Simulated Workplace Protection Factor Study Using Four Clemco Industries Type-CE Supplied-Air Respirators

CLEMCO

TC-19C-130

TC-19C-338

TC-19C-358

TC-19C-339

CLEMCO® INDUSTRIES CORP.
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INDUSTRIAL HYGIENE • SAFETY • ENVIRONMENTAL CONSULTING

Simulated Workplace Protection Factor Study
Using Four
Clemco Industries Type-CE Supplied-Air Respirators

February, 2010

NIOSH Approval Numbers for Respirators Tested:

TC-19C-338
TC-19C-339
TC-19C-130
TC-19C-358

This study was funded by:

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Introduction:

Clemco Industries, Corp. located in Washington, Missouri manufactures an extensive line of abrasive blasting equipment. To complement the heavy-duty abrasive-handling systems and hardware, Clemco also manufactures Type-CE Continuous-Flow Supplied-Air Respirators and accessories used for worker respiratory protection during abrasive blasting activities. Clemco offers four NIOSH-approved respirator models: NIOSH TC-19C-338, -339, -130 and -358. The four NIOSH approval numbers correspond to two different helmet models, each paired with two different air-supply hoses (high- and low-pressure).

On August 24, 2006, after many years of effort, OSHA finalized rulemaking changes to 29 CFR Parts 1910, 1915, and 1926 to include Assigned Protection Factors (APF) for all respirator types. The APF is the highest level of protection an employer is allowed to claim. APFs are different for different respirator types. When used along with published worker exposure limits, the APF defines the environmental limitations of that respirator type. Supplied-air helmets and hoods were given an APF of only 25. However, recognizing that some supplied-air respirators were probably much better than that, OSHA provided a way for employers to claim an APF of 1,000.

Several OSHA standards contained in 29CFR parts 1910, 1915 and 1926 include an identical Table 1: Assigned Protection Factors. The APF for supplied-air respirators is listed as " [4]25/1,000 ". Footnote 4 states:

> "4 The employer must have evidence provided by the respirator manufacturer that testing of these respirators demonstrates performance at a level of protection of 1,000 or greater to receive an APF of 1,000. This level of performance can best be demonstrated by performing a WPF or SWPF study or equivalent testing. Absent such testing, all other PAPRs and SARs with helmets/hoods are to be treated as loose-fitting facepiece respirators, and receive an APF of 25."

OSHA defines SWPF as:

> "**Simulated Workplace Protection Factor (SWPF) study** –a study, conducted in a controlled laboratory setting and in which Co and Ci sampling is performed while the respirator user performs a series of set exercises. The laboratory setting is used to control many of the variables found in work place studies, while the exercises simulate the work activities of respirator users. This type of study is designed to determine the optimum performance of respirators by reducing the impact of sources of variability through maintenance of tightly controlled study conditions."

In the discussion section of the August 24, 2006 Federal Register, OSHA suggests criteria for SWPF studies intended to support an APF of 1000 (p.50168):

> "The Agency is setting an APF of 1,000 for tight-fitting facepiece PAPRs with hoods and helmets when the manufacturers of these respirators conduct testing that demonstrates that the respirators provide a level of protection of at least 1,000 (e.g., demonstrating WPFs of at least 10,000 or greater divided by a safety factor of 10, or **lower fifth percentile SWPFs of at least 25,000 divided by a safety factor of 25**)."

Therefore, this SWPF study was designed to determine if the four Clemco respirator models are capable of meeting the recommended OSHA protection level criteria of 1000 after applying a safety factor of 25 (i.e. a 5^{th} percentile SWPF of 25,000 or greater).

Study Objective:

Conduct a Simulated Workplace Protection Factor (SWPF) study on four Clemco NIOSH-approved Type-CE supplied-air respirators to determine if these respirators can achieve lower fifth percentile SWPF values above 1,000 after applying a safety factor of 25.

Study Method:

Respirators Tested:

Four Clemco Industries Type-CE Supplied-Air Respirators were tested. The NIOSH Approval Numbers were:

TC-19C-338
TC-19C-339
TC-19C-130
TC-19C-358

All respirators were tested in their NIOSH-approved configuration using 100-percent Clemco components and accessories.

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NIOSH

TYPE C AND CE CONTINUOUS FLOW SUPPLIED-AIR RESPIRATOR IS APPROVED ONLY IN THE FOLLOWING CONFIGURATIONS:

TC#	Protection [1]	Model / Part No.	Respirator Components: Helmets: Apollo 60 (10506)	Apollo 600 (23824)	Apollo 20 (21302)	Alternate Regulators: CAT (04410)	CCT (04411)	Clem-Cool A/C (23825)	CFC/High Pressure (21422)	CFC/Low Pressure (21777)	ACV (100024)	Hose Air Lines: Yellow 3/8" x 25 Ft. (04397)	Yellow 3/8" x 50 Ft. (04415)	Yellow 3/8" x 100 Ft. (04398)	Black 1/2" x 100 Ft. (21413)	Black 1/2" x 50 Ft. (22510)	Cautions and Limitations [2]
19C-338	CF/SA	20HP			(×)	×	×	×	(×)		×	×	(×)	×			ABCDEJMNOS
19C-339	CF/SA	20LP			(×)					(×)					×	(×)	ABCDEJMNOS
19C-130	CF/SA	60/600HP	×	(×)		×	×	×	(×)		×	×	(×)	×			ABCDEJMNOS
19C-358	CF/SA	60/600LP	×	(×)						(×)					×	(×)	ABCDEJMNOS

NIOSH Approval Label. Circles indicate test configurations used for this study

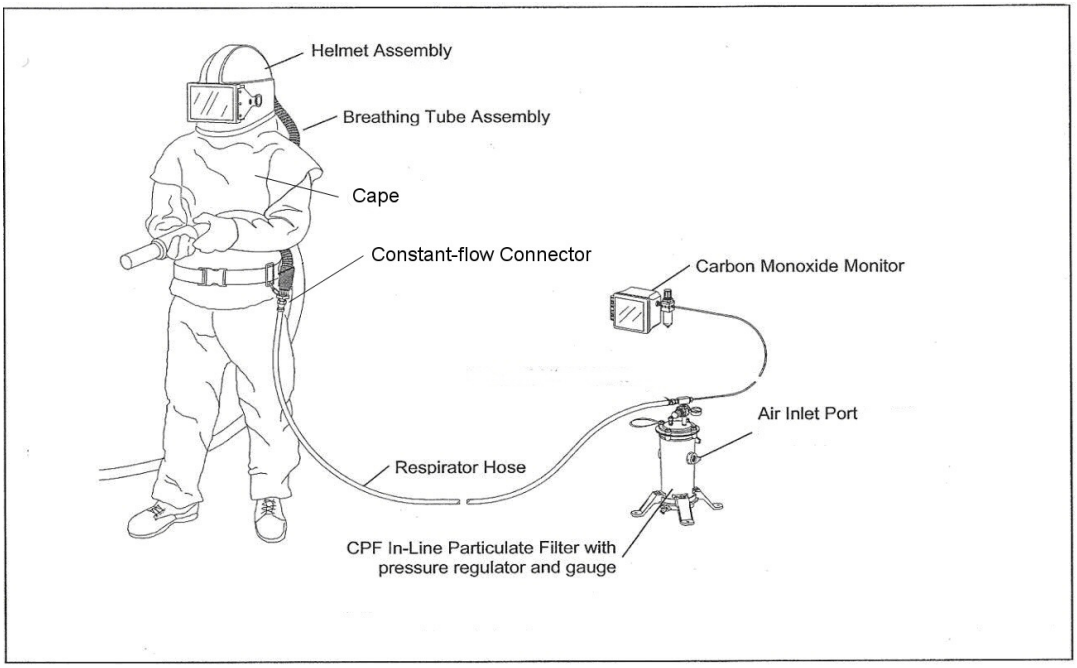


Diagram Showing a Typical Clemco Abrasive Blasting Helmet Respirator Configuration

Test Subjects:

Four volunteers (test subjects) were each tested 3 times, wearing each of four NIOSH-certified respirators operating with a 6 cfm air supply (12 tests per subject for a sum of 48 tests). One subject was also tested in all 4 respirators operating at 9 cfm and then at 15 cfm (8 tests). The total number of SWPF tests performed was 56.

The three male and one female test subjects were selected to represent a range of body sizes. All subjects were required to be non-smokers and in good health.

Subject	Gender	Age	Height ft. - in.	Weight lbs.	Neck Size in.
1	Male	31	5 -10	138	15-1/4
2	Female	30	5 - 6	130	12-3/8
3	Male	51	5 – 8	210	18
4	Male	51	6 - 0	240	18-1/2

Air Supply Flow Rate:

Prior to the start of SWPF testing, a Key Instruments SCFM Air Rotameter was temporarily connected in-line with the 50-foot low-pressure respirator hose, LP constant-flow connector (21777) and breathing tube assembly to precisely calibrate the air supply regulator for delivery of the desired flow rate. The same was done for the high-pressure respirator hose, HP constant-flow connector (21422) and breathing tube assembly. These pressure settings were used to set the flow rate for all subsequent SWPF tests.

Regulator Settings (psi)		
Flow (cfm)	**Low-pressure**	**High-pressure**
6	4	40
9	6	65
15	11	114

A flow rate of 6 cfm was chosen for this study because it is the minimum allowed by NIOSH for certification testing of Type-CE supplied-air respirators (42CFR84). That flow rate was expected to yield SWPF results that were the same or lower than at higher flow rates. This assumption was evaluated by having subject #1 test all four respirators at both 9 cfm and 15 cfm (8 additional tests). The results of those 8 tests confirmed that there was no reduction in SWPF values compared to the 6 cfm measurements. It should be noted that the Clemco operation manuals call out a minimum supply pressure of 6 and 65 psi respectively for the low-pressure and high-pressure respirators. Six and 65 psi corresponded to a flow rate of 9 cfm for the respirators as configured in this study.

The air supplied was Grade-D breathing air fed through a Clemco CPF In-Line Particulate Filter as well as an additional high-efficiency submicron filter (described later).

Test Booth:

A paint spray booth located at the Clemco factory in Washington, Missouri was modified to serve as the test chamber for the study. The room dimensions were 9 ft long x 12 ft wide x 8 ft high. The booth had large windows, allowing the researchers to observe the test subjects at all times. A pair of portable radios was used to allow the researchers to send exercise commands to the test subjects.

SWPF Test Exercise Protocol:

The test protocol consisted of ten (10) exercises selected to represent motions characteristic of workers doing abrasive blasting. Test subjects removed the blasting helmet in-between each 15-minute test.

Exercise Description	**Duration** (sec)
Normal breathing (NB)	90
Deep breathing (DB)	90
Turn head side to side (SS)	90
Raise head up and down (UD)	90
Talk out loud (T)	90
Simulate abrasive blasting motion (BLM)	90
Bend down to touch floor and reach to ceiling (RFC)	90
On hands and knees - turn head side to side (HKSS)	90
Climb stairs (CS)	90
Normal breathing (NB)	90
Total	900 (=15 min)

Test Instrumentation:

Aerosol concentration data was taken from inside and outside the respirator using a PortaCount® Respirator Fit Tester Model 8020 along with FitPlus v3.4.2 Fit Test Software (TSI Inc. Shoreview, Minnesota). The PortaCount is a condensation particle counter (CPC) that measures the concentration of submicron particles by counting individual particles.

In order to accurately measure very high SWPFs in the range of 25,000 and above with a condensation particle counter like the PortaCount, it is necessary to maintain an aerosol challenge concentration well above naturally occurring ambient levels. Three high-output ultrasonic humidifiers (particle generators) were used to maintain an elevated challenge concentration in the test booth. Ultrasonic humidifiers generate large quantities of submicron aerosol particles by launching billions of droplets into the air. The water in the droplets evaporates almost instantly leaving a solid particle composed of the residual mineral content that was dissolved in the water. The size of the resulting particles can be decreased using higher purity water or increased by adding a non-toxic contaminant such as salt (NaCl). For this study it was found that the local tap water produced sufficient aerosol in the proper size range for the PortaCount to detect (0.02 – 1 micron). The booth exhaust system normally used for paint spray operations was always off, but some fresh air from outdoors was constantly flowing into the test booth due to the building's overall negative-pressure, caused by the numerous exhaust systems that were in constant operation throughout the factory. A 20-inch portable box fan inside the

booth was used to help circulate and mix the aerosol. The three particle generators were put in different locations and operated at full output, which allowed the test booth to reach equilibrium at a challenge aerosol concentration averaging 50,000 particles/cc. Concentration measurements made using the PortaCount in count mode at various locations within the booth showed that the aerosol was stable and evenly distributed. The particle generators and fan were left on overnight during the project to eliminate start-up delays each morning.

Another consideration necessary to ensure accurate measurement of very high SWPFs for any air-supplied respirator is the quality of the supplied air. If there are any particles delivered to the helmet in the air supply they will be interpreted as leakage by the PortaCount. The PortaCount cannot determine the difference between a particle that entered through a leak and one that was delivered with the breathing air. The particle-free supply air necessary for this study far exceeds the specification for Grade-D breathing air.

The air supply used for this study was grade-D with the usual Clemco CPF filter. That configuration was not tested for particles, however just to make certain all particles were eliminated, an additional high-efficiency (Motor Guard Submicronic M-60) filter was added in-line between the CPF filter and the pressure regulator. Measurements of the air supply using the PortaCount showed that the air entering the helmet was indeed particle-free.

The computer doing the data collection was located outside the test booth and was connected to the PortaCount which was inside the booth. A 15-foot RS232 interface cable connecting them was fed through an access hole. The printer was located next to the computer to print hard-copy SWPF results as a backup in case the computer failed.

The exercise protocol included whole-body exercises such as the blasting motion, crawling on hand and knees and climbing stairs, which could not be accommodated using the 5-foot sample tube provided by the PortaCount manufacturer. A 15-foot sample tube assembly was fabricated using two equal lengths of 1/8 ID x 1/4in OD Tygon R-3603 tubing. One tube was for the mask sample and one was for the test booth (challenge) sample. The reason that the tubes are kept equal length is to cancel out particle losses when SWPF ratios are calculated. The two tubes were fastened together with tape every 6 inches to keep them together. One end of the assembly was connected to the mask and ambient ports on the PortaCount and the other end was secured to the breathing hose just behind the respirator helmet. The last 8 feet of sample tube assembly on the helmet end was secured along the air supply hose with Velcro strips to provide strain relief and prevent the test subject from tangling or stepping on the tubes.

The end of the challenge sample tube was left open behind the helmet and positioned so that there could be no interference. This is where the test booth sample was taken. Even though the booth aerosol concentration appeared to be evenly distributed, it was important for this sample to be taken from the vicinity of the helmet, thus avoiding potential biases caused by unforeseen variations.

The mask sample was taken from inside the helmet in the breathing zone of the test subject immediately in front of the nose and mouth. This was done by extending the mask sample tube from behind the helmet, through a metal feed-thru fitting located on the respirator cape, and then

into the helmet. The fitting was at the back of the subject's neck in the area between the respirator collar and the helmet. A 1/8in ID x 3/16in OD Tygon® tube about 12 inches long was connected to the inside barb of the fitting and secured along the left inside surface of the helmet with tape. The open end of the tube was secured to the inside of the helmet in front of the subject's nose and mouth using a small clip and suction cup. Preliminary testing in the booth showed that the same aerosol concentration value was obtained through either the mask sample or challenge sample tubes when the helmet was not being worn and the air supply was off (both sample points exposed to booth challenge concentration), indicating that there were no pinch-points or other flow restrictions in either sample tube. Both sample tubes were checked for leaks by attaching a small HEPA filter to the open end and watching the PortaCount concentration reading drop quickly to zero and hold there.

The PortaCount instrument uses the same particle detector for both the mask and challenge sample utilizing a valve to switch from one sample tube to the other. At the moment the valve switches, particles from the previous sample remain inside the instrument and sample tubes, so it is necessary to wait a period of time before a fresh sample reaches the instrument. This period is called purge time and occurs in two different situations during SWPF (and fit factor) measurements. Ambient purge is the wait time needed prior to recording the ambient concentration or in the case of this study, the challenge concentration inside the test booth. Mask purge is the wait time needed prior to recording the mask (or helmet) concentration. Purge times when switching from a high concentration to a low concentration are always longer than from low to high because it's necessary for ALL leftover ambient particles to exit before a mask sample can be taken. A few leftover particles from the mask sample are of no consequence when a high concentration ambient measurement is made.

The factory set purge times for a PortaCount using the standard 5-foot sample tube are 4 seconds for the ambient purge and 11 seconds for the mask purge. Since this study utilizes sample tubes that are 15 feet long, it was necessary to increase the purge times to accommodate the longer time it would take for an aerosol sample to travel from the sample point to the PortaCount. Preliminary purge time measurements were made using the small HEPA filter and a stopwatch. With the PortaCount showing the challenge concentration being pulled through the mask sample tube, the stopwatch was started at the moment the filter was attached at the sample point. The number of seconds it took to reach a concentration of zero was noted as the preliminary mask purge time. For the challenge sample tube, the HEPA filter was first attached to the sample point to allow the concentration to hold at zero, and then the stopwatch was started at the moment the filter was removed. The number of seconds it took to reach the full challenge concentration was noted as the preliminary ambient purge time.

The purge times, as well as the mask and ambient measurement timings are adjustable using the FitPlus Fit Test Software provided with the PortaCount. To verify that the preliminary purge times were sufficient, the preliminary purge values were programmed into the computer, and an SWPF measurement was made with the HEPA filter attached to the end of the mask sample tube inside the helmet. The helmet was in the test booth lying on a table. This simulates a perfect SWPF since the mask sample will surely be particle free. If the purge times are adequate, an extremely high SWPF will result. If the purge times are too short, low SWPFs will result.

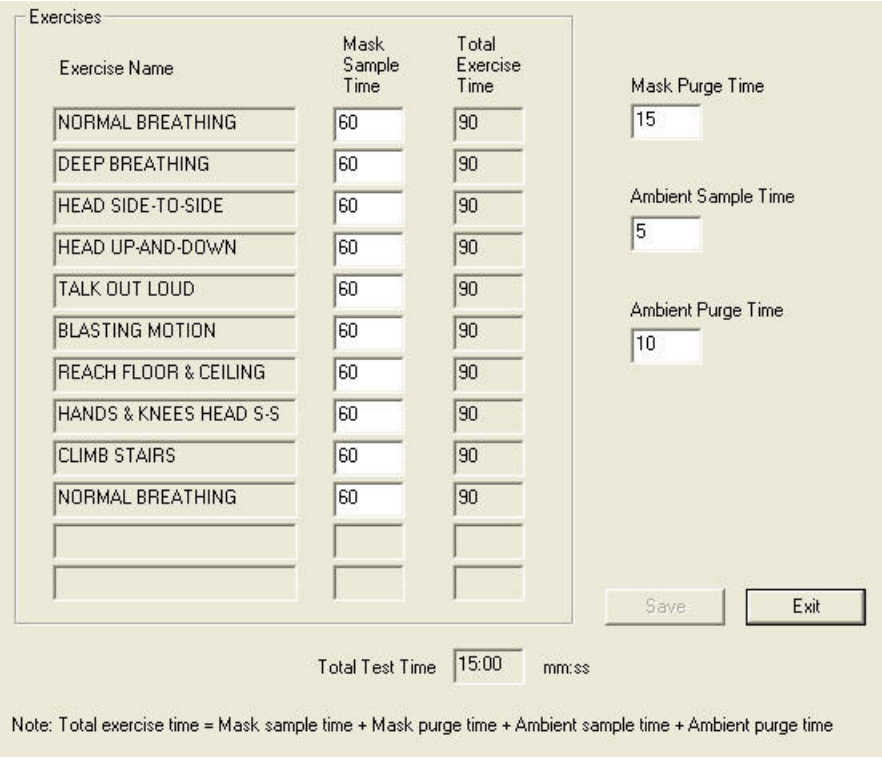
The testing showed that the preliminary purge times were adequate for good measurements. The SWPFs were 999,000 which is the highest value the PortaCount will display. In the interest of caution, the preliminary values were increased further. The 5-second ambient (challenge) sample time and the 60-second mask sample time were predetermined as part of the study protocol, resulting in a total time of 90 seconds per SWPF exercise.

Sample Timing for Each Exercise

	Duration (seconds)
Ambient purge	10
Ambient sample	5
Mask purge	15
Mask sample	60
Total	**90**

SWPF Data Collection:

The PortaCount and FitPlus software work together to execute the SWPF protocol measurements. The computer was programmed with the desired exercise descriptions, sequence and sample timing.



Once an SWPF test is started, the software prompts the operator through the exercise sequence and records the data. Each test using the Clemco SWPF protocol used for this study required 15 minutes to complete.

SWPF was recorded for each exercise and the Overall SWPF was calculated for each test. SWPF for each exercise is calculated as a ratio of two measurements, just like a fit factor.

$$SWPF = \frac{C_{challenge}}{C_{mask}}$$

Where:

$C_{challenge}$ = Challenge concentration
C_{mask} = Mask concentration

To account for variations in challenge concentration during an exercise, a challenge concentration measurement is taken immediately before and after each mask sample, averaged together, and then used as the challenge concentration for that exercise.

The Overall SWPF is calculated as the harmonic mean of the individual exercise SWPFs. This is just like the way an overall fit factor is calculated. This method is well-known and is described in OSHA 29CFR1910.134, ANSI Z88.10 and elsewhere. For a 10-exercise protocol as used in this study:

$$\text{Overall SWPF} = \frac{10}{\frac{1}{SWPF1} + \frac{1}{SWPF2} + \frac{1}{SWPF3} + \frac{1}{SWPF4} + \frac{1}{SWPF5} + \frac{1}{SWPF6} + \frac{1}{SWPF7} + \frac{1}{SWPF8} + \frac{1}{SWPF9} + \frac{1}{SWPF10}}$$

Where:

SWPF1 = SWPF for exercise 1
SWPF2 = SWPF for exercise 2
SWPF3 = SWPF for exercise 3
…Etc.

Statistical calculations were made using Microsoft Office Excel 2003 software.

Study Results:

SWPF measurements consistently showed that there was virtually no leakage into the respirator from the test booth environment for any of the 4 respirators on any of the test subjects. Individual exercise SWPFs ranged from a low of 44,100 to the instrumentation system limit of 999,000. Overall SWPFs ranged from 193,000 to 986,000. Lower 5th percentile SWPF values easily exceeded the target value of 1,000 after applying the safety factor of 25 suggested by OSHA, and ranged from 8,930 to 20,942. The results are summarized below.

Overall SWPF Results

Respirator	A	B	C	D
NIOSH Apr. No. TC-	**19C-338**	**19C-339**	**19C-130**	**19C-358**
Subject				
1	739000	344000	283000	698000
1	479000	708000	432000	599000
1	597000	617000	322000	616000
2	864000	744000	329000	193000
2	871000	741000	669000	544000
2	786000	862000	553000	468000
3	560000	504000	376000	430000
3	637000	511000	436000	374000
3	737000	370000	282000	248000
4	920000	940000	400000	417000
4	886000	935000	354000	492000
4	958000	986000	350000	552000
Average	752833	688500	398833	469250
High	958000	986000	669000	698000
Low	479000	344000	282000	193000
Median	762500	724500	365000	480000
Standard Deviation	155360	221487	113620	148404
Lower 5th Percentile	523550	358300	282550	223250
Lower 5th Percentile/25	**20942**	**14332**	**11302**	**8930**

The two helmets tested were always supplied with 6 cfm of air at the point where the air hose connects to the helmet, with either the high-pressure or low-pressure configuration. This permits the high- and low-pressure data for each helmet to be combined so there are 24 data points instead of 12. Doing so did not significantly alter the results with respirator A/B and C/D achieving lower 5th percentile SWPFs/25 of 15,454 and 10,124 respectively.

Discussion:

The particle concentrations measured inside the helmets were extremely low. This was expected based on results obtained by others for similar respirators where SWPFs in excess of 100,000 were common. The fact that SWPFs measured during this study were even higher than the previous researchers reported can be explained by examining the instrumentation used. Previous SWPF studies utilized a photometer for measuring aerosol concentrations. The upper limit for concentration ratios measured by a photometer is limited by the background signal level (noise level) measured when the aerosol concentration is zero. The background noise is caused by light from the high-intensity light source reaching the photo detector after reflecting off the walls of the optics chamber. Photometer designers go to great lengths to minimize this effect by coating the inside walls of the optics chamber with anti-reflective material. The light scattered from an aerosol must exceed the noise level by a measurable margin to distinguish an actual reading from the noise level. When SWPF aerosol concentrations inside the respirator approach the noise level, the researchers cannot say exactly what the SWPF was. All they can do is say that the SWPF equal to or greater than the maximum. This is why many of the existing studies report SWPFs of ">40,000" or in other cases, percent penetrations of "<0.001".

This study differs from past studies in that the instrument used was a Condensation Particle Counter (CPC). A CPC can "see" a single particle and count it. There is essentially no background noise level. The test booth concentration in this study averaged 50,000 particles/cc. One particle detected during a 60-second sample (as used for this study) would result in an SWPF of 5 million. The software used for this study was not capable of recording SWPF in excess of 6 digits, resulting in a ceiling SWPF of 999,999 which was then truncated to 3 significant digits or 999,000.

CPC measurements do have limitations. The statistical variability of high SWPF measurements can be high when very few particles are counted during the mask sample. For this study, a single-exercise SWPF measurement of 990,000 has a margin of error of ± 44%. That's because only 5 particles would have been counted inside the respirator. One particle more, or one particle less, has a great effect on the calculated SWPF. This study was designed to reduce the margin of error for overall SWPFs by using a very high test chamber concentration of about 50,000 particles/cc, and long in-mask sample time of 10 minutes (one minute for each of 10 exercises). Thus the margin of error for an overall SWPF of 25,000, 100,000 and 999,000 computes to ± 2%, ± 4% and ± 14% respectively. (Margin of Error(%) = 100/sqrt(n) where n is the number of particles counted during the sample.)

Another issue to be concerned with when few particles are measured during the mask sample is whether or not there was a problem taking that sample. A blocked or partially blocked mask sample tube would result in SWPFs that are very, very high since the instrument would think there are no particles in the mask. We know that there was no such mask sample tube blockage during this study for the following reasons:

- After changing to a different helmet, one test subject had an SWPF result for the very first exercise of about 14. All previous tests were getting SWPFs above 100,000. The test was immediately terminated. Attaching the small HEPA filter to the mask sample

tube caused the particle count to drop to zero proving that there were no leaks in that tube. After a few minutes of investigation it was discovered that the breathing tube had not been properly tightened where it connects to the back of the helmet. It was very loose and took several turns to tighten properly. Particles were being drawn into the helmet via a venturi-effect resulting in the abnormally low SWPF. In other words, the measurement system worked as expected.

- Two tests (different test subjects) were aborted because the test subject coughed. Coughing produces large numbers of microscopic body-generated particles which are detected by the instrumentation. The sample point inside the helmet is located directly in front of the test subject's mouth. These particles were interpreted as leakage by the instrument resulting in SWPF values below 20 for that exercise. If the sampling system were faulty, these particles would not have been detected.

- At one point we ran a complete 10-exercise test on a person wearing a helmet but not the cape. The collar that usually seals around the neck is part of the cape, so the helmet was wide open all the way around the bottom. The SWPF was near 5 for all exercises, showing that the sampling system was effective. The reason the SWPF was not even lower is because particle-free air was being delivered to the helmet, diluting the particle-laden air that was leaking in.

Yet another concern involves body-generated particles. It is well known that cigarette smokers exhale significant numbers of smoke particles for a while after smoking, which is why our test subjects were required to be non-smokers. But even non-smokers usually exhale a few particles. The total number of particles detected during the entire 10-minutes of mask sampling for each of the 48 tests ranged from 59 to 226. It is possible that some or even all of the particles detected inside the helmet were body-generated, or were dislodged from the person's skin or hair. Determining the source of the particles sampled inside the helmet was beyond the scope of this study. If any of the particles were body-generated, it means the SWPFs were actually even higher than reported in this study.

Conclusion:

This SWPF study demonstrated that OSHA-compliant employers are justified in applying an Assigned Protection Factor (APF) of 1,000 when their workers use any of the four Clemco Type-CE Supplied-Air Respirators in accordance with Clemco instructions and configured with 100% Clemco components. OSHA requires lower 5th percentile SWPF values to exceed 1,000 after applying a safety factor of 25. The four Clemco respirators with NIOSH approval numbers TC-19C-338, -339, -130 and -358 achieved lower 5th percentile SWPFs/25 of 20,942, 14,332, 11,302 and 8,930 respectively.

References:

- Clemco Industries Operation Manuals:
O.M. 21990 *Apollo Supplied-Air Respirator Helmet Model 20 High Pressure 65 psi to 100 psi*
O.M. 21991 *Apollo Supplied-Air Respirator Helmet Model 20 Low Pressure 6 psi to 20 psi*
O.M. 23929 *Apollo Supplied-Air Respirator Helmet Model 600 Low Pressure 6 psi to 20 psi*
O.M. 23930 *Apollo Supplied-Air Respirator Helmet Model 600 High Pressure 65 psi to 100 psi*

- 42CFR84 Respiratory Protective Devices
National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention, Public Health Service, HHS.

- Federal Register, vol. 71, no. 164, p.50122 – 50191, August 24, 2006
29 CFR Parts 1910, 1915, and 1926 Assigned Protection Factors
Occupational Safety and Health Administration (OSHA), Department of Labor.

- Cohen HJ, Hecker LH, Mattheis DK, Johnson JS, Biermann AH, Foote KL., *Simulated workplace protection factor study of powered air-purifying and supplied air respirators*, University of New Haven, Department of Occupational Safety and Health, West Haven, CT 06516, USA, AIHAJ. 2001 Sep-Oct;62(5):595-604.

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- Trujillo A, Bradley OD, *Aerosol Penetration and Pressure Testing of Clemco Model 20/60 Abrasive Blasting Hoods*, Los Alamos National Laboratory, September 12, 1996.

- Federal Register /Vol. 68, No. 109/Friday, June 6, 2003/Proposed Rules, p.34103

Appendix A: SWPF Data

	Clemco HP Abrasive Blasting Helmet TC-19C-0338 @ 6cfm										
											Overall
Subject	NB	DB	SS	UD	T	BLM	RFC	HKSS	CS	NB	SWPF
1	999000	999000	999000	462000	999000	999000	999000	311000	925000	947000	739000
1	999000	561000	219000	587000	818000	783000	545000	209000	600000	999000	479000
1	999000	999000	436000	297000	999000	999000	974000	289000	626000	999000	597000
2	999000	999000	915000	999000	815000	999000	999000	450000	975000	999000	864000
2	999000	999000	999000	999000	966000	999000	999000	452000	821000	999000	871000
2	999000	999000	999000	999000	999000	915000	407000	551000	747000	999000	786000
3	999000	999000	689000	643000	999000	999000	538000	175000	446000	999000	560000
3	999000	999000	531000	471000	999000	999000	550000	279000	788000	999000	637000
3	999000	999000	744000	708000	839000	959000	999000	335000	877000	694000	737000
4	999000	999000	999000	999000	999000	999000	567000	999000	999000	919000	920000
4	999000	999000	999000	999000	999000	576000	999000	999000	999000	651000	886000
4	999000	999000	704000	999000	999000	999000	999000	999000	999000	999000	958000
Average	**999000**	**962500**	**769417**	**763500**	**952500**	**935417**	**797917**	**504000**	**816833**	**933583**	**752833**
High	**999000**	**999000**	**999000**	**999000**	**999000**	**999000**	**999000**	**999000**	**999000**	**999000**	**958000**
Low	**999000**	**561000**	**219000**	**297000**	**815000**	**576000**	**407000**	**175000**	**446000**	**651000**	**479000**
Median	**999000**	**999000**	**829500**	**853500**	**999000**	**999000**	**986500**	**392500**	**849000**	**999000**	**762500**
Std Dev	**0**	**126440**	**264076**	**265535**	**78253**	**129939**	**247301**	**316347**	**182550**	**125002**	**155360**
5th Percentile	**999000**	**801900**	**338350**	**387750**	**816650**	**689850**	**479050**	**193700**	**530700**	**674650**	**523550**
5th Percentile/25	**39960**	**32076**	**13534**	**15510**	**32666**	**27594**	**19162**	**7748**	**21228**	**26986**	**20942**

	Clemco LP Abrasive Blasting Helmet TC-19C-0339 @ 6cfm									
Subject	NB	DB	SS	UD	T	BLM	HKSS	CS	NB	OVERALL SWPF
1	544000	375000	293000	593000	464000	999000	112000	305000	433000	344000
1	707000	756000	999000	999000	999000	920000	418000	437000	999000	708000
1	474000	999000	409000	481000	999000	953000	406000	821000	544000	617000
2	999000	999000	999000	999000	999000	999000	266000	999000	598000	744000
2	933000	875000	865000	999000	999000	999000	529000	424000	999000	741000
2	999000	999000	999000	738000	999000	837000	697000	624000	999000	862000
3	556000	930000	274000	227000	846000	884000	320000	955000	982000	504000
3	999000	804000	576000	262000	442000	999000	267000	366000	999000	511000
3	999000	919000	300000	400000	497000	999000	96000	999000	999000	370000
4	999000	999000	999000	999000	999000	999000	659000	971000	999000	940000
4	999000	999000	999000	999000	670000	999000	841000	999000	999000	935000
4	999000	999000	999000	940000	937000	999000	999000	999000	999000	986000
Average	**850583**	**887750**	**725917**	**719667**	**820833**	**965500**	**467500**	**741583**	**879083**	**688500**
High	**999000**	**999000**	**999000**	**999000**	**999000**	**999000**	**999000**	**999000**	**999000**	**986000**
Low	**474000**	**375000**	**274000**	**227000**	**442000**	**837000**	**96000**	**305000**	**433000**	**344000**
Median	**999000**	**964500**	**932000**	**839000**	**968000**	**999000**	**412000**	**888000**	**999000**	**724500**
Std Dev	**214092**	**182026**	**325123**	**311359**	**234143**	**55889**	**284174**	**287412**	**216566**	**221487**
5th Percentile	**512500**	**584550**	**284450**	**246250**	**454100**	**862850**	**104800**	**338550**	**494050**	**358300**
5th Percentile/25	**20500**	**23382**	**11378**	**9850**	**18164**	**34514**	**4192**	**13542**	**19762**	**14332**

	Clemco HP Abrasive Blasting Helmet TC-19C-0130 @ 6cfm										
Subject	NB	DB	SS	UD	T	BLM	RFC	HKSS	CS	NB	OVERALL SWPF
1	366000	505000	189000	294000	431000	999000	262000	89500	391000	999000	283000
1	999000	336000	356000	542000	724000	999000	999000	133000	384000	999000	432000
1	676000	587000	146000	269000	489000	999000	999000	95500	580000	999000	322000
2	174000	397000	999000	999000	999000	560000	111000	175000	999000	634000	329000
2	999000	779000	999000	437000	999000	459000	783000	385000	765000	999000	669000
2	787000	999000	999000	545000	999000	497000	362000	229000	552000	999000	553000
3	999000	999000	434000	151000	709000	999000	360000	118000	999000	999000	376000
3	999000	999000	681000	341000	999000	999000	262000	149000	359000	824000	436000
3	999000	999000	367000	217000	999000	999000	159000	71300	467000	644000	282000
4	999000	999000	335000	193000	389000	409000	335000	249000	999000	560000	400000
4	176000	999000	420000	953000	245000	827000	262000	237000	582000	331000	354000
4	579000	999000	192000	710000	447000	374000	238000	143000	489000	999000	350000
Average	**729333**	**799750**	**509750**	**470917**	**702417**	**760000**	**427667**	**172858**	**630500**	**832167**	**398833**
High	**999000**	**999000**	**999000**	**999000**	**999000**	**999000**	**999000**	**385000**	**999000**	**999000**	**669000**
Low	**174000**	**336000**	**146000**	**151000**	**245000**	**374000**	**111000**	**71300**	**359000**	**331000**	**282000**
Median	**893000**	**999000**	**393500**	**389000**	**716500**	**913000**	**298500**	**146000**	**566000**	**999000**	**365000**
Std Dev	**331892**	**267607**	**326403**	**288118**	**291115**	**272894**	**314405**	**89126**	**247739**	**232539**	**113620**
5th Percentile	**175100**	**369550**	**169650**	**174100**	**324200**	**393250**	**137400**	**81310**	**372750**	**456950**	**282550**
5th Percentile/25	**7004**	**14782**	**6786**	**6964**	**12968**	**15730**	**5496**	**3252**	**14910**	**18278**	**11302**

Subject	NB	DB	SS	UD	T	BLM	RFC	HKSS	CS	NB	SWPF
1	340000	645000	999000	575000	999000	999000	887000	514000	999000	999000	698000
1	866000	419000	999000	639000	625000	999000	267000	524000	755000	999000	599000
1	491000	999000	999000	570000	666000	680000	529000	337000	626000	999000	616000
2	493000	338000	373000	243000	420000	272000	209000	44100	205000	628000	193000
2	723000	999000	876000	892000	999000	819000	502000	153000	510000	999000	544000
2	999000	999000	801000	477000	999000	465000	212000	163000	999000	999000	468000
3	999000	999000	364000	421000	999000	999000	199000	204000	314000	999000	430000
3	999000	999000	531000	158000	991000	787000	267000	202000	282000	510000	374000
3	634000	761000	320000	218000	79000	637000	176000	220000	238000	999000	248000
4	999000	738000	389000	351000	999000	498000	241000	143000	999000	999000	417000
4	999000	999000	522000	641000	999000	999000	163000	287000	679000	581000	492000
4	496000	999000	618000	999000	715000	999000	192000	583000	999000	467000	552000
Average	**753167**	**824500**	**649250**	**515333**	**790833**	**762750**	**320333**	**281175**	**633750**	**848167**	**469250**
High	**999000**	**999000**	**999000**	**999000**	**999000**	**999000**	**887000**	**583000**	**999000**	**999000**	**698000**
Low	**340000**	**338000**	**320000**	**158000**	**79000**	**272000**	**163000**	**44100**	**205000**	**467000**	**193000**
Median	**794500**	**999000**	**574500**	**523500**	**995000**	**803000**	**226500**	**212000**	**652500**	**999000**	**480000**
Std Dev	**252851**	**244577**	**270755**	**259559**	**300473**	**253174**	**215438**	**172963**	**320818**	**225933**	**148404**
5th Percentile	**423050**	**382550**	**344200**	**191000**	**266550**	**378150**	**170150**	**98495**	**223150**	**490650**	**223250**
5th Percentile/25	**16922**	**15302**	**13768**	**7640**	**10662**	**15126**	**6806**	**3940**	**8926**	**19626**	**8930**

	Combined LP and HP Data for Respirators TC-19C-0130 and TC-19C-0358 @ 6cfm										
Subject	NB	DB	SS	UD	T	BLM	RFC	HKSS	CS	NB	OVERALL SWPF
1	366000	505000	189000	294000	431000	999000	262000	89500	391000	999000	283000
1	999000	336000	356000	542000	724000	999000	999000	133000	384000	999000	432000
1	676000	587000	146000	269000	489000	999000	999000	95500	580000	999000	322000
2	174000	397000	999000	999000	999000	560000	111000	175000	999000	634000	329000
2	999000	779000	999000	437000	999000	459000	783000	385000	765000	999000	669000
2	787000	999000	999000	545000	999000	497000	362000	229000	552000	999000	553000
3	999000	999000	434000	151000	709000	999000	360000	118000	999000	999000	376000
3	999000	999000	681000	341000	999000	999000	262000	149000	359000	824000	436000
3	999000	999000	367000	217000	999000	999000	159000	71300	467000	644000	282000
4	999000	999000	335000	193000	389000	409000	335000	249000	999000	560000	400000
4	176000	999000	420000	953000	245000	827000	262000	237000	582000	331000	354000
4	579000	999000	192000	710000	447000	374000	238000	143000	489000	999000	350000
1	340000	645000	999000	575000	999000	999000	887000	514000	999000	999000	698000
1	866000	419000	999000	639000	625000	999000	267000	524000	755000	999000	599000
1	491000	999000	999000	570000	666000	680000	529000	337000	626000	999000	616000
2	493000	338000	373000	243000	420000	272000	209000	44100	205000	628000	193000
2	723000	999000	876000	892000	999000	819000	502000	153000	510000	999000	544000
2	999000	999000	801000	477000	999000	465000	212000	163000	999000	999000	468000
3	999000	999000	364000	421000	999000	999000	199000	204000	314000	999000	430000
3	999000	999000	531000	158000	991000	787000	267000	202000	282000	510000	374000
3	634000	761000	320000	218000	79000	637000	176000	220000	238000	999000	248000
4	999000	738000	389000	351000	999000	498000	241000	143000	999000	999000	417000
4	999000	999000	522000	641000	999000	999000	163000	287000	679000	581000	492000
4	496000	999000	618000	999000	715000	999000	192000	583000	999000	467000	552000
Average	**741250**	**812125**	**579500**	**493125**	**746625**	**761375**	**374000**	**227017**	**632125**	**840167**	**434042**
High	**999000**	**999000**	**999000**	**999000**	**999000**	**999000**	**999000**	**583000**	**999000**	**999000**	**698000**
Low	**174000**	**336000**	**146000**	**151000**	**79000**	**272000**	**111000**	**44100**	**205000**	**331000**	**193000**
Median	**826500**	**999000**	**478000**	**457000**	**857500**	**823000**	**262000**	**188500**	**581000**	**999000**	**423500**
Std Dev	**288802**	**251034**	**301812**	**269141**	**292832**	**257437**	**269220**	**145490**	**280322**	**224369**	**134167**
5th Percentile	**200600**	**346850**	**189450**	**163250**	**266600**	**379250**	**159600**	**74030**	**244600**	**473450**	**253100**
5th Percentile/25	**8024**	**13874**	**7578**	**6530**	**10664**	**15170**	**6384**	**2961.2**	**9784**	**18938**	**10124**

	Combined LP and HP Data for Respirators TC-19C-0338 and TC-19C-0339 @ 6cfm										
Subject	NB	DB	SS	UD	T	BLM	RFC	HKSS	CS	NB	OVERALL SWPF
1	999000	999000	999000	462000	999000	999000	999000	311000	925000	947000	739000
1	999000	561000	219000	587000	818000	783000	545000	209000	600000	999000	479000
1	999000	999000	436000	297000	999000	999000	974000	289000	626000	999000	597000
2	999000	999000	915000	999000	815000	999000	999000	450000	975000	999000	864000
2	999000	999000	999000	999000	966000	999000	999000	452000	821000	999000	871000
2	999000	999000	999000	999000	999000	915000	407000	551000	747000	999000	786000
3	999000	999000	689000	643000	999000	999000	538000	175000	446000	999000	560000
3	999000	999000	531000	471000	999000	999000	550000	279000	788000	999000	637000
3	999000	999000	744000	708000	839000	959000	999000	335000	877000	694000	737000
4	999000	999000	999000	999000	999000	999000	567000	999000	999000	919000	920000
4	999000	999000	999000	999000	999000	576000	999000	999000	999000	651000	886000
4	999000	999000	704000	999000	999000	999000	999000	999000	999000	999000	958000
1	544000	375000	293000	593000	464000	999000	572000	112000	305000	433000	344000
1	707000	756000	999000	999000	999000	920000	622000	418000	437000	999000	708000
1	474000	999000	409000	481000	999000	953000	999000	406000	821000	544000	617000
2	999000	999000	999000	999000	999000	999000	999000	266000	999000	598000	744000
2	933000	875000	865000	999000	999000	999000	539000	529000	424000	999000	741000
2	999000	999000	999000	738000	999000	837000	999000	697000	624000	999000	862000
3	556000	930000	274000	227000	846000	884000	723000	320000	955000	982000	504000
3	999000	804000	576000	262000	442000	999000	999000	267000	366000	999000	511000
3	999000	919000	300000	400000	497000	999000	276000	96000	999000	999000	370000
4	999000	999000	999000	999000	999000	999000	928000	659000	971000	999000	940000
4	999000	999000	999000	999000	670000	999000	999000	841000	999000	999000	935000
4	999000	999000	999000	940000	937000	999000	999000	999000	999000	999000	986000
Average	**924792**	**925125**	**747667**	**741583**	**886667**	**950458**	**801208**	**485750**	**779208**	**906333**	**720667**
High	**999000**	**999000**	**999000**	**999000**	**999000**	**999000**	**999000**	**999000**	**999000**	**999000**	**986000**
Low	**474000**	**375000**	**219000**	**227000**	**442000**	**576000**	**276000**	**96000**	**305000**	**433000**	**344000**
Median	**999000**	**999000**	**890000**	**839000**	**999000**	**999000**	**986500**	**412000**	**849000**	**999000**	**740000**
Std Dev	**166336**	**157956**	**290517**	**283879**	**183496**	**99020**	**243081**	**294672**	**238583**	**175154**	**189961**
5th Percentile	**545800**	**590250**	**276850**	**267250**	**468950**	**791100**	**426650**	**121450**	**374700**	**552100**	**386350**
5th Percentile/25	**21832**	**23610**	**11074**	**10690**	**18758**	**31644**	**17066**	**4858**	**14988**	**22084**	**15454**

SWPF Tests Conducted at 9cfm and 15cfm

Subject	Respirator Model	Flow Rate (cfm)	NB	DB	SS	UD	T	BLM	RFC	HKSS	CS	NB	Overall SWPF
1	TC-19C-0130	15	999000	771000	584000	819000	999000	999000	415000	184000	251000	862000	494000
1	TC-19C-0130	9	999000	999000	493000	989000	999000	999000	375000	112000	905000	532000	462000
1	TC-19C-0338	15	999000	999000	551000	565000	999000	999000	999000	318000	157000	999000	523000
1	TC-19C-0338	9	999000	999000	712000	999000	594000	801000	221000	999000	387000	999000	607000
1	TC-19C-0339	15	338000	571000	487000	620000	335000	688000	270000	261000	550000	629000	420000
1	TC-19C-0339	9	999000	363000	962000	505000	999000	948000	136000	326000	667000	405000	430000
1	TC-19C-0358	15	596000	999000	300000	204000	394000	799000	305000	264000	335000	999000	388000
1	TC-19C-0358	9	451000	770000	375000	539000	999000	764000	999000	398000	436000	989000	582000

Appendix B: Equipment Details

Test Location:

Clemco Industries, Corp.
One Cable Car Drive
Washington, MO 63090

Test Facility:

A paint booth was modified to serve as the test chamber for the study. The room dimensions were 9 feet x 12 feet x 8 feet.

Test Instruments:

- PortaCount® Plus Model 8020 Respirator Fit Tester (s/n 17739)
  TSI Inc, Shoreview, Minnesota. This instrument was factory-serviced and calibrated approximately 3 months prior to this study.

- Dell Model C840 Notebook Computer, WinXP Pro
  Dell Corporation, Austin, Texas

- FitPlus™ Fit Test Software v3.4.2.
  TSI Inc, Shoreview, Minnesota

Aerosol Generators:

(2) Sunbeam Brand UltraSonic Visible Mist Humidifiers, Model SUL 496 and (1) Idylis Brand UltraSonic Humidifier, Model IHWM-10-25.

Airline Supply:

Clemco Respirator Air Supply Hose, Yellow, 3/8in x 50ft was used on high-pressure respirators TC-19C-0130 and TC-19C-0338.

Clemco Respirator Air Supply Hose, Black, 1/2in x 50ft was used on low-pressure respirators TC-19C-0339 and TC-19C-0358.

Air Supply:

Grade-D Breathing Air was provided by a Sullair Brand Compressor, Model # TS 20 – SPL. The compressed air was fed through (2) Ultra Air Dryers Model UA1000 AL into a Clemco Brand CPF Air Filter. A Clemco Industries Brand Dynamation Inc. Carbon Monoxide Monitor, Model ABL-4021 was attached to air line system. For this study, a MotorGuard Submicronic M-60 filter was placed in line to filter out submicron size particles. A Flow Regulator controlled the air flow and pressure was measured with an Ashcroft Pressure Gauge.

Air Flow Calibration:

A Key Instruments (KI) Brand SCFM Air Rotameter (0-25 Cubic Feet per Minute CFM) was used to calibrate the pressure regulator and pressure gauge controlling the air flow rate entering the respirator helmets.