Materials and Methods for Respirator Performance against Nanoparticles under Simulated Workplace Activities Dataset

Eight NIOSH-approved respirator models (Table A) were randomly selected from among models previously tested (Vo et al., 2012; Rengasamy et al., 2013) in the laboratory. Each respirator filter had a multilayer structure with the main layers of these filters composed of electrostatically charged polypropylene fibers; however, each filter had different characteristics, such as the number of layers, thickness, and hydrophilic/hydrophobic fiber materials.

Table A. Summary GM-SWPF and fifth percentile values by respirator model

Respirator type	Class of filter	Respirator model	Respirator features	GM_SWPF [a] (± GSD)	Fifth percentile
FFRs	N95	N95-A	Cup, nonadjustable straps, metal nosepiece, one size	103±3.3	14
		N95-B	Cup, nonadjustable straps, metal nosepiece, one size	94±2.0	30
	P100	P100-A	Cup, adjustable straps, exhalation valve, metal nosepiece, one size	6586±2.8	1207
		P100-B	Cup, adjustable straps, exhalation valve, metal nosepiece, one size	3200±5.2	213
EHRs	N95	N95-A	S, M, L sizes, adjustable straps, exhalation valve	136±1.9	47
		N95-B	S, M, L sizes, adjustable straps, exhalation valve	257±1.9	88
	P100	P100-A	S, M, L sizes, adjustable straps, exhalation valve	8157±2.9	1388
		P100-B	S, M, L sizes, adjustable straps, exhalation valve	9923±2.9	1759

[a]Total number of observations (*n*) of each respirator-model GM-SWPF data point = 75 (*n* = 1 model × 3 replicates × 25 subjects).

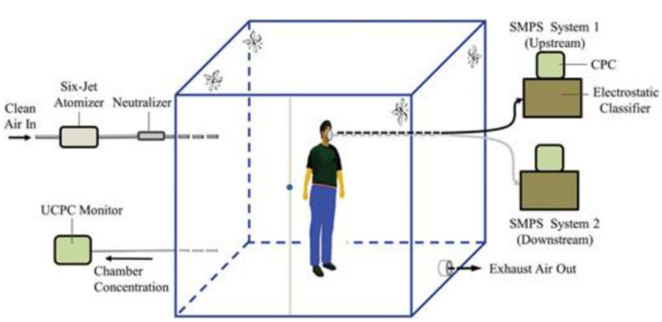
Twenty-five subjects (13 females and 12 males) participated in this study. The age of the panel members ranged from 19 to 65 years. The NIOSH bivariate panel was used for placement of test subjects in specific face length by face width cells (Zhuang et al., 2007). This study was approved by the NIOSH Institutional Review Board (IRB) and all subjects gave written consent to participate.

Two sodium chloride solutions in distilled water were used as generator solutions. The solution concentrations for the fit test generator and the simulated workplace protection factor (SWPF) test atomizer were 2 and 0.2%, respectively. These different solution concentrations were chosen to ensure that adequate particle concentrations were generated for the standard fit test as described by Lawrence et al. (2006) and the SWPF test as described by Vo and Zhuang (2013).

A particle generator (Model 8026, TSI, Shoreview, MN) and a PortaCount Plus (Model 8038; TSI) were used for the fit test.

An aerosol chamber testing system (ACTS) consisting of an aerosol generation set, an exposure chamber system, and a particle detector component was used for the SWPF test (see Figure 1). The aerosol generation set has a six-jet atomizer (Model 9306, TSI), a Kr-85 aerosol neutralizer (Model 3054, TSI), and an ultrafine condensation particle counter (UCPC, model 3776, TSI) to track the particle concentration in the testing chamber. A compressed air supply for the generator was filtered with a high efficiency particulate air (HEPA) filter (Model 2074B, TSI). The chamber testing system consisted of an exposure chamber (Model 222–6, Dynatech, Albuquerque, NM, USA), a humidity/temperature sensor (Model RHXL3SD, Omega Engineering, Stamford, CT, USA), circulation fans, and a 14-cm diameter exhaust port. The exposure chamber height, width, and depth were 2.5×2.5×1.5 m, respectively. The chamber contained sufficient space for a human subject, with a respirator, to perform a SWPF test inside comfortably. The particle detector component consisted of two scanning mobility particle sizers (SMPSs, Model 3080 with Model-3772 CPCs, TSI). Two SMPSs were used simultaneously to measure the upstream (outside the respirator) and downstream (inside the respirator) test aerosol (Fig. 2).

Figure 1.



Schematic diagram of an aerosol chamber testing system: including an aerosol generator system with a particle concentration monitor, exposure chamber with an exhaust port, and particle detector systems [scanning mobility particle sizer (SMPS)].

Test procedures

Fit test

A fit test was conducted under laboratory conditions for each subject and each respiratory protective device prior to the start of a SWPF test. A particle generator (Model 8026, TSI) was used to keep room concentration levels between 3000 and 8000 particles cm^{-3} for the fit test. When the laboratory particle concentrations reached the designated level, subjects trained by a test operator (the training included demonstrating how to don a respirator using the manufacturer's user instructions) donned the FFR or EHR and connected the PortaCount sample line to the respirator. The fit test was initiated after the test operator assured that the respirator was properly donned by the test subject, including performance by the subject of the standard respirator user seal check. Subjects performed the eight exercises described in the OSHA standard fit test (OSHA, 2002). The eight exercises were performed in the following order: (i) normal breathing, (ii) deep breathing, (iii) turning head side to side, (iv) moving head up and down, (v) talking out loud, (vi) reaching for floor and ceiling, (vii) grimacing, and (viii) normal breathing. The fit factor (FF) was determined by the PortaCount Plus based on the ratio of the upstream and downstream concentrations of each exercise. A harmonic mean of the FFs measured for these exercises, except the grimace exercise (the grimace exercise was excluded from the overall FF calculation), was also obtained directly from the PortaCount. If the subject received a FF value of ≥100, the fit test was considered a pass. If the subject received a FF value of <100, the fit test was considered a failure. If the subject did not pass the fit test during the first trial, to ensure they passed, a test operator was required to help them don the respirator, adjust its head straps, and reshape its metal nosepiece (if equipped). Once a proper fit was achieved, the subject continued to don the respirator with the connector tube sealed using a clamp, and was escorted to the exposure chamber for the SWPF test.

SWPF

A NaCl solution was aerosolized using the single jet mode of the six-jet atomizer at a dispersion of 30 l min^{-1}. The output aerosol was dried with 30% dilution air in an atomizer self-contained dilution system, followed by neutralizing with the Kr-85 charging source before entering into the exposure testing chamber (Fig. 2). The aerosol in the exposure chamber was mixed using four internal fans positioned on the top of four inner corners of the chamber (Fig. 2). Throughout the experiment, an UCPC tracked the total particle concentration at 1.5 l min^{-1}, and the climate conditions were tracked by a humidity/temperature sensor (Fig. 2). During particle generation and sampling, NaCl aerosol particles were continuously dispersed into the chamber, while the exhaust port was in the open position to remove excess air and maintain neutral pressure. When the NaCl aerosol concentration in the chamber stabilized at the exposure level of ~2×10^5 particles cm^{-3}, the subject pre-donned with the respirator entered into the exposure chamber for the SWPF test.

After connecting the SMPS sample line to the respirator, the clamp on the connector tube was removed by the test operator to allow aerosol flow. The SWPF test was then performed using six exercises for 3 minutes each: (i) normal breathing, (ii) deep breathing, (iii) moving head side to side, (iv) moving head up and down, (v) bending at the waist, and (vi) a simulated laboratory-vessel cleaning motion. The simulated laboratory-vessel cleaning motion involved the subject moving their arms forward-down and backward-up in a shovel-scooping-like fashion, with a distance of about 30cm at a rate of approximately one completed motion every 5 seconds to simulate a common workplace activity observed by Dahm et al. (2011) . Test data was recorded and each individual exercise SWPF was calculated as a ratio of the upstream and downstream particle concentrations as in (equation 1):

$$SWPF_i = \frac{C_o}{C_{in}} \qquad (1)$$

where SWPF, simulated workplace protection factor for a given exercise; i, exercise number; C_{out} , upstream particle concentration; C_{in} , downstream particle concentration

An overall SWPF for each respirator model obtained from the six individual SWPF exercises was derived using (equation 2):

$$Overall\ SWPF = \frac{6}{\frac{1}{SWPF_1}+\frac{1}{SWPF_2}+\cdots+\frac{1}{SWPF_5}+\frac{1}{SWPF_6}} \qquad (2)$$

After completing testing with each respirator model, the subject removed the respirator and gave it to the test operator. The subject then donned the next respirator model and repeated the fit test and the SWPF test for all eight respirator models. This procedure was conducted three times for each respirator model for each subject on three different days.

Data Analysis

The data analysis was performed using an analysis of variance (ANOVA) model provided by the Statistical Analysis System version 9.3 (SAS Institute Inc., Cary, NC, USA). The ANOVA was also used for analyzing statistical computations, including overall SWPF, geometric mean (GM) SWPFs, and all pairwise SWPF comparisons. $P < 0.05$ were considered significant. The fifth percentile SWPF was computed from the formula $GM/GSD^{1.645}$, where GSD equals the geometric standard deviation (Lenhart and Campbell, 1984).

References:

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