Workplace Performance of an N95 Respirator in a Concrete Block Manufacturing Plant

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ABSTRACT

The purpose of this study was to determine workplace performance of a trifold N95 filtering facepiece respirator in a concrete block manufacturing plant. Tasks included bagging cement mix, handling concrete blocks, sweeping and shoveling, and repairing pallets. The protocol for the study was based on the recommendations made by Johnston *et al*. (1992). Nineteen workers were qualitatively fit-tested following the Bitrex® protocol specified in 29 CFR 1910.134. Three to four pairs of air samples of inside and outside dust were then collected from each worker each day for four days. Trained observers assisted in the study to ensure sample validity. The dust had a mass median aerodynamic diameter ranging from 4.1 to 4.7 μm and a geometric standard deviation (GSD) ranging from 3.5 to 3.7. Samples were analyzed by x-ray emission spectroscopy. Silicon and calcium predominated in all samples; the mass of these two elements was combined and used to calculate a workplace protection factor (WPF) for each set of samples. The geometric mean WPF was 233 with a fifth percentile of 24, which exceeds the assigned protection factor (APF) of 10 generally given to this class of respirators.

Keywords: N95, respirator, workplace protection factors, concrete block manufacturing

INTRODUCTION

A workplace protection factor study was conducted to determine the performance of a National Institute for Occupational Safety and Health (NIOSH) approved N95 trifold, filtering facepiece respirator. For NIOSH approval, N95 filters must permit no more than 5% penetration of a sodium chloride aerosol with a mass median aerodynamic diameter (MMAD) of approximately 0.3 μm (equivalent to a count median diameter of 0.186 μm), typically assumed to be the “most penetrating” particle size (42 CFR 84). ANSI (1992) has designated an assigned protection factor (APF) of 10 for this class of respirators. When measuring the performance of a respirator in the workplace, the geometric mean and 5th percentile WPFs are typically calculated to verify the APF (Myers, 1996; Nelson, 1996).

MATERIALS AND METHODS

The respirator tested was a NIOSH approved N95 trifold, filtering facepiece respirator (FFR), the 3M™ 9211 (3M, St. Paul, MN). The workplace was a concrete block manufacturing plant. A work site with dust was chosen as representative of a typical use for an N95 FFR respirator. Workers in a concrete block manufacturing plant were sampled while performing their jobs. The main airborne contaminant from the various manufacturing processes was cement dust, comprised mostly of calcium and silicon.

Tasks performed by the workers included bagging cement mix, handling concrete blocks, and repairing pallets.

Workers were sampled in the bagging, block-making, tumbling, and pallet repair areas of the plant where the dust exposure was the highest. During a preliminary visit to the plant, personal air sampling results showed the presence of calcium (ranging from 0.5 – 200 mg/m^3) and silicon (0.5 – 11 mg/m^3) throughout these areas.

In the bagging area, workers placed bags over chutes, the bags were filled pneumatically, and the workers placed the filled bags onto pallets. In the block manufacturing and tumbling areas, workers handled concrete blocks, swept and shoveled dust and block pieces into containers, and cleaned out mullers with chipping tools. The pallet repair area consisted of an outdoor shelter, surrounded by stacks of used pallets and exposed to the wind. Workers used hand and power tools to replace broken boards on pallets. Airborne cement dust was generated from the movement of pallets and from the outdoor air currents.

The sampling equipment used in the study included Escort™ Elf personal sampling pumps (MSA, Pittsburgh, PA) calibrated to 2 Lpm with a Sierra TopTrak, Model # 821-S1-L-1PS mass flow meter (Sierra Instruments, Inc., Monterey, CA) using an appropriate filter cassette in-line at the start and end of each day for each worker. The C_i samples were collected on 0.8 µm polycarbonate filters mounted in 25 mm 3-piece cassettes with porous plastic back-up pads (Millipore Corp., Bedford, MA). For the C_o samples, 0.8 µm mixed cellulose ester filters were used (Millipore).

The protocol for the study was based on the recommendations made by Johnston *et al*. (1992). Several conditions were established before testing that could invalidate a sample pair. These included:

- in-facepiece sample fell off the probe during sampling,
- respirator was removed before sampling was terminated, or
- sampling pump malfunctioned or a similar equipment problem occurred such as leaky probes, loose sampling hoses or loose cassettes.

The sampling probe was built to the specifications of a probe designed to minimize particle entry losses (Liu et al., 1984). The probe in this study was further modified to project into the respirator from the inner surface of the respirator by approximately 1 cm (Figure 1). It is recommended that the probe location be approximately midway between the nose and the mouth and never above the nose, based on work by Myers (1983) and others. Because this respirator has an exhalation valve, the probe was positioned opposite the mouth near the midline of the respirator, to the right of the exhalation valve. A thread sealant was used to prevent leakage around the probe.

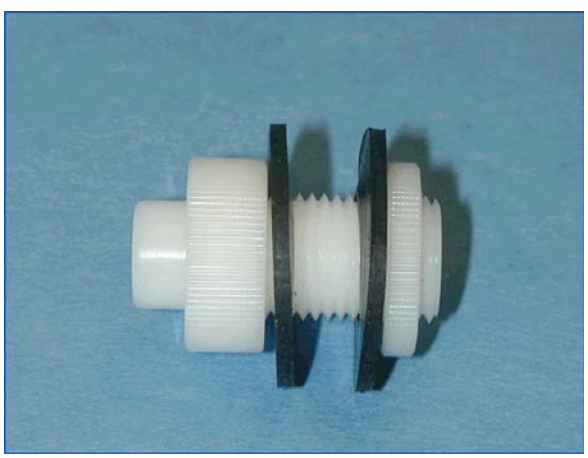

Figure 1. Probe Assembly.

A sample cassette was attached directly to the probe for collection of the in-facepiece sample (Myers, 1995). A cassette heater, based on a design by Weiss (1992), was used to prevent condensation of water vapor from exhaled breath inside the C_i sample cassette. The heater consisted of a bonnet, battery pack, an LED as an on-off indicator, and switch. The bonnet fit over the cassette and contained a coiled heating element, powered by a rechargeable Ni-Cd battery. A porous, plastic back-up pad inside the C_i sample was also used to support the filter due to the moisture from the exhaled breath.

Particle size sampling was done with an eight-stage Marple Personal Cascade Impactor (Thermo Anderson, Smyrna, GA). Two area samples were taken, one in the bagging area and another in the tumbling area, where workers were sampled.

Trained observers were used to ensure sample validity, make sure the equipment did not interfere with worker safety, verify proper respirator use, and record observations about work conditions. One observer was assigned to each subject being sampled. Observers stayed in the areas of the workers during the entire sampling periods.

Nineteen male workers participated in the study. The workers were informed of the purpose, procedures, and their role in the study. In accordance with OSHA's respirator use requirements, the workers were required to be clean-shaven at the beginning of the workday and were provided with instruction on the proper donning, fitting and operation of the respirator. To be included in the study, each worker had to pass a Bitrex® qualitative fit test per OSHA's protocol in 29 CFR 1910.134. The FT-30 Bitter Qualitative Fit Test Kit (3M, St. Paul, MN) was used.

Respirator donning and doffing, along with sample train connection and removal, was done in a clean area, a quality laboratory, to reduce sample contamination. The integrity of the respirator was checked, and the integrity of the sample train verified before going to the work areas. Both calibrated sampling pumps were started after the respirator was donned and the sample connected. At the end of sampling, both pumps were stopped before the respirator and samples were removed.

Each worker was sampled for an entire shift. The outside sample was placed in the breathing zone of the worker, defined as a hemisphere in front of the shoulders with a radius of 6 to 9 inches, in order to collect a sample that represented what the worker would inhale if not wearing a respirator (ACGIH, 1995). A modified Lui probe was also attached to the outside sample, so if any particle loss did occur as a result of the probe, both inside and outside samples would be affected.

Observers noted pump function at varying intervals throughout the sampling by reading the digital display of flow and sample time. Experience from past studies with these pumps demonstrated the reliability of the digital display. The samples were collected at 2 Lpm. Sampling times ranged from 33 to 172 minutes, and depended upon breaks in the shift such as worker break and lunch times. Up to four sample sets per day were collected on each worker.

Field blanks were collected to see if sample handling caused contamination. They were uncapped, capped and handled by the observers and worn by workers in the same manner as the samples, except no air was drawn through them. Manufacturer blanks were unused filters of each style used in the study. These were sent to the analytical laboratories in their cassettes to determine if there was background contamination on the filters.

Sample Analyses

The C_i samples and corresponding blank samples were analyzed with proton induced x-ray emission spectroscopy (PIXE). Detection limits were 0.133 µg per filter for silicon and 0.152 µg per filter for calcium. The outside samples and cascade impactor samples were analyzed for silicon and calcium by inductively coupled plasma/atomic absorption spectroscopy (AA) using NIOSH method 7300 (NIOSH, 1994). Detection limits were 5.0 and 2.5 µg per filter for silicon and calcium, respectively.

For in-facepiece samples with no detectable calcium or silicon, 70 percent of the detection limit was substituted as the inside mass for these samples for statistical analysis. The logic for this will be discussed later in the paper. Workplace protection factors were then calculated by dividing the outside concentrations by the corresponding inside concentrations. WPFs were calculated for each set of samples for the combined masses of both elements. From those, the geometric mean WPF, standard deviation, and fifth percentile WPF were calculated (Myers et al., 1984: NIOSH, 1987).

RESULTS

Calcium was reported in detectable quantities on all 73 C_i samples; silicon was detected on 62 of the C_i samples. The inside calcium concentrations ranged from 0.0009 to 0.43 mg/m^3. The geometric mean was 0.0164 mg/m^3 and the GSD was 4.35. The inside silicon concentrations ranged from non-detected to 0.15 mg/m^3. The geometric mean was 0.0063 mg/m^3 and the GSD was 4.45.

The outside calcium concentrations ranged from 0.5 to 51 mg/m^3. The geometric mean (GM) was 2.81 mg/m^3 and the geometric standard deviation (GSD) was 3.31. The outside silicon concentrations ranged from 0.45 – 11.8 mg/m^3; the geometric mean was 2.49 mg/m^{3}and the GSD was 2.63.

Three sample sets were invalid because they fell off the sample probe or equipment problems occurred. Neither field blank nor manufacturer blank samples had any detectable amounts of silicon or calcium; therefore, none of the inside or outside data is blank-corrected.

Silicon was not detected on eleven of the inside samples. For those samples, 70 percent of the detection limit was substituted as the inside mass for these samples (see *Discussion* below for *Use of non-detectable data*). They were then included in the statistical analysis. Non-detected data on the Ci samples indicates good respirator performance.

The WPFs for the combined masses of calcium and silicon are shown in Table I. The distribution of the data is not significantly different from a log-normal model (Figure 2) (AIHA, 1990). The geometric mean WPF was 233, and the geometric standard deviation was 4.0. The 5th percentile WPF was 24.

A significant correlation was found between log WPF values and log C_i concentrations with an r^2 of 0.50 (Figure 3). The correlation coefficient is negative, indicating that WPFs decreased as C_i levels increased. Log WPF values and log C_o concentrations showed poor correlation with an r^2 of 0.11 (Figure 4).

In the bagging area, the mass median aerodynamic diameter (MMAD) of the cement dust (includes calcium and silicon) was 4.7 µm with a geometric standard deviation (GSD) of 3.7. Sampling in the tumbling area showed an aerosol with a MMAD of 4.1 µm and a GSD of 3.5. These two areas have aerosols with very similar size distributions. The slight difference in MMAD may be due to sampling variability (AIHA, 1986).

DISCUSSION

The filtering facepiece respirator used in this study reliably provided workplace protection factors greater than 10 when properly fitted, worn, and used. The estimated 5th percentile WPF for this respirator model based on this study exceeds the APF of 10 assigned to this respirator class by ANSI Z88.2-1992 and proposed by OSHA (Federal Register, 2003). These results support the APF of 10 for this class of respirator.

While occupational exposure levels (OELs) are important in exposure assessment, they are not relevant to the objective of this study. The objective was to measure WPFs by determining the mass of the contaminants outside and inside the respirator. In order to measure C_o and C_i, sufficient amounts of contaminant are required for sampling. The dust consisted predominantly of Portland cement with sand and gravel. These materials do not have specific OELs. Portland cement consists primarily of calcium and silicon compounds such as tricalicum silicate, dicalcium silicate, alumina, tricalcium aluminate and iron oxide. Calcium and other silicates are also common in sand and gravel. Sampling results from both the preliminary visit and the WPF study support statistical analysis based on calcium and silicon because they comprise 85 to 95 percent of the mass that was found.

Table I. Summary of Sample Volume (V), Masses of Silicon and Calcium (Si+Ca), Concentrations (C), and Workplace Protection Factor (WPF)

Worker	Area/Job	Set #	V_o [1] (L)	Si_o+Ca_o (µg)	C_o (µg/m^3)	V_i (L)	Si_i+Ca_i [2] (µg)	C_i (µg/m^3)	WPF (C_o/C_i)
1	Tumbler	68	213	1110	5207	211	2.08	9.9	528
1	Tumbler	69	184	2500	13584	173	8.18	47.3	287
1	Tumbler	73	251	3800	15152	253	24.5	96.6	157
1	Tumbler	78	249	3500	14073	253	50.88	200.7	70
2	Block/Cuber	5	313	720	2299	313	3.34	10.7	215
2	Block/Cuber	10	220	320	1452	220	2.03	9.2	157
2	Block/Cuber	15	181	340	1874	181	3.52	19.4	97
2	Block/Cuber	20	212	680	3212	210	18.49	88.2	36
3	Block	65	251	1050	4191	237	1.83	7.7	541
3	Block	75	212	1410	6661	198	2.62	13.3	502
3	Block	80	220	5800	26325	208	26.49	127.3	207
4	Pallet Repair	67	252	980	3885	234	9.39	40.1	97
4	Pallet Repair	72	278	1440	5185	262	2.66	10.2	510
4	Pallet Repair	76	170	580	3420	162	0.4	2.5	1373
4	Pallet Repair	77	216	870	4023	206	5.32	25.8	156
5	Pallet Repair	43	224	1840	8227	227	0.59	2.6	3144
5	Pallet Repair	48	160	670	4194	154	0.66	4.3	978
5	Pallet Repair	53	155	780	5016	158	0.24	1.5	3310
5	Pallet Repair	58	200	1580	7891	203	0.27	1.4	5843
6	Block/Laborer	23	212	260	1225	43	0.87	20.4	60
6	Block/Laborer	28	212	260	1225	92	1.97	21.5	57
6	Block/Laborer	33	177	340	1919	175	0.73	4.2	461
6	Block/Laborer	38	202	290	1437	200	1.87	9.4	154
7	Tumbler	41	234	3500	14957	133	10.59	79.5	188
7	Tumbler	46	224	1310	5848	230	4.36	19	308
7	Tumbler	51	226	3000	13274	232	11.26	48.6	273
7	Tumbler	61	189	2500	13256	193	4.93	25.5	519
8	Dry Mix/Operator	21	116	1810	15614	69	13.7	197.7	79
8	Dry Mix/Operator	26	228	3020	13263	231	53.61	232.1	57
9	Pallet Repair	42	189	1670	8855	175	0.31	1.8	4887
9	Pallet Repair	47	269	1670	6219	252	8.8	34.9	178
9	Pallet Repair	52	154	510	3317	150	1.85	12.4	268
9	Pallet Repair	57	197	1030	5234	191	1.58	8.2	635
10	Tumbler	44	232	2700	11656	228	15.74	68.9	169
10	Tumbler	54	201	1050	5227	255	0.76	3	1749
10	Tumbler	59	180	3400	18847	177	71.29	401.7	47
10	Tumbler	62	180	990	5507	180	53.72	298.9	18
11	Block/Cuber	1	269	710	2641	269	6.36	23.7	112
11	Block/Cuber	6	210	310	1476	210	1.17	5.6	264
11	Block/Cuber	11	187	280	1498	187	1.58	8.5	177
11	Block/Cuber	16	242	499	2066	242	4.36	18.1	114
12	Block/Cuber	4	316	880	2788	311	21.61	69.5	40

12	Block/Cuber	9	224	370	1655	218	5.03	23.1	72
12	Block/Cuber	14	173	230	1326	169	1.35	8	166
12	Block/Cuber	19	199	1150	5792	196	95.95	490.3	12
13	Block	25	205	330	1610	200	1.22	6.1	264
13	Block	30	219	300	1367	241	0.64	3	456
13	Block	35	168	202	1205	157	1.88	12	101
13	Block	40	221	590	2664	198	3.66	18.5	144
14	Tumbler	45	230	2400	10445	216	9.39	43.5	240
14	Tumbler	50	190	2700	14178	182	15.34	84.2	168
14	Tumbler	55	259	2080	8039	238	10.47	44.1	182
14	Tumbler	60	178	2600	14605	170	24.68	144.9	101
14	Tumbler	63	209	2050	9809	200	13.65	68.4	143
15	Dry Mix/Operator	3	380	13800	36304	354	33.62	94.9	383
15	Dry Mix/Operator	8	243	8700	35788	227	39.57	174.6	205
15	Dry Mix/Operator	13	194	12200	62731	181	6.56	36.1	1736
15	Dry Mix/Operator	18	148	5700	38495	138	44.55	322.8	119
16	Dry Mix/Bagger	2	251	11800	46995	245	4.03	16.4	2865
16	Dry Mix/Bagger	7	215	5200	24161	216	3.23	15	1616
16	Dry Mix/Bagger	12	200	7700	38414	198	9.12	46.2	832
16	Dry Mix/Bagger	17	207	11900	57549	203	3.71	18.2	3159
17	Block	64	231	970	4201	258	4.96	19.2	219
17	Block	74	200	2420	12119	200	9.48	47.5	255
17	Block	79	210	350	1666	210	2.1	10	167
18	Block	24	218	470	2152	226	13.53	60	36
18	Block	29	223	290	1303	226	12.92	57.3	23
18	Block	34	175	220	1259	176	11.93	67.7	19
18	Block	39	218	210	962	224	10.75	48.1	20
19	Block/Sweeper	22	244	640	2620	236	1.86	7.9	333
19	Block/Laborer	27	215	920	4274	206	1.65	8	535
19	Block/Sweeper	32	195	410	2107	190	0.39	2	1032
19	Block/Sweeper	37	217	5600	25765	212	12.86	60.6	425

1 Subscript "$_o$" means ambient samples and subscript "$_i$" means in-facepiece samples.
2 Where the C_i mass for Si was non-detected, 70% of the detection limit (0.09 µg) was used. This includes sample sets: 6, 17, 23, 30, 32, 33, 42, 43, 48, 53, and 58.

Traditionally, WPF studies have shown the performance data of the respirator by each element (Colton *et al*., 1991; Myers *et al*., 1996). A regression analysis of the WPFs for Ca and Si has an r^2 of 0.73. The slight variation in the WPFs is likely due to normal random sampling and analytical errors, or possibly non-uniformity of the challenge aerosol over time. Since the majority of the mass collected was comprised of calcium and silicon, the WPFs were calculated from combining the masses of both elements.

Use of non-detectable samples

A large number of C_i samples were found to be below the analytical detection limit in many of the previous WPF studies (Lenhart, 1984; Colton, 1990; 1994; 1999). This further supports the good performance of these respirators because no measurable amount of contaminant was found on the C_i

samples. A WPF, however, cannot be directly calculated when no material is detected on the Ci sample. Several methods have been suggested to analyze data with non-detectable results (Hornung and Reed, 1990; Perkins *et al*., 1990). Waters (1993) suggested that a simple substitution of a value for non-detectable samples may be used. A value of 70 percent of the detection limit results in an estimate of the distribution with the least amount of bias.

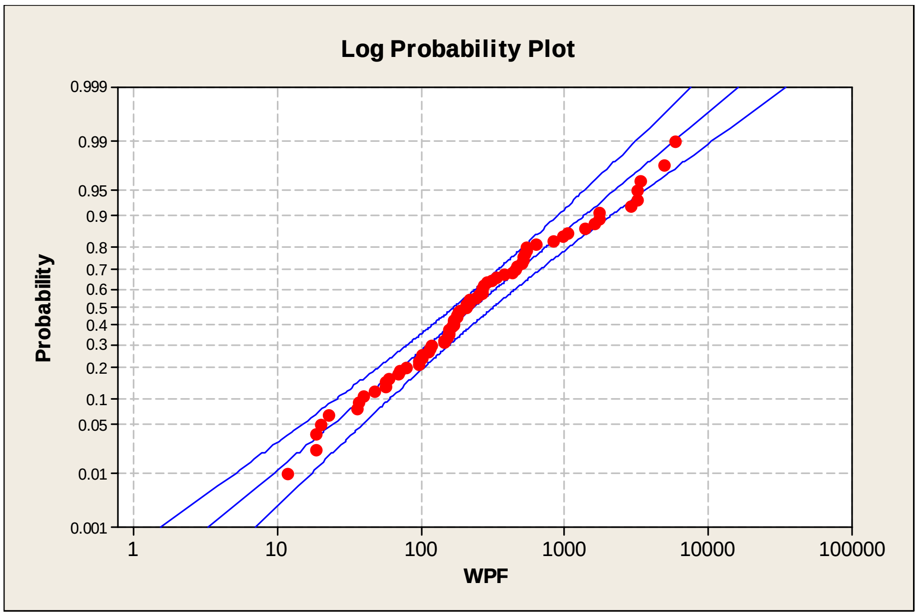

Figure 2. Probability plot of work place protection factors.

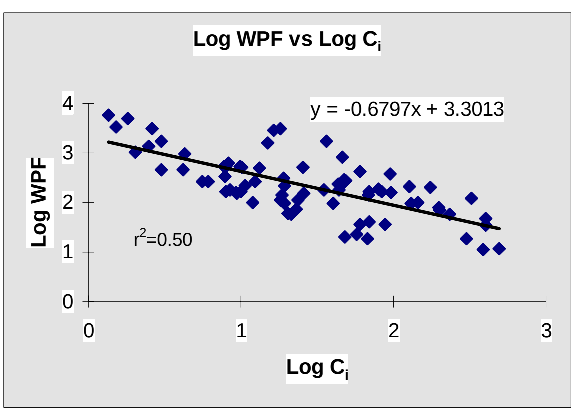

Figure 3. Plot of log-transformed workplace protection factors (WPF) against log-transformed in-facepiece concentration (C_i).

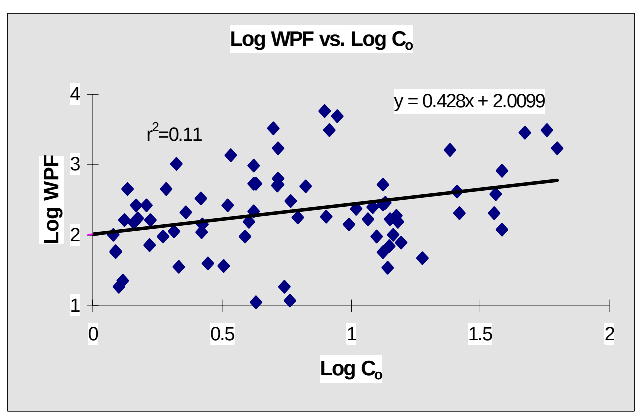

Figure 4. Plot of log-transformed workplace protection factors (WPF) against log-transformed ambient concentration (C_o).

In the study described in this paper, 11 of the 73 C_i samples were below the detection limit for silicon. The value of 70 percent of the detection limit was substituted into the calculations for those samples. The authors decided that the best estimate of respirator performance was to include all valid samples, rather than rejecting those that were non-detected. The samples that received this treatment are identified in Table I.

CONCLUSIONS

In this study, the filtering facepiece respirator reliably provided workplace protection factors above 10 when properly fitted, worn, and used. The estimated 5th percentile WPF for this respirator model exceeds the APF of 10 assigned to this respirator class by ANSI Z88.2-1992 and proposed by OSHA. These results support the APF of 10 for this class of respirator.

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