered the top of the chamber, passed through an air-distributor into the body of the chamber, and was drawn through the HEPA filter into an exhaust duct connected to a general exhaust system. A small axial fan located below the air-distributor and directed upward assured complete aerosol mixing within the chamber. Previous work showed that this combination of air-distributor and mixing fan produced a homogeneous aerosol concentration within the chamber.

Air for dilution and aerosol generation was obtained from a house compressor, passed through a drying filter, and divided into two separate airstreams adjusted with valved rotameters. One airstream was directed through an aerosol generator (discussed below) into a TSI,Inc. (St. Paul, MN) Kr-85 charge neutralizer; the other was directed into a 4.4 m^3 plastic cylindrical chamber in which an ultrasonic humidifier was located. The humidifier output was adjusted by voltage regulator for an average relative humidity (RH) of 50% in the test chamber, chosen to meet the NIOSH certification test requirements of 20-80% RH. Humidified dilution air was then combined with the aerosol as it entered a 7.6 cm diameter duct connected to the top of the exposure chamber.

A Vaisala (Woburn, MA) capacitive thin film humidity sensor and a Gulton Industries, Inc. (East Greenwich, CT) thermistor were placed immediately after the HEPA filter (previous work confirmed that relative humidity measured at this location was similar to that within the chamber). The output from these probes, attached to a digital readout data logger (Gulton Industries, Inc. Rustrak Ranger), was monitored continuously. Manual adjustments to the dilution air humidifier were made as necessary to preserve 50% relative humidity within the test chamber. A record of humidity and temperature during each test run was obtained by transferring stored data from the data logger to an IBM-compatible personal computer and analyzing the results with a software program (Pronto, Gulton Industries, Inc.) to determine mean relative humidity and temperature for each experimental run.

A manometer attached to a static pressure tap measured pressure within the chamber, which was kept slightly negative by adjusting a blast gate located in the exhaust duct immediately after the HEPA filter. Prior to the experiments, the collection efficiency of the HEPA filter was tested with mineral oil and an Air Techniques, Inc. (Baltimore, MD) light-scattering photometer and found to be >99.99%.

The silica aerosol was generated with a Wright dust feeder.[11] The aerosol, #28 silica (200 mesh) from Whittaker, Clark and Daniels, Inc. (South Plainfield, NJ), met the criterion of the NIOSH certification tests (>99% free silica). The asbestos aerosol, using UICC (Union Internationale Contre le Cancer) amosite obtained from Dr. R.E.G. Rendall of the Pneumoconiosis Research Group (Johannesburg, South Africa), was produced with a modified Timbrell generator.[12]

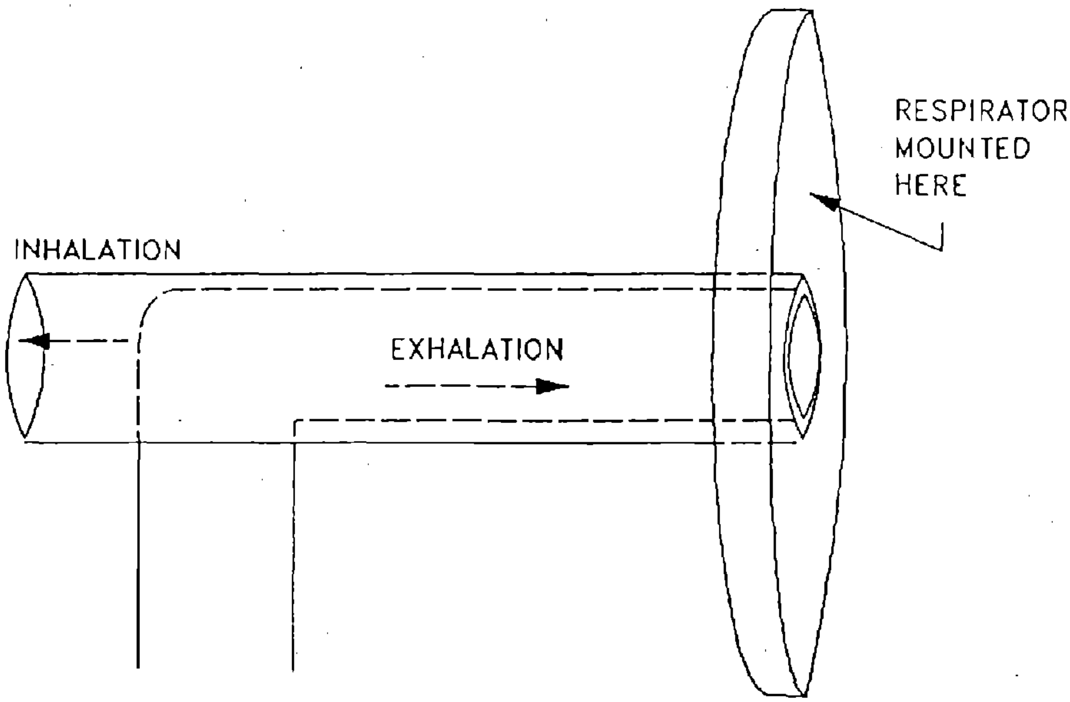
The silica aerosol was sized with a scanning electron microscope and found to have a count median diameter (CMD) of 0.46 μm and a geometric standard deviation (GSD) of 2.5. Transmission electron microscope measurements of the length and width of fibers on two samples of the asbestos aerosol yielded a pooled distribution of lengths with a CMD of 4.5 μm (GSD of 2.7) and of widths with a CMD of 0.2 μm (GSD of 2.5).

Samples of the silica and asbestos aerosol concentrations within the chamber were obtained by drawing air through 1.36 and 0.72 cm diameter probes, respectively, with inlets located near the respirator facepiece. Probe diameters were selected to meet the still-air sampling criteria of Davies.[13] In the silica experiments, the aerosol was sampled for three consecutive 30 min periods onto pre-weighed 47 mm diameter Whatman (Maidstone, England) GF/A glass fiber filters at 0.01 m^3/min through a calibrated critical orifice attached to a rotary vane pump. Pressure downstream of the orifice was continuously monitored with a pressure gauge to verify that filter loading did not affect the sample air flow. The silica concentration in the chamber was maintained at 50-60 mg/m^3, as required by the NIOSH certification test methods. Downstream silica samples were collected on pre-weighed 50 mm diameter filters for one 90 min period at 0.032 m^3/min, as required by the NIOSH test protocol for these respirators. Total mass collected on the upstream and downstream filters was determined gravimetrically. Mass penetration was calculated by dividing the downstream concentration by an average of the three upstream concentrations.

The asbestos aerosol was sampled upstream for 30 min onto a 47 mm diameter Millipore or Gelman 0.8 μm pore size mixed cellulose ester filter using a Dupont Alpha-1 personal sampling pump at a flow of 100 cm^3/min. Downstream asbestos samples were collected on 47 or 25 mm diameter filters at a flow of 0.032 m^3/min for 90 min. A portion of the filter was prepared and counted by phase contrast microscopy according to the NIOSH 7400 method.[14] Asbestos concentrations within the chamber ranged from 800-1200 f/cm^3.

Each respirator facepiece was sealed to a filter mount (Figure 2) designed to direct the movement of inhalation and exhalation air through the facepiece and was attached by a compression fitting to the rear wall of the exposure chamber. During steady flow experiments the exhalation portion of the filter holder was closed off, and a downstream sample was taken at a continuous rate of 0.032 cm^3/min through the respirator filters onto a filter mounted on the outside of the chamber. A rotary vane pump fitted with a calibrated critical orifice and a pressure gauge regulated flow through the downstream sampling train.

A cyclic flow pattern representative of the human breathing cycle at a medium work rate was created through the use of a breathing machine fitted with a 622 kg-m/min cam, as described by Silverman[15] and Wilson and Harrod.[16] The flow was sinusoidal, with a peak value of 0.1 m^3/min, a period of 2.55 sec, a mean flowrate of 0.076 m^3/min, and a minute volume of 0.037 m^3. The airflow was divided into separate exhalation and inhalation


RESPIRATOR
MOUNTED
HERE
INHALATION
EXHALATION

air currents by a valve placed at the outlet of the breathing machine. Heating and humidification of the exhalation air were accomplished by a method described by Nelson.[17] Exhalation air from the breathing valve was directed into a 500-ml flask seated in a metal-jacketed heating mantle, the temperature of which was controlled with a voltage regulator, bubbled through 50 ml heated water, and then directed through a glass condenser tube, which removed most of the large water droplets. This highly humidified air then passed through a section of brass pipe wrapped with heat tape, also controlled by a voltage regulator.

A temperature probe was placed in the air stream immediately ahead of the entry point into the test chamber. Before and after each experiment a humidity probe was also placed in the exhalation air stream at the same point. Appropriate adjustments to the heating mantle and heat tape voltage regulators were made to maintain 94 +/- 3% RH and 35 +/- 2 C temperature in the exhalation air, as required by the appropriate NIOSH certification test.[10] These data were stored using a digital data logger in the same manner as described for the test chamber probes.

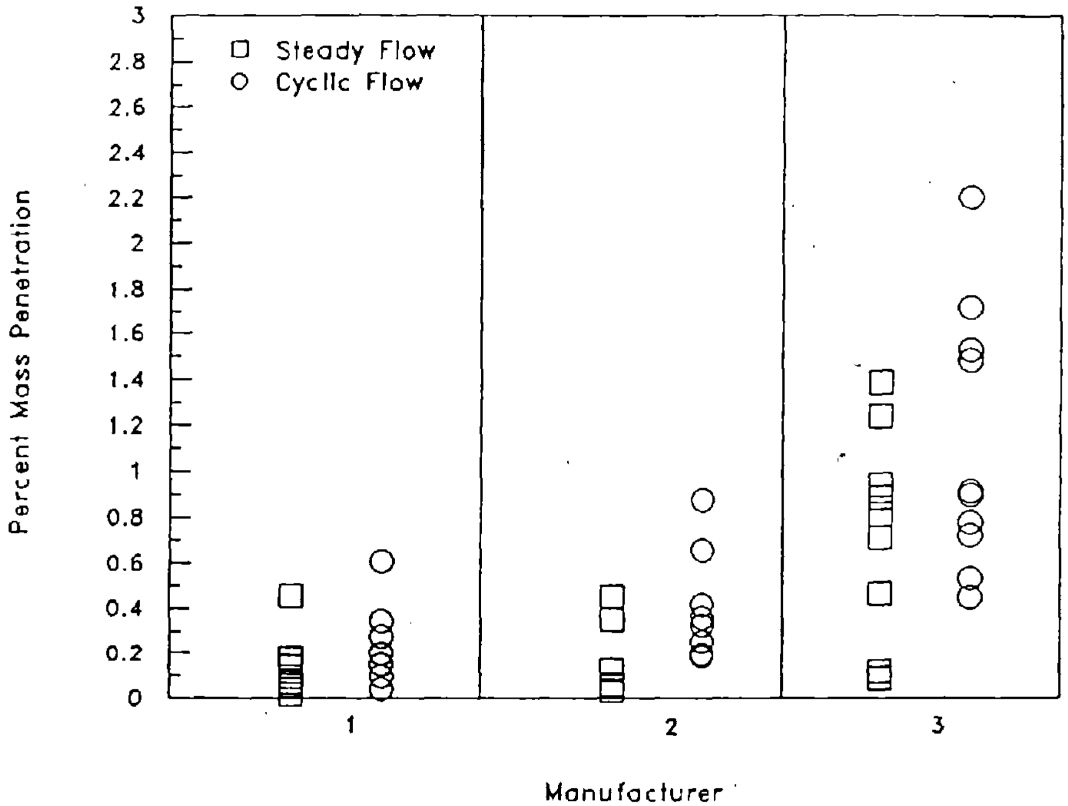
Each of the test facepieces was sealed with clear silicone adhesive onto a fiberglass mold fashioned to fit the facepiece contour, which was then sealed to a lucite disc into which 6 holes had been drilled. The disc was then screwed to the front of the filter holder onto which a rubber gasket was glued. Each facepiece was tested for leaks after sealing by mounting the entire setup on the filter holder, closing off the respirator filter and exhalation openings, and drawing air for several seconds with a pump through the inhalation portion of the filter mount. If the facepiece collapsed slightly inward it was assumed that the facepiece was well-sealed.

A 50x102 cm lucite window placed over a gasketted opening at the front of the test chamber and held in place with four clamps was designed to allow access to the apparatus within. Exhaust was adjusted with the use of a blast gate when the chamber was open to create a minimum face velocity of 30 m/min at the opening. Personal and area air samples were collected periodically and analyzed for asbestos to ensure that aerosol was not being released to the room during filter changing.

Safety precautions were taken to minimize personal exposure to the asbestos aerosol; these included loading the dust generator in a glove box and wearing a respirator equipped with high efficiency filters when the chamber was opened for mounting a new test filter. At the end of each test, the respirator facepiece was carefully wiped down with wet towels before removal from the chamber and the entire filter mount was immersed in water before applying a new respirator/filter test combination. The entire area around the chamber was regularly cleaned with a HEPA-equipped asbestos vacuum.

Results

Mass penetration of silica (Figure 3) under continuous flow conditions was typically less than 0.1%. The average penetration was 0.1% for

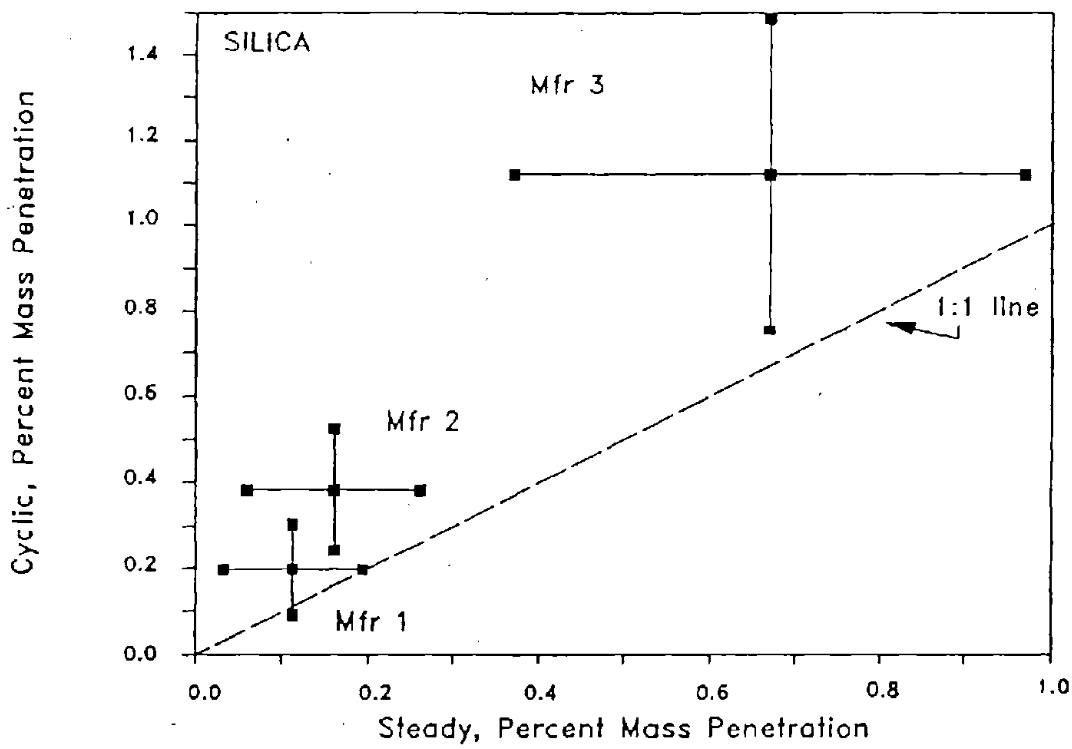

Steady Flow
Cyclic Flow
Percent Mass Penetration
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
Manufacturer

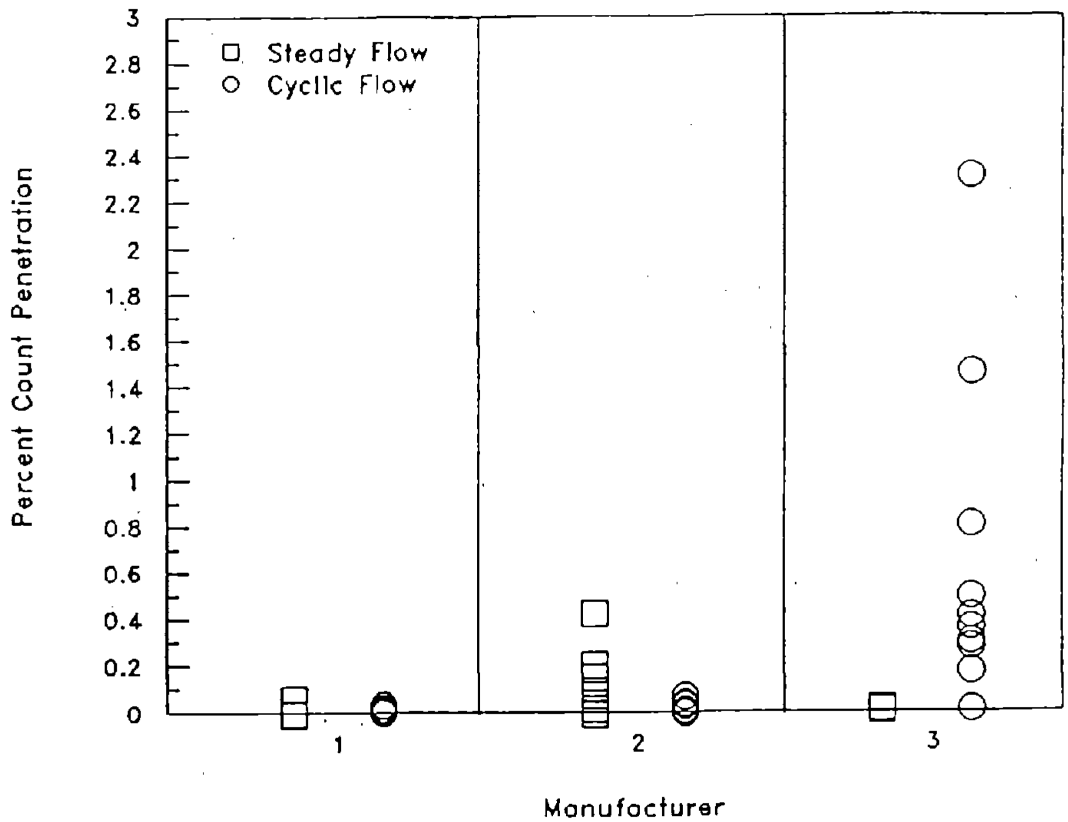
manufacturer 1, 0.2% for manufacturer 2, and 0.8% for manufacturer 3. Mass penetration of silica at cyclic flow averaged 0.2% for manufacturer 1, 0.4% for manufacturer 2, and 1.1% for manufacturer 3. Under both flow conditions the results for manufacturer 3 exhibited greater variability than those for the other manufacturers.

Generally, the penetration of silica under conditions of cyclic flow was about one and a half times as great as that measured under steady flow conditions (Figure 4). Thus, for silica, within the experimental errors of the system, the steady flow results were reasonable predictors of the cyclic flow results.

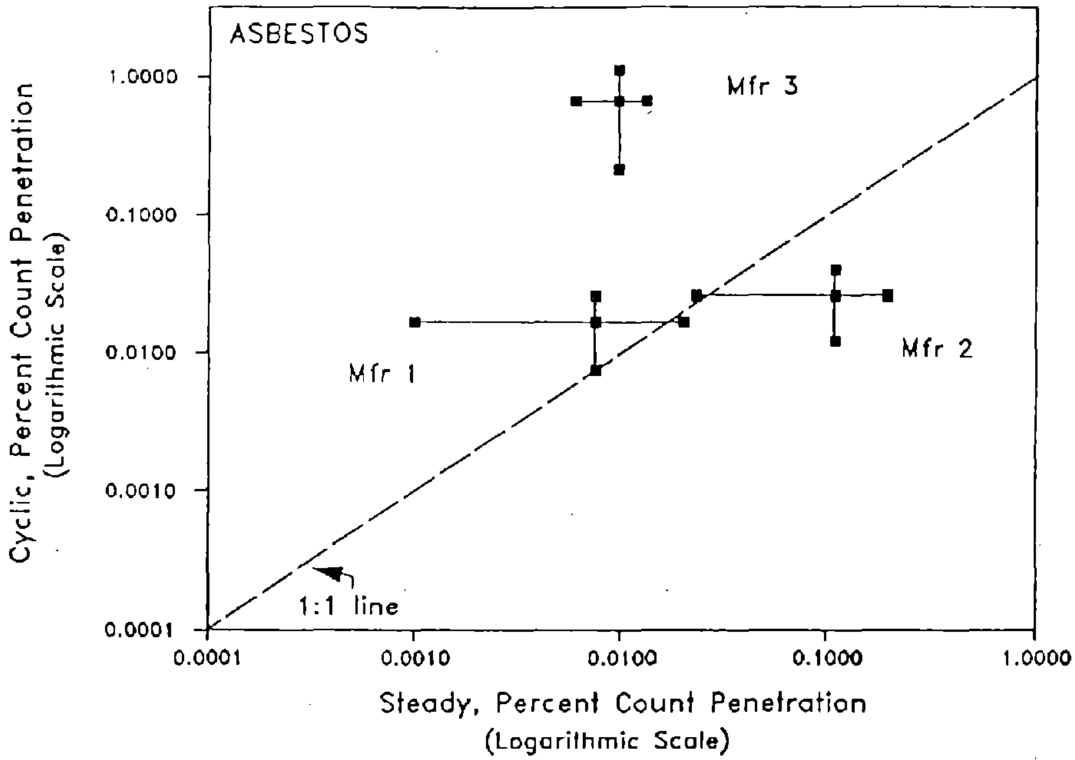
Count penetration of asbestos (Figure 5) under conditions of continuous flow was almost always less than 0.5%. The average count penetration was 0.01% for manufacturer 1, 0.1% for manufacturer 2, and 0.01% for manufacturer 3. Under cyclic flow conditions penetration was consistently less than 0.1% for manufacturers 1 and 2; but for manufacturer 3 average penetration was about 0.6% and results were variable with some tests showing penetration greater than 2%.

For asbestos, therefore, the results are not as simple to interpret (Figure 6). Within the error of these experiments, the switch from steady to cyclic flow did not affect the performance of two manufacturers' filters (manufacturers 1 and 2). But the performance of the third manufacturer's filters was 100 times worse under cyclic flow than under continuous flow.


SILICA
Mfr 3
Mfr 2
Mfr 1
1:1 line
Cyclic, Percent Mass Penetration
Steady, Percent Mass Penetration
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4



Steady Flow
Cyclic Flow
Percent Count Penetration
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
Manufacturer



ASBESTOS
Mfr 3
Mfr 1
Mfr 2
1:1 line
1.0000
0.1000
0.0100
0.0010
0.0001
0.0001
0.0010
0.0100
0.1000
1.0000
Cyclic, Percent Count Penetration
(Logarithmic Scale)
Steady, Percent Count Penetration
(Logarithmic Scale)

Discussion

Several aspects of these tests are significant, including the penetration patterns measured, the causes of high asbestos penetration for manufacturer 3 at cyclic flow, and the implications of these results for the use of dust/mist respirators in asbestos-containing atmospheres. Each of these points is discussed below.

Analysis of Penetration Data

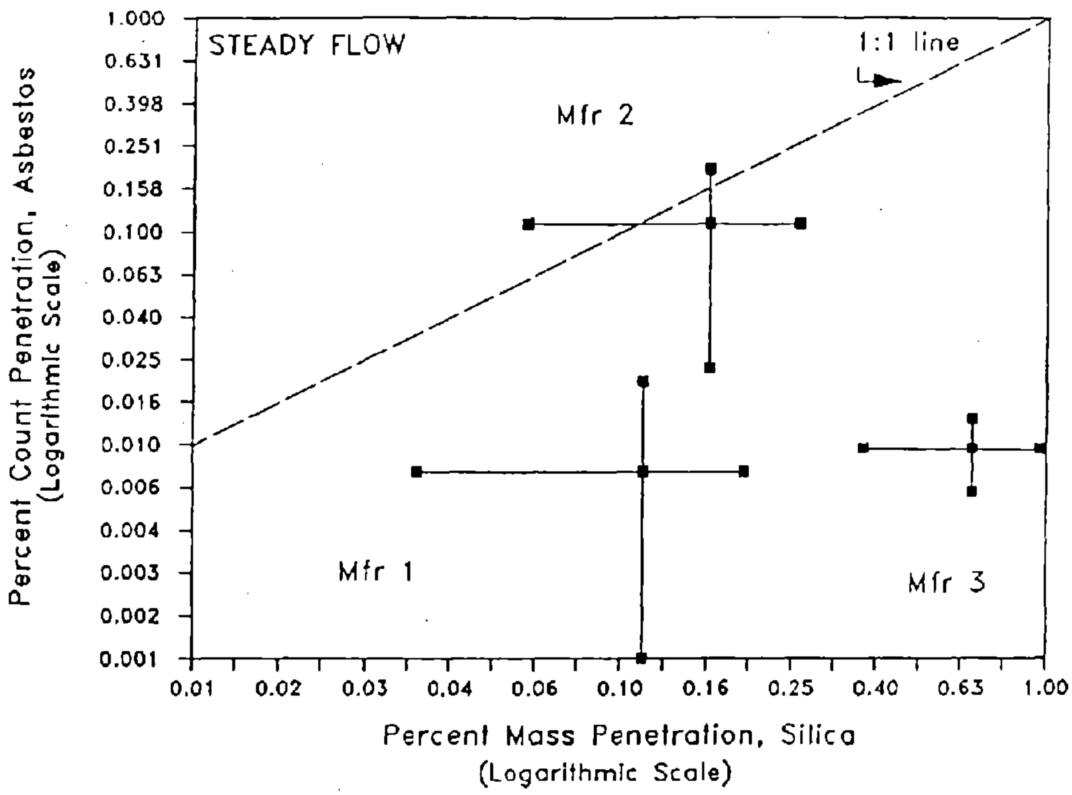
The results obtained for the steady flow, silica experiments might be expected to characterize a particular filter's performance in tests with other aerosols and under more realistic conditions of flow, since this is the test prescribed by the NIOSH certification procedure for these filters. The results of the silica experiments were consistent with this view. Although silica penetration under cyclic flow was somewhat greater than under steady flow, the performance of a respirator filter under steady flow appears to be predictive of its performance under cyclic flow.

Studies by Stafford *et al.*,[18] using monodisperse latex aerosols ranging in size from 0.2 to 2.0 μm, found that cyclic flow penetration was higher than that under steady flow; for some particles sizes, penetration under cyclic flow was five times greater than under steady flow.

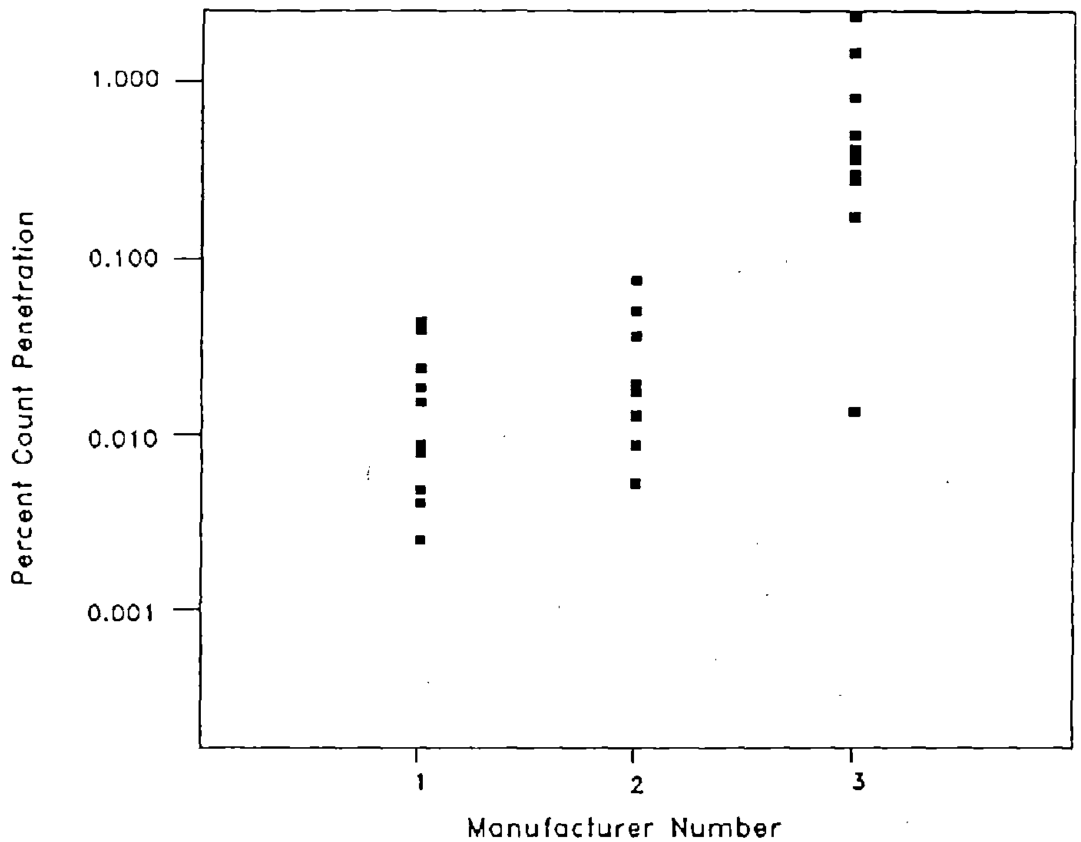
Although steady flow silica experiments may be predictive of cyclic flow silica results, they do not appear to be predictive of the penetration of an asbestos aerosol. As Figure 7 indicates, there appears to be no simple relationship between mass penetration of silica and count penetration of asbestos.

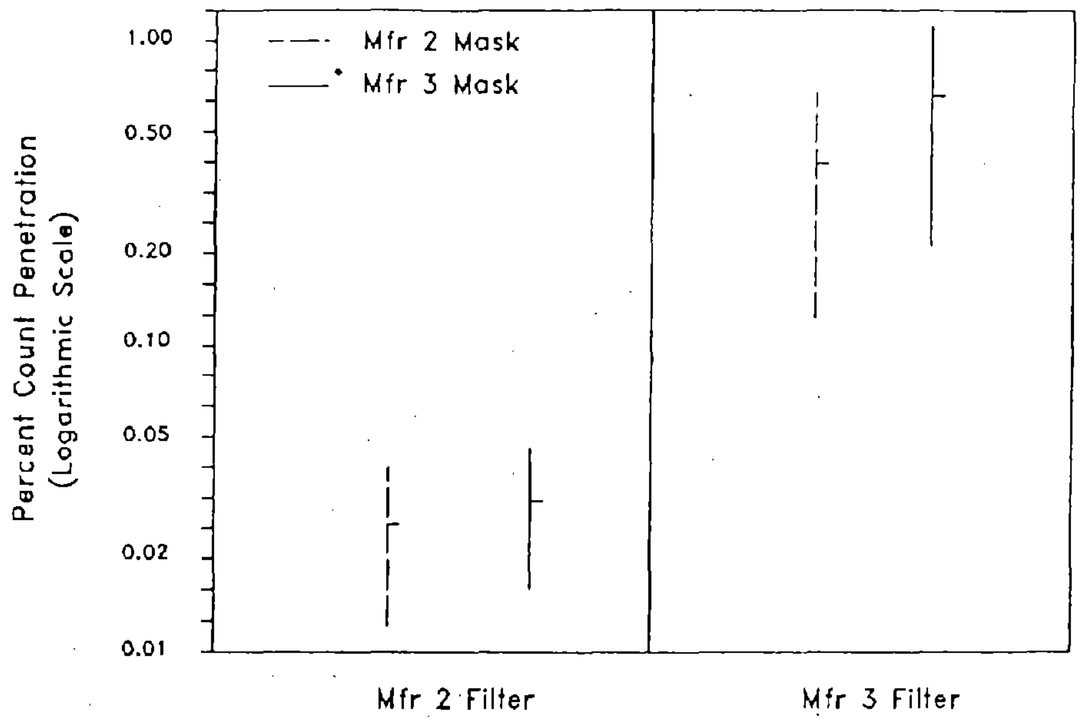
A similar comparison of the two aerosols' penetration at cyclic flow was not attempted, because asbestos cyclic flow data (replotted logarithmically in Figure 8) suggested two modes of performance for manufacturer 3. The single lowest data point is comparable to performance of the other two respirator models, and might be indicative of "normal" penetration for this respirator. The remaining data points indicate a much higher penetration, and might represent a failure mode for this respirator.

To evaluate this possibility, an additional set of experiments was performed. In these experiments, the filters and facepieces of manufacturers 2 and 3 were switched, such that manufacturer 2's filters were combined with manufacturer 3's facepieces, and vice versa. Five replicate tests of each of the two new filter/facepiece combinations were performed to measure asbestos penetration under cyclic flow. The results of the additional experiments (Figure 9) indicated that the facepiece and not the filter was responsible for the atypical performance of manufacturer 3's respirators.



STEADY FLOW
1:1 line
Mfr 2
Mfr 1
Mfr 3
1.000
0.631
0.398
0.251
0.158
0.100
0.063
0.040
0.025
0.016
0.010
0.006
0.004
0.003
0.002
0.001
0.01
0.02
0.03
0.04
0.06
0.10
0.16
0.25
0.40
0.63
1.00
Percent Count Penetration, Asbestos
(Logarithmic Scale)
Percent Mass Penetration, Silica
(Logarithmic Scale)


1.000
0.100
0.010
0.001
Percent Count Penetration
1
2
3
Manufacturer Number



Mfr 2 Mask
Mfr 3 Mask
1.00
0.50
0.20
0.10
0.05
0.02
0.01
Percent Count Penetration
(Logarithmic Scale)
Mfr 2 Filter
Mfr 3 Filter

Exhalation Valve Failure

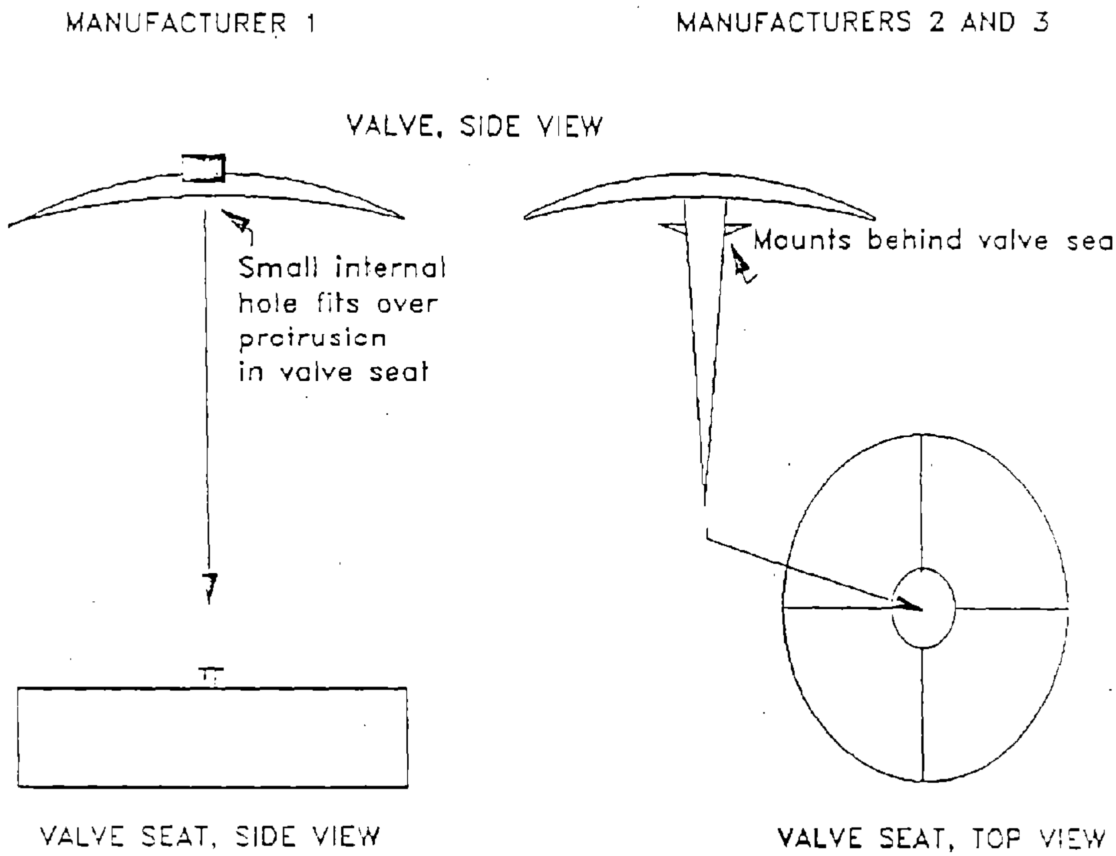
The relatively poor performance of manufacturer 3's respirators under cyclic flow can most likely be attributed to exhalation valve performance. Scrutiny of manufacturer 3's used valves revealed that the cyclic flow pattern caused the valves to deform, becoming convex rather than concave; this change in form apparently affected the valve's ability to close during the inhalation cycle.

One initially puzzling aspect of this explanation of the asbestos data is that similar degradation of manufacturer 3's valve performance was not evident in the silica cyclic flow experiments. This apparent discrepancy may be related to size-dependent penetration of the leaky valve and valve seat. Because smaller particles have less inertia they may follow more easily the tortuous airflow paths around a valve and through the valve seat openings. Relatively large changes in the penetration of small particles are necessary to produce noticeable changes in mass penetration; however, these same changes are readily observed in count penetration. Thus, it is possible that degradation of manufacturer 3's valve performance also occurred in the silica cyclic flow experiments, but that it was not detectable.

Although in these experiments the exhalation valves of manufacturer 3's respirators apparently failed under cyclic flow, there is no obvious explanation for this phenomenon. All three manufacturers' exhalation valves are of essentially similar design, consisting of a slightly concave rubber disc (Figure 10). Those of manufacturers 2 and 3 are attached to the valve seat by a long, thin stem projecting from the center of the disc, which is pulled through an opening in the valve seat; manufacturer 1's valves are attached by slipping a reinforced hole in the valve's center over a plastic protrusion on the valve seat. The valves of manufacturer 1 also differ slightly in shape from those of manufacturers 2 and 3 in that they are not entirely concave, but rather consist of an inner flat portion and a slightly concave outer component.

Work by Los Alamos Scientific Laboratory,[19] using a polydisperse DEHS aerosol (no size distribution was indicated), found that, after 5-6 min at a cyclic flow created by a breathing machine operated at a work rate of 622 kg-m/min, the penetration through exhalation valves of similar design was less than or equal to 0.01%.

Using small particles (0.2 μm) and longer testing periods (60 min) Burgess and Anderson[20] evaluated the performance of "mushroom" valves similar to those used in the respirators we tested. Penetration of new valves was typically less than 0.01% even at airflow rates higher than those used in our experiments. Used valves exhibited *lower* instantaneous penetration than did new valves. This improvement in performance was thought to be the result of valve and seat conditioning. Although aerosol penetration was not evaluated for discarded valves, they exhibited exceptionally low opening pressures, thought to be due to incomplete seating and "warped valve diaphragm elements." Their findings suggest that during



MANUFACTURER 1
MANUFACTURERS 2 AND 3
VALVE, SIDE VIEW
Small internal
hole fits over
protrusion
in valve seat
Mounts behind valve seat
VALVE SEAT, SIDE VIEW
VALVE SEAT, TOP VIEW

the life cycle of an exhalation valve performance may at first improve due to conditioning, but will eventually degrade due to warping and other physical changes.

Dust/Mist Respirators in an Asbestos Atmosphere

Our results with amosite indicate that (with properly functioning exhalation valves) penetration would be expected to be less than 0.1%. Even when exhalation valves "failed" (i.e., manufacturer 3, cyclic flow), the typical count penetration was less than 1%. Thus it would appear that protection factors of at least 100 and perhaps 1000 could be achieved with respirators using dust/mist filters in asbestos atmospheres.

Recent work by Ortiz *et al.*,[21] using UICC chrysotile asbestos at relatively low concentrations (5-50 f/cm^3), found similar values of count penetration less than 0.1% for electret and resin-impregnated wool felt respirator filters, for 1-hr tests at a continuous flow of 0.032 m^3/min.

It should be recognized, however, that current regulations do not allow the use of dust/mist respirators in asbestos atmospheres; that factors such as high humidity, high temperature, or exposure to oil or solvent mists can degrade filter performance;[21] and that charged particles may be collected with different efficiencies than the neutralized aerosols used in our experiments.[22]

Although NIOSH originally approved dust/mist respirators for use in asbestos atmospheres,[1] they no longer do so.[23] Many respirator manufacturers also no longer recommend use of their respirators for asbestos atmospheres.[24] These actions were prompted more by the fact that asbestos is a carcinogen[5] and by issues of liability than by any evidence that air purifying respirators do not provide adequate protection in an asbestos atmosphere.

Occupational Safety and Health Administration (OSHA) regulations[6] allow the use of high efficiency air purifying respirators when asbestos concentrations are below 0.2 f/cm^3, the permissible exposure limit. These filters typically achieve efficiencies of at least 99.99%, but offer significant breathing resistance, particularly after they are worn long enough to become loaded with an aerosol.[1] This increase in resistance may not only make breathing more difficult, but may eventually lead to increased leakage around the face seal.

We found that facepiece elements (other than filters) may contribute significantly to respirator leakage. A high efficiency (HEPA) filter causes a greater change in pressure across the respirator facepiece and thus places greater stress on facepiece elements, such as exhalation valves, than does a dust/mist filter. The likelihood of exhalation valve failure may thus be greater for a half-facepiece air purifying respirator equipped with HEPA filters than for one equipped with dust/mist filters.

A joint Environmental Protection Agency (EPA)/NIOSH guide[5] recommends only a pressure-demand self-contained breathing apparatus (SCBA) or a combination air line (type C) respirator with an auxiliary SCBA (both pressure-demand) for asbestos atmospheres. Although these systems provide significant worker protection, they can be inconvenient and physiologically demanding to wear. The actual reduction in worker exposure, and therefore risk, achieved by the use of respirators is the product of the fraction of time respirators are worn and the collection efficiency when they are worn. It is apparent that small changes in worker acceptance can more than offset apparently large differences in collection efficiency.

Conclusions

This study suggests that the results of respirator tests using silica aerosols may not be indicative of the performance that will be experienced when respirators are challenged with asbestos aerosols. Furthermore, the study indicates that greater aerosol penetration occurs under conditions of cyclic flow than under steady flow. Finally, it appears that the stress on exhalation valves under cyclic flow may be sufficient to induce valve failure and dramatically increased aerosol penetration into the respirator.

NIOSH testing methods, which rely on assessment of mass penetration of silica aerosols under steady flow conditions should be re-considered. In addition, methods for evaluating the life-cycle performance of respirator components such as exhalation valves should be developed.

There are trade-offs between various types of respiratory protection with respect to the burdens they place on the wearer (e.g., breathing resistance, restriction of movement, physiologic stress) and the degree to which they are influenced by external factors (e.g., aerosol loading, temperature, relative humidity, other aerosols, charge). In the case of an asbestos aerosol, the dust/mist filters were highly efficient (99.90 to 99.99%) for two of the three experimental manufacturers at both flow conditions. The third manufacturer's behavior at cyclic flow (an average of 99.2% efficiency) was shown to be determined largely by the performance of facepiece elements. It can be concluded from these results that the filters of manufacturers 2 and 3 did not differ significantly and that all three manufacturers' dust/mist filters should provide protection in an asbestos atmosphere equivalent to that of high efficiency filters, with the qualifications discussed above.

Acknowledgements

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16. Abstract (Limit: 200 words)

Experiments were described which evaluated the predictive ability of tests using a silica (7631869) aerosol under conditions of steady flow for determining respiratory efficiency. Measurements taken of silica penetration at steady flow were reasonably predictive of silica penetration under cyclic flow. Mass penetration of silica under continuous flow conditions was typically less than 0.1 percent. In general, the penetration of silica under conditions of cyclic flow was about one and a half times as great as that measured under steady flow conditions. However, the same was not true for testing with asbestos (1332214) fibers under steady versus cyclic flow. Furthermore, the potential for exhalation valve failure under cyclic flow was also identified. The authors indicate that these results call for a reevaluation of the current NIOSH protocols for evaluating respirator performance. The authors urge the development of a NIOSH testing method for evaluating the life cycle performance of respirator components such as exhalation valves.

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