WORKPLACE PROTECTION FACTOR STUDY FOR AIRBORNE METAL DUSTS.

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Paper presented on June 4, 1987, at the American Industrial Hygiene Conference In Montreal.

ABSTRACT

The respirator selection table in the OSHA Lead Standard (29 CFR 1910.1025) specifies half-mask air purifying respirators with high efficiency filters for airborne lead concentrations not exceeding 0.5 mg/m^3 (10X PEL). In January, 1979, OSHA issued an administrative stay of this provision. The stay, which allows use of respirators with dust/mist and dust/fume/mist filters, remains in effect.

This study provides additional information on the effectiveness of dust/mist respirators against lead and other metal dusts. Workplace protection factors were determined for workers wearing half-mask disposable respirators. The workplace selected was a manufacturer of aircraft components. The workers were required to pass a saccharin qualitative fit test before participating in the study. They were also observed at all times to help ensure sample validity.

Results support use of half-mask respirators with dust/mist filters for airborne metal dust concentrations not exceeding 10X the PEL. When properly fit tested and worn, the respirators reliably provided workplace protection factors in excess of 10.

The results also demonstrate an important relationship between outside sample filter loading and protection factors. This relationship needs to be carefully considered when designing workplace studies and analyzing and interpreting results.

INTRODUCTION

(Slide 1) Title Slide

The purpose of this study was to quantify workplace protection factors provided by a maintenance free half-mask respirator used against airborne metal dusts. We want to share our results with you this morning, but we also want to share some things we've learned about designing workplace protection factor studies and interpreting their results.

This type of study is becoming increasingly accepted as an important means of assessing respirator effectiveness, but a consensus on how to do such studies has not yet been reached. So, before we start evaluating the importance or validity of individual studies, it is critical that we define and carefully examine as many of the intricacies of such studies as we can. There are several important questions that remain to be answered about how to set them up and how to properly interpret their results.

TEST SITE

(Slide 2) Photo

In this study, the test site selected was a metal fabricating facility involved with the manufacture of aircraft components. A polishing/grinding department was the primary area of interest. Air contaminants included silicon dust from abrasive wheels and titanium and aluminum dusts from metal parts being processed. Lead and other elements were also present at lower concentrations.

(Slide 3) Photo

A limited amount of sampling was also conducted in a coating department, where a lead containing material was being sprayed onto parts, and in a blasting department, where parts were being run through blasting cabinets containing aluminum oxide or zirconium silicate abrasives.

EQUIPMENT

(Slide 4) List of Items

The equipment used in the study included Spectrex air sampling pumps, calibrated with a TSI Model 67 Mass Flow Meter. The filters were 25 mm polycarbonate filters, mounted in three piece cassettes. These filters were selected because of their low background levels of the elements of interest.

(Slide 5) Photo

The respirator used was a 3M Brand 8715 Dust/Mist Respirator, probed with a special nylon probe, designed by Dr. Ben Liu from the University of Minnesota for minimizing particle entry losses.

TEST PROCEDURE

Test Subject Screening

(Slide 6) -Fit Testing -Education Assessment

Prior to the testing, workers doing jobs of interest were selected, instructions on proper fitting of the respirators were provided, and fit testing was conducted. The saccharin fit test was used, following the protocol defined in Appendix D of the OSHA Lead Standard. Six (6) subjects were qualified for inclusion in the study. Five (5) were active participants.

After the fit testing was completed, the workers were informed about the study we intended to conduct to be sure they fully understood its purpose, the procedures, and the actions expected of them.

Sampling Procedure

(Slide 7) Sampling Procedure Details

Our sampling procedures included calibration of the sampling pumps three (3) times per day, before the shift, at lunch, and at the end of the shift. Inside and outside flow rates were set in the same range at between 1.5 and 2 liters per minute.

The respirators were probed with care taken to be sure probe locations were consistent, gaskets were in place on both sides of the facepiece, and fibers from the respirator filter didn't get into the screw threads of the probe. A probe was also added to the outside filter cassette to ensure that probe entry losses, if any, would be equivalent for inside and outside samples.

(Slide 8) Photo

To ensure sample validity and make sure we weren't causing problems for the workers, once the respirators and sampling equipment were in place, the test subjects were observed continuously, one observer for each subject. During setup and removal of the equipment, an attempt was made to minimize potential for contamination of the samples from handling, but we had two concerns here. First, air contaminant concentrations were lower than had been expected. This required use of long sampling times to get meaningful analytical results. Actual sample times ranged from 35 to 235 minutes. The sampling equipment had to be removed for breaks, sometimes three or four times, during the longer samples. This introduced multiple handling of the cassettes, greatly increasing the odds of significant contamination--especially for the inside samples.

Secondly, logistics required removal of the cassettes in the work area. We attempted to ensure minimum dust levels were present in the removal locations. Nevertheless, this presented additional contamination potential. Blank samples were handled in much the same manner as the test samples to help define expected levels of contamination from handling, but it is difficult to fully simulate surface contamination conditions of cassettes being worn.

(Slide 9) sampling locations

In all, a total of twenty-two (22) sample sets were collected for the respirator. nineteen (19) were from the polishing/grinding area, two from the blasting area, and one from the coating area. One of the 19 samples from the polishing/grinding area was subsequently discarded because the worker was called away from his station just after he started working. So, our total working data base was 21 sample sets.

Sample Analysis

(Slide 10) Sample Analysis

The samples were analyzed by Element Analysis Corporation using proton induced x-ray emission analysis or (PIXE), which is an extremely sensitive and precise non-destructive surface analysis technique, capable of quantifying all elements with an atomic number greater than 10. The analytical detection limits for the main elements quantified—aluminum, silicon, and titanium—ranged from approximately 9-35 ng per sample. Analytical precision, expressed as a coefficient of variation, was less than $\pm$ 7% for the geometric mean outside filter weights of the three elements.

Unfortunately, it wasn't possible to take full advantage of the ng sensitivities. The field blanks we collected generally had contaminant levels significantly above the stated analytical detection limits. Thus, the mean field blank values became the true baseline detection limits that could be applied to our test samples.

RESULTS

(Slides 11-17)

Build Slide of Rules

The PIXE results were handled as follows for the eighteen (18) sample sets from the polishing/grinding area.

(11) - First, field blank filter weights for Si, Al, and Ti were tabulated in separate data bases. Each set of numbers was checked for outliers using Boxplot, part of the Minitab program developed at Penn State. Values identified as outliers, at a 99% confidence level, were removed from the data base, and mean field blank values were determined for each element.

(12) - Next, outside filter weights for the same three elements were tabulated. If sample weights were less than 11 times the appropriate field blank value, the sample set was rejected. If sample weights were greater than 11 times the mean blank value, the sample set was accepted. I'll explain the rationale behind this in a minute.

(13) - Next, inside filter weights were tabulated. If inside sample filter weights were less than the mean blank value, the sample set was rejected. (We did not want to include greater than PF's in our statistics.) If inside sample filter weights were greater than the mean field blank value, the corresponding sample set remained in the data base.

(14) - Next, the mean field blank values were subtracted from the outside
(15) and inside filter weights for each element, and the resulting net weights were divided by the appropriate sample volumes to determine outside and inside concentrations. The mean outside concentrations ranged from 100-300 $\mu g/m^3$. The mean inside concentrations were from 0.5-2 $\mu g/m^3$ - extremely low concentrations inside the respirators.

(16) - Workplace protection factors were then calculated by dividing the outside concentrations by the inside concentrations. The resulting values were checked for outliers, at a 99% confidence level, again using Minitab Boxplot.

(17) - Finally, after removing WPF outliers from the working data base, geometric means, geometric standard deviations, and 5th percentiles were determined.

(Slide 18) These were the results we obtained:

Results

Substance	n	Xg	sg	5th
Al	10	145	2.3	32
Ti	14	59	1.7	24
Si	14	172	3.1	24

Out of the original 18 sample sets, 8 were rejected for Al. 7 because of low outside filter loading and 1 because of a non-detectable inside filter loading. 4 sample sets were rejected for Ti, all because their WPF values were identified as outliers at a 99% confidence level. They were either too far above or too far below the geometric mean to be considered valid data points. If these 4 data sets are added back in, the geometric mean PF for Ti shifts from 59 to 45. 4 sample sets were also rejected for Si, 3 because of non-detectable inside filter weights and 1 because of a PF outlier. If this data set is added back in, the geometric mean PF for Si shifts from 172 to 137.

(Slide 19)
Lead WPF's

Some of the polishing/grinding sample sets also showed small amounts of lead. Using the same rules applied to Ti, Si, and Al, most of the data sets were eliminated for Pb, since even the highest outside filter weights were less than 35 times the mean blank value. Nevertheless, despite these light dust loadings, the ability of the respirator to provide a WPF of 10 or more was already evident. When greater than PF values were left in the data base, the eleven sample sets that had the capability to show whether or not PF's of 10 were obtained showed a mean WPF of > 24. This is a conservative number since corrections for blanks were not included, and they would tend to increase the PF values.

(Slide 20) Misc. WPF's

We only got three sample sets in the spray coating and blasting departments so we didn't attempt to do any statistical analysis of these. But for your information, this is what we found there. We didn't get a particle size measurement of the spray mist but did expect that it would be relatively larger.

~~(Slide 21)~~ Blank

Those are the numbers that we feel best represent the performance of the respirator in this study. Why did we use these rules?

It is important to remember that there are many sources of errors for studies such as this, and it is probable that the numbers you obtain will be affected by one or more of these errors to some extent. So, you need to establish guidelines, for sample collection, analysis, and data handling that will provide you with the most accurate information.

(Slide ~~22~~ 21) Potential Errors

There are several types of errors. Some are relatively easy to address; some are not. For example, these types of problems can generally be minimized through good sampling techniques, careful worker observation, good recordkeeping, and other good basic IH procedures in general.

(Slide 22) Potential Errors

Other sources of error can be minimized through good experimental design. For example: (1) Potential for probe leakage can be checked with leak detector tests; (2) Probe designs can be experimentally verified, and outside and inside samples can be equipped with the same probes; (3) Probe placement questions may not be answerable yet, but variability can be reduced by consistent probe location; (4) Analytical methods which are sensitive and specific to the ambient air contaminants can be used. Gravimetric techniques in particular are not specific, and not very sensitive or precise, and should be discouraged. If they are used, a designed experiment to allow correction for particulate matter expelled from the nose and mouth of your test subjects, and to allow determination of how much desiccation is needed to totally remove moisture from the filters, would be required to give the results validity. (5) Another thing you can do is apply proper fit testing methods. A recently published study reported that a standard Dynatech QNFT, which is designed for HEPA respirators, was used to check fit of D/M respirators. That won't tell you anything useful. Be sure to select and use meaningful fit tests. (6) Also use good training techniques and be sure the workers understand proper respirator use; (7) and pay close attention to sample handling procedures, collection of appropriate field blanks, and respirator cleanliness. Sample contamination is an extremely critical concern. It isn't very hard to inadvertently get ng quantities of materials on a sample being handled, and that can dramatically affect results. There are other factors you could add to this list, including the number of test subjects, which is a possible weakness of this study.

(Slide 24) Potential Errors

These types of concerns need to be carefully addressed, but just as important is the procedure used to evaluate the analytical numbers you receive. It's critical that a thorough method for evaluating the validity of the numbers in your final data base be developed.

I referred earlier to the rule we used for outside sample filter loading. In this study, we rejected sample sets with outside filter weights < 11 times the mean blank value. After we corrected for blanks, this meant we were working only with sample sets with outside filter weights > 10 times the mean field blank value. This is a very conservative treatment. If you want to prove or disprove that a respirator provides a PF of 10, you need at least that much differential between your inside and outside samples. Actually, 50X, 100X, or possibly an even higher multiple of the blank value would be more appropriate.

(Slide 25) Confidence Factors

Because the confidence you have in analytical results is directly related to filter loading; NOT concentration—but the amount of material on the filter. The closer to the blank value you get, the less confidence you have in the numbers. Conversely, as your filter loading increases from blank levels, your confidence in those numbers also increases, at least to a certain point.

Another thing to remember is that because of the many potential sources of errors, confidence in individual PF values is going to be significantly less than confidence in mean PF values.

(Slide 26) Filter Weight vs. WPF Chart

Interestingly, when we looked at the relationship between outside filter weight and protection factor, using mean values, we found an important relationship. The higher the filter weight, the higher the measured protection factor.

Using our titanium results as an example, the geometric mean PF for all 18 sample sets was 45. If you look only at those sample sets where outside sample filter weights were greater than 100 times the mean blank value, the geometric mean PF increases to 58. For those sample sets with outside filter weights greater than 250X the blank, the geometric mean PF increases to 72. At 500X the blank, it is 69, and at 1000X the blank, it is 78.

(Slide 27) Fil Wt. Vs. PF Graph

A plot of these PF versus filter weight values looks like this. When you think about it, in the green zone, you have a high degree of confidence in your analytical results. In the red zone, you have much lower confidence, and the yellow zone is a transition area. PF's are higher where weights are higher and where analytical confidence is higher.

(Slide 28) Log-Log Plot

On a graph of log of filter weight versus log of protection factor, the relationship looks like this. It has a slope of 0.45 and an R-square value of 76%.

(Slides 28, 29, 30) Log-Log Plots

And this relationship isn't a fluke. It shows up throughout our data. This is a log plot of mean outside filter weight vs. mean PF for our silicon data. This is a log plot of mean filter weight versus mean PF for our Aluminum data. Both show a statistically significant correlation, with slopes of 0.72 and 0.53 and R-square values of 90% and 82%, respectively.

(Slide 31) Log Plot

And the relationship doesn't apply just to or air purifying respirators. This is a log plot of mean filter weight versus mean protection factor for an air supplied respirator studied in a sand blasting operation. The slope is 0.59 and the R-square value 89%.

(Slide 32) Log Plot

Furthermore, it doesn't apply just to our work or to a specific analytical method or laboratory. This is a log plot of mean outside filter weight versus mean protection factor for a study that was recently published in the Applied Industrial Hygiene Journal--a study which, in my opinion, contains several errors in design; and as a result, is very misleading. This plot shows a slope of 1.15 and an R-square value of 89%. A slope of this magnitude indicates that outside filter weights are increasing rapidly without a corresponding increase in inside filter weight. So the conditions under which the respirator's capability could be accurately assessed do not appear to have been reached.

(Slide 33) Blank

This outside filter weight-protection factor relationship is real. The question is what does it mean and how should it be handled?

There would appear to be two possible explanations for it. One is that respirators work better at higher concentrations. This assumes that the higher dust loadings on outside filters were due to higher concentrations—which wasn't the case in our study. The other possible explanation is that WPF measurements are more accurate when your outside filters have higher dust loadings. This appears more likely. In any case, it points out that if you want to accurately assess the protection capability of a respirator, you will probably need to do the testing under worst case type conditions for its assigned protection factor, or you will need to define a proper weight versus PF curve for predicting true performance characteristics.

SUMMARY

(Slide 32) Conclusions

In summary, this study lends additional support to the validity of using NIOSH approved dust/mist respirators for metal dusts and mists, including lead dusts and mists, for concentrations up to 10X the PEL. When properly selected, fit tested, and worn, good worker protection capability was again demonstrated.

This study also raises some important questions on how WPF data are interpreted. We identified a statistically significant relationship between outside sample filter loading and WPF's. This relationship needs to be more fully characterized and evaluated before the validity of WPF studies can be determined and meaningful PF assignments made for individual respirators.

(Slide 1 - Title Slide)

ABSTRACT

This study provides quantitative information on the effectiveness of full facepiece respirators against lead aerosols. Workplace protection factors for full facepiece respirators equipped with high efficiency filters were measured during several operations at a secondary lead smelter. Respirator leakage measurements were determined on respirators properly selected, fitted, worn and maintained. Thirteen workers were trained in donning the respirator and passed a quantitative fit test before participating in the study. The workers were observed at all times to help ensure sample validity. The results of the study indicate that the lead concentrations measured inside the respirator were significantly less than the OSHA lead exposure limit of 0.05 mg/m^3. The mean workplace protection factor was 3929. When properly fit tested and worn, the respirators reliably provided workplace protection factors in excess of 50.

WORKPLACE PROTECTION FACTOR STUDY ON A FULL FACEPIECE RESPIRATOR

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Prepared for presentation on May 25, 1989 at the
American Industrial Hygiene Conference, St. Louis, MO.

INTRODUCTION

The use of protection factors in the selection of respiratory protection is fairly well accepted and understood. However, the basis of these assigned numbers is not as well understood. The assigned protection factors that are used for respirator selection were originally based on laboratory evaluation of respirator performance, specifically quantitative fit testing and in some situations, professional judgment.

Since Myers et. al. evaluated some powered air purifying respirators in a secondary lead smelter, there has been increased emphasis on testing the performance of respirators in the workplace. In addition, studies have shown that there appears to be no correlation between quantitative fit factors and workplace protection factors. As was pointed out in the previous paper, workplace testing has been proposed for respirator certification. This increased emphasis is due, we feel, because workplace protection factor studies have the potential to be excellent sources of information for developing or verifying the validity of assigned protection factors for various respirators. At least there is the capability to reduce the number of assumptions to be made in workplace testing as compared to laboratory testing, since it is so much closer to the real world.

The one way the various methods of testing respirators are similar is that the concentration of the challenge substance, whether it is laboratory produced or workplace produced, is measured outside the respirator and inside the respirator. It is the conditions of the test, however, that determine what type of measurement is made. Earlier we heard some of the different terms that can be used to describe different types of measurements. Since all of the terms are types of protection factors and the differences between terms can be very subtle, it is important that as industrial hygienists, we know what type of measurement was made in this and other studies in order to look at them critically. We must pay close attention to how the measurements were made so that we know exactly what this study or any other study actually measured, despite what it is called. Studies have claimed to be workplace protection factor studies that really were "effective" or "program" protection factor studies.

Since the objective of this study, like the previous study, was to determine workplace protection factors, we want to restate the definition of this term.

(Slide 2 WPF Definition)

According to the AIHA Respiratory Protection Committee, a workplace protection factor (WPF) is a "measure of the protection provided in the workplace, under the conditions of that workplace by a properly selected, fit tested and functioning respirator when it is correctly worn and used."

(Slide 3 WPF Definition Continued)

It is further defined as the workplace contaminant concentration which the worker would inhale if not wearing the respirator (C_O) (a breathing zone sample) divided by the workplace contaminant concentration inside the respirator facepiece (C_I). Both outside (C_O) and inside (C_I) concentrations are determined from samples taken simultaneously, only while the respirator is properly worn and used during normal work activities.

(Slide 4 Recap of Important Items of Definition)

While this definition sets the scope of the testing to be done, the exact protocol is not specified. Many interesting points about testing protocol were raised during the previous paper. We must evaluate each study according to this definition. We must look at when sampling was conducted, where it was conducted, training of workers, type of fit testing conducted, fit test protocol followed, respirator condition and respirator selected for the contaminant. All of these points are from the quoted definition.

The purpose of this study was to measure workplace protection factors for a full facepiece air purifying respirator equipped with high efficiency filters. To the best of our knowledge this is the first study to report workplace protection factors for a full facepiece respirator.

MATERIALS AND METHODS

(Slide 5 Respirator Tested)

The respirator tested was the 3M 7800 Full Facepiece Respirator with 7255 high efficiency filters and 7288 filter retainers. The respirator is NIOSH/MSHA approved, number TC-21C-362.

(Slide 6 Composite of Work Area)

The test site was a secondary lead smelter. Air sampling for lead was conducted on 5 days in four areas of the plant. These were blast furnace, reverberatory furnace, casting, and warehouse areas.

(Slide 7 Test Equipment)

The equipment used in the study included MSA Heavy Duty Flow Lite sampling pumps (P/N 482700) calibrated with a TSI Model 67 Mass Flow Meter. The filters were 0.8 micron pore size polycarbonate filters mounted in 25mm three piece cassettes. These filters were selected because of their low background levels of the element of interest.

(Slide 8 & 9 Respirator Probe - Probe Placement)

The respirators were equipped with ABS resin probes built to the specifications of the probe designed at the University of Minnesota by Dr. Ben Liu et. al. for minimizing particle entry losses. The probe was inserted in place of the speaking diaphragm assuring a gas tight seal. This was determined to be the best place for probing this full facepiece respirator since it is equipped with a nosecup. This method also provided a consistent probe location that was as close to the breathing orifices as possible. A sleeve was added to allow attachment of the filter cassette. The inside sample filter and cassette were then attached to the probe. A similar probe was placed on the outside filter cassette to ensure that probe entry losses, if any, would be similar for inside and outside samples.

(Slide 10 Sampling Procedure)

Pump calibration was conducted in line before and after each sample. Sampling outside the respirator was conducted at 0.5 to 2 Lpm. The lower flow rates were used to avoid overloading the filter which is a concern for the chosen analytical method. The inside filter sampling flow rate was 2 Lpm. Sampling periods ranged from 30 minutes to 3 hours. Samples were handled as carefully as possible to minimize contamination. To ensure sample validity and make sure the equipment was not causing problems for the workers once the respirators and sampling equipment were in place, the test subjects were observed continuously, one observer for each subject being sampled.

(Slide 11 Test Subject Training)

Prior to testing, workers who normally wore full facepiece respirators were selected for participation in the study. The workers were informed about the purpose of the study, the procedures we would follow and the actions expected of them. They were then provided instructions on the proper donning and fitting of the respirators and fit testing was conducted.

(Slide 12 Fit Testing)

Quantitative fit testing was done using the TSI Portacount using high efficiency filters on the respirator following the exercise sequence specified in Appendix D of the OSHA Lead Standard for qualitative fit testing. They were fit tested with other required personal protective equipment in place. Care was taken to assure that head coverings did not project into the seal. The pass/fail criterion was a fit factor of 500; 10 times the protection factor of 50 assigned to this type of respirator in the lead standard. Thirteen workers were qualified for inclusion in the study.

(Slide 13 Face Measures)

Face length and width measurements were then taken.

Respirators were donned and doffed and the sample train hook up and removal was done in a clean area to reduce sample contamination. During equipment hookup and removal of the equipment, we attempted to minimize the potential for contamination of the samples from handling. Before the pumps were turned on, the integrity of the respirators and fit were checked and the integrity of sampling trains were verified. Sampling pumps were shut off before the respirator and sampling equipment was removed.

(Slide 14 Sample Invalidation Reasons)

If an inside sample came loose from the probe, a respirator was removed prior to termination of sampling, a sample pump failed or a similar problem was experienced, the sample was invalidated and another pair of samples was set up. To evaluate contamination due to sample handling, several field blanks were collected. They were uncapped, capped and handled in the same manner as the samples with the exception that no air was drawn through them.

Going into the study it was also pre-established that if outside filter weights were less than 51 times the field blank value the sample set would be rejected. This means that after we correct for blanks we were only working with sample sets with outside filter weight greater than 50 times the mean field blank value. You need at least this much differential between inside and outside samples if you want to prove or disprove that a respirator provides a PF of 50. This is conversative. Probably some higher multiple is more appropriate. In addition, it was also predetermined that if inside sample filter weights were less than the mean blank value, the sample set would be rejected. This was to eliminate negative numbers. We did not want to include "greater than" WPFs in our statistics.

(Slide 15 Sample Analysis)

The samples were analyzed for lead via proton induced x-ray emission. This method was chosen because of its good sensitivity. For PIXEA this is typically 10 ng per sample.

(Slide 16 Calculations Procedure)

Detectable amounts of lead were found on the field blanks. Next, the mean value of the field blanks was used to correct inside and outside sample weights. The resulting net weights were used to determine outside and inside lead concentrations. Workplace protection factors were then calculated by dividing the outside concentrations by the corresponding inside concentrations. The resulting values were then checked for outliers at a 99% confidence level. No outliers were found.

Finally the geometric mean WPF, geometric standard deviation and 5th percentile WPF were determined.

(Slide 17 Particle Size Analysis)

Area samples were also taken for particle size evaluation. The area samples were obtained using Marple Personal Cascade Impactors (Model 290) in the reverberatory furnace, casting, and warehouse areas. Sampling was conducted for 2-6 hrs. at a flow rate of 2 Lpm. This gave impactor stage effective cut off diameters of 10, 6, 3.5, 2, 0.9, 0.5 and 0.25 micrometers. The samples were taken as close to the workers as feasible approximating the breathing zone height of a worker. The mylar filters on each impactor stage were coated with a thin film of Vaseline by immersion of the filter in a 2% Vaseline/toluene solution. The samples were analyzed by graphite furnace atomic absorption.

RESULTS

(Slide 18 LANL Face Panel)

All of the workers except 1 were in Grids 1-4 of the Los Alamos Test Panel. The one worker was off the grid. His face was wider than those accomodated by the Los Alamos Test Panel.

None of the workplace protection factor sample sets were rejected because the outside filter weights were less than 5lx the field blank value. Several sets were rejected for other reasons mentioned above. A total of 20 sample sets were left for calculation of workplace protection factors. These 20 sample sets were from 9 different workers.

(Slide 19 Results)

The outside concentrations ranged from 150 - 3380 ug/m^3. The inside concentrations ranged from 0.03 ug/m^3 - 3.0 ug/m^3. No worker was overexposed to lead. After the workplace protection factors were calculated we found:

(Slide 20 WPF)

WPF Statistics of All Samples

N	$\bar{X}g$ WPF	Sg	5th% WPF
20	3929	9.6	95

The definition of assigned protection factor is a measure of the minimum anticipated workplace level of protection provided to a large percentage of users. No numerical value is stated. The fifth percentile was selected for showing as other investigators have used this value for the assigned protection factor. Under the conditions of this study, we would expect 95% of the workplace protection factors to be above 95.

(Slide 21 Filter Wt. vs WPF)

When we looked at subsets of the data using multiples of the field blanks mean value, we found the following:

Outside Filter Weight
versus
Workplace Protection Factor
for Full Facepiece Respirator

Multiple of Field Blank	N	$\bar{X}g$ WPF
1,000X	20	3929
1,500X	18	4929
2,500X	16	7037
5,000X	13	7779
10,000X	11	7283
15,000X	9	10235
25,000X	6	8194

(Slide 22 Filter Wt. vs 5th%)

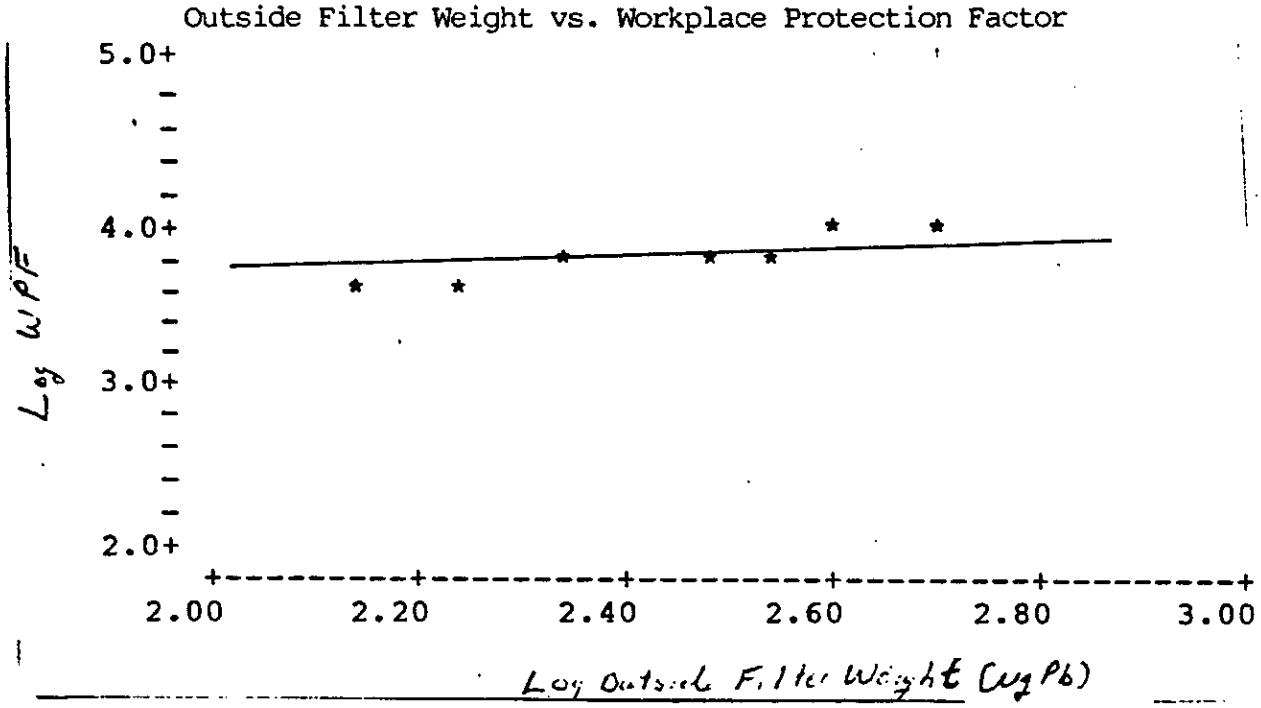
The geometric standard deviations and fifth percentiles are shown in this slide. The fifth percentile WPF appear to show a similar relationship of filter weight to workplace protection factor.

Fifth Percentile WPFs and
Standard Deviations
for Full Facepiece Respirator

Multiple of Field Blank	Sg	5th Percentile WPF
1,000X	9.6	95
1,500X	8.4	148
2,500X	7.3	265
5,000X	7.6	277
10,000X	9.3	186
15,000X	8.8	284
25,000X	7.5	299

(Slide 23 Log Filter Wt. vs Log WPF)

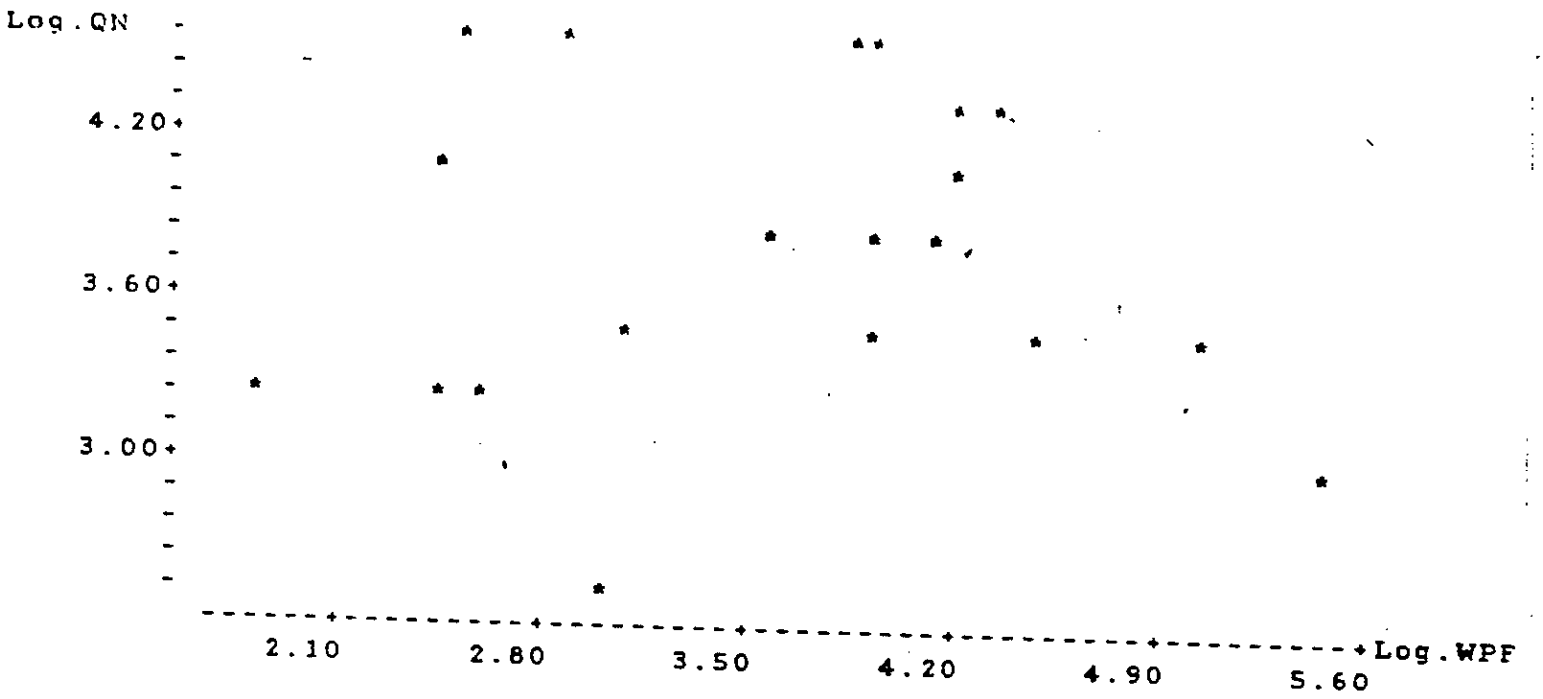
When we look at the graph of the log of the mean filter weight and log of mean WPF as suggested in the earlier presentation, we find a strong correlation between filter weight and workplace protection factor. The correlation coefficient is 0.901. The graph has a slight positive slope. We appear to be close to the plateau region.



(Slide 24)

The quantitative fit factors that were obtained did not predict which workers would have the highest or lowest WPF. Although the data were limited, it appears there was no correlation between WPF and quantitative fit factor. This finding is consistent with that of other investigators.

Workplace Protection Factor vs. Quantitative Fit Factor



(Slide 25 Particle Size Results)

The particle size analysis indicated that there were particles in the size range limits of <0.25 um to >10 um. The impactor samples showed that around 65% of the lead aerosol was greater than 10 um and up to 15% of the aerosol was less than 0.9 um. These data are similar to that reported by Myers et. al. from sampling of a lead smelter. In operations of this type, one would expect to find both lead dust and fume present.

(Slide 26 Conclusions)

CONCLUSIONS

In summary, the results of this study indicate that this full facepiece respirator with high efficiency respirators reliably provides workplace protection factors in excess of 50 against lead dust and fume aerosol. In this study the 5th percentile WPF is near 100, which appears to support the ANSI assigned protection factor of 100.

The lead concentrations measured inside the respirator were considerably less than the OSHA permissible exposure limit for lead of 0.05 mg/m^3.

The aerosol was characterized as typically what one would expect at a secondary lead smelter and

Quantitative fit factors did not appear to correlate with workplace protection factors.

Workplace Protection Factor Study On A Full Facepiece Respirator

C.E. Colton, A.R. Johnston, H.E. Mullins and C.R. Rhoe

COLTON1

Workplace Protection Factor

A measure of the protection provided in the workplace, under the conditions of that workplace, by a properly selected, fit tested, and functioning respirator when correctly worn and used.

Workplace Protection Factor

$$WPF = \frac{\text{Outside Concentration } (C_o)}{\text{Inside Concentration } (C_i)}$$

Both concentrations are determined simultaneously while respirator is worn.

Workplace Protection Factor

- C_o & C_i must be measured during respirator wear
- Workers must be trained
- Proper and complete fit testing must be done
- Good respirator condition
- Proper respirator selection

Test Equipment

- MSA Heavy Duty Flowlite Pumps
- TSI Model 67 Mass Flow Meter
- Nucleopore® 25mm Polycarbonate Filters (0.8 μm)
- 3-Piece Cassettes
- Dr. Liu Probe Design

COLTON7

Sampling Procedure

- Calibration in-line
- Calibration before and after each sample
- Flow Rates: Inside - 2 Lpm
  Outside - 0.5-2 Lpm
- Sampling Time: 0.5 - 3 hours
- Consistent probe location
- Handling to avoid contamination
- Continuous observation

COLTON10

Test Subject Screening

- Normally wore full facepiece respirator
- Informed about purpose of test
- Education/training on respirator
- Quantitative fit test

Reasons For Sample Set Invalidation

- Inside sample cassette came off probe
- Probe broke
- Respirator removed before sampling ended
- Sample pump failure
- Outside filter weight < 51x blank
- Inside filter weight < blank

Sample Analysis

- Proton Induced X-ray Emission (PIXE)
- Sensitivity $\sim$10 ng

Calculation Procedures

- Subtract blank value from sample weights
- Calculate outside and inside concentrations
- Calculate workplace protection factors
- Do statistical analysis

Particle Size Analysis

Marple Personal Cascade Impactors

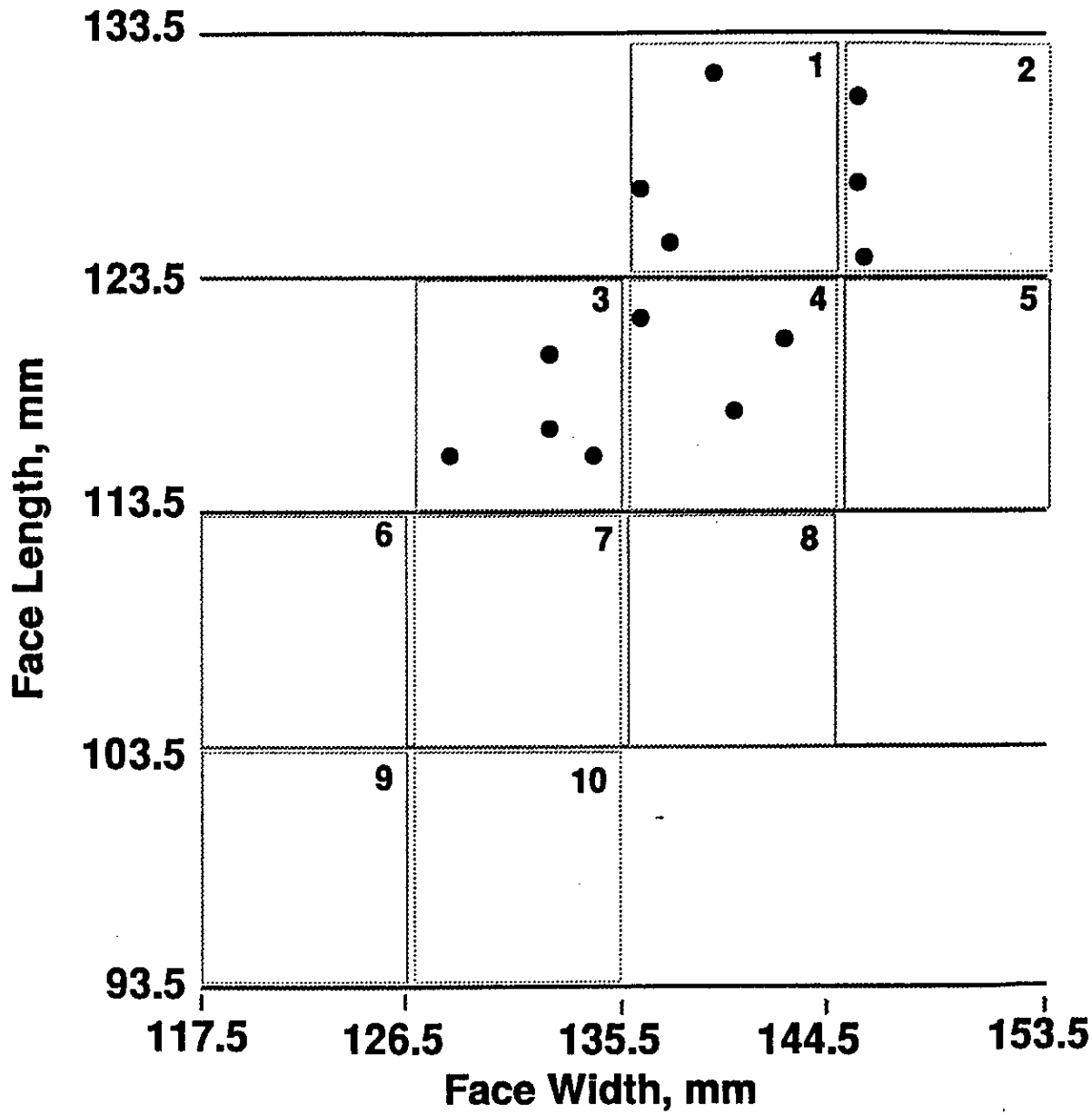
Flow Rate: 2 Lpm

Cut Points: 10, 6, 3.5, 2, 0.9, 0.5 and 0.25 μm

Analysis: Graphite Furnace Atomic Absorption

COLTON17

Face Measurements of Test Subjects in Full Facepiece Respirator Study



COLTO18A

Full Facepiece WPF Study Lead Aerosol Concentrations

Outside Samples: 150 - 3380 $\mu g/m^3$

Inside Samples: 0.03 - 3.0 $\mu g/m^3$

COLTON19

WPF Statistics For All Samples For Full Facepiece Respirator

$n = 20$

$\overline{X}g = 3929$

$\sigma g = 9.6$

$5^{th} = 95$

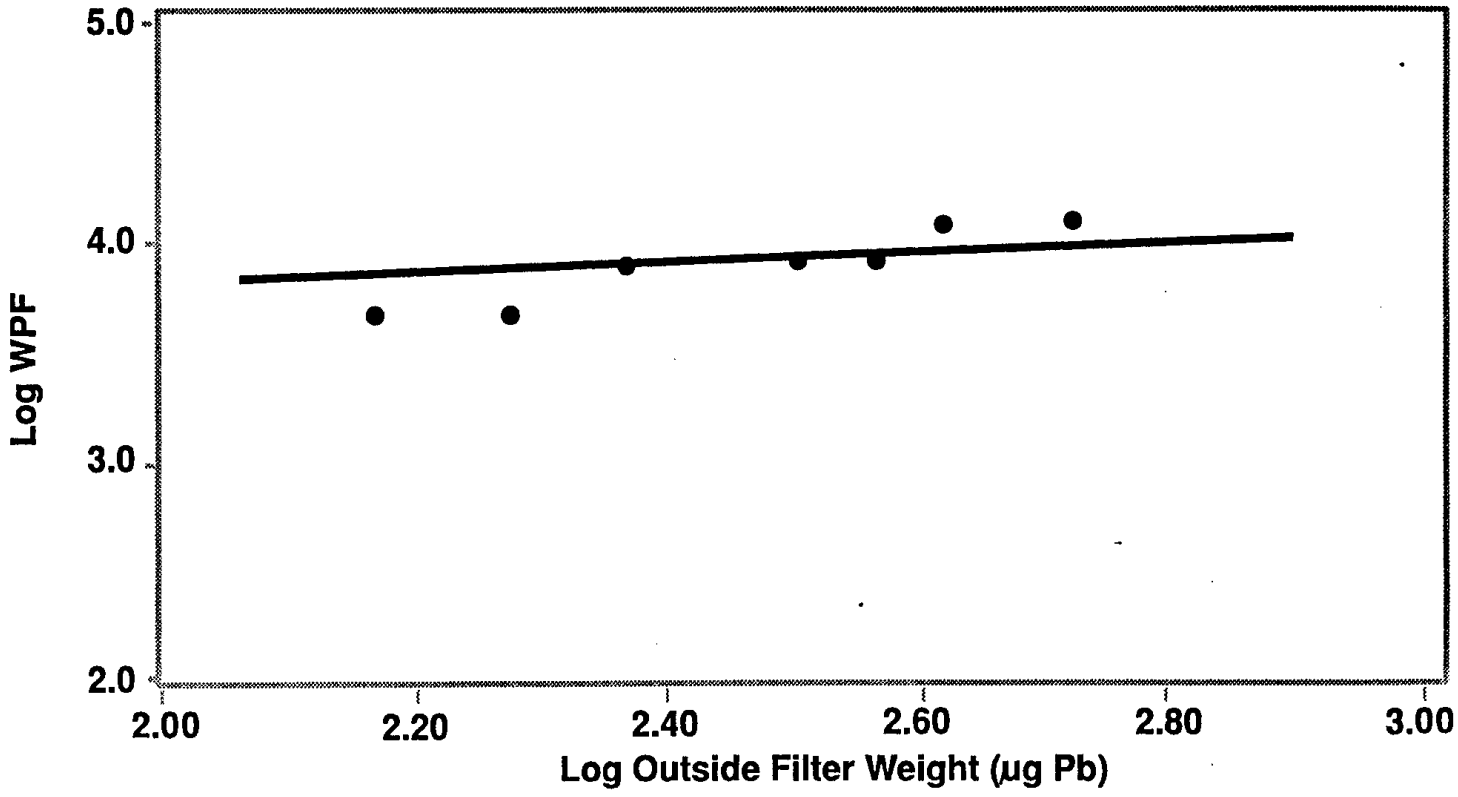
COLTON18

Outside Filter Weight vs. Workplace Protection Factor For Full Facepiece Respirator

Multiple of Blank	N	$\overline{Xg}$ WPF
> 1000x	20	3929
> 1500x	18	4929
> 2500x	16	7037
> 5000x	13	7779
> 10,000x	11	7283
> 15,000x	9	10,235
> 25,000x	6	8194

COLTON21

Outside Filter Weight vs. Workplace Protection Factor



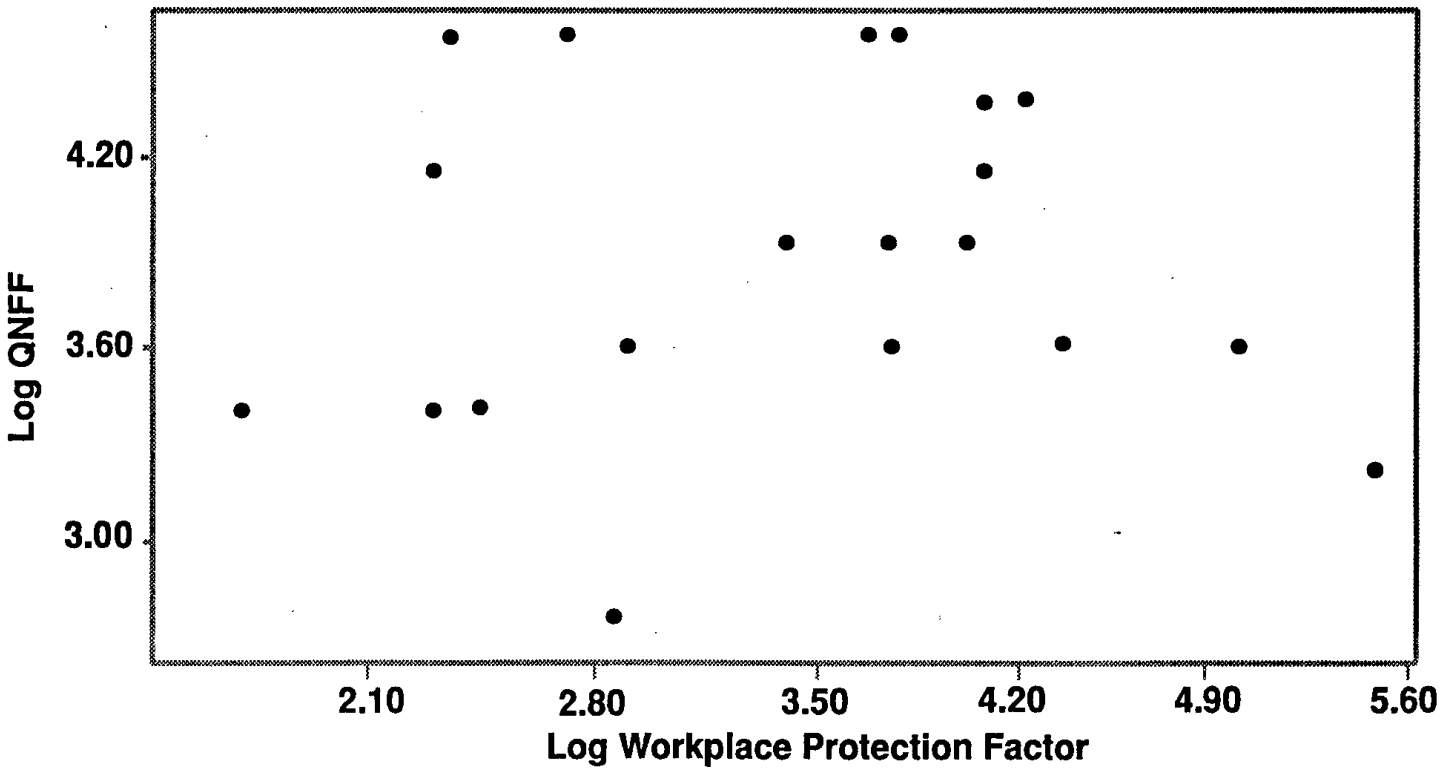
COLTONB

Outside Filter Weight vs. 5th Percentile WPF

Multiple of Blank	σg	5th Percentile WPF
> 1000x	9.6	95
> 1500x	8.4	148
> 2500x	7.3	265
> 5000x	7.6	277
> 10,000x	9.3	186
> 15,000x	8.8	284
> 25,000x	7.5	299

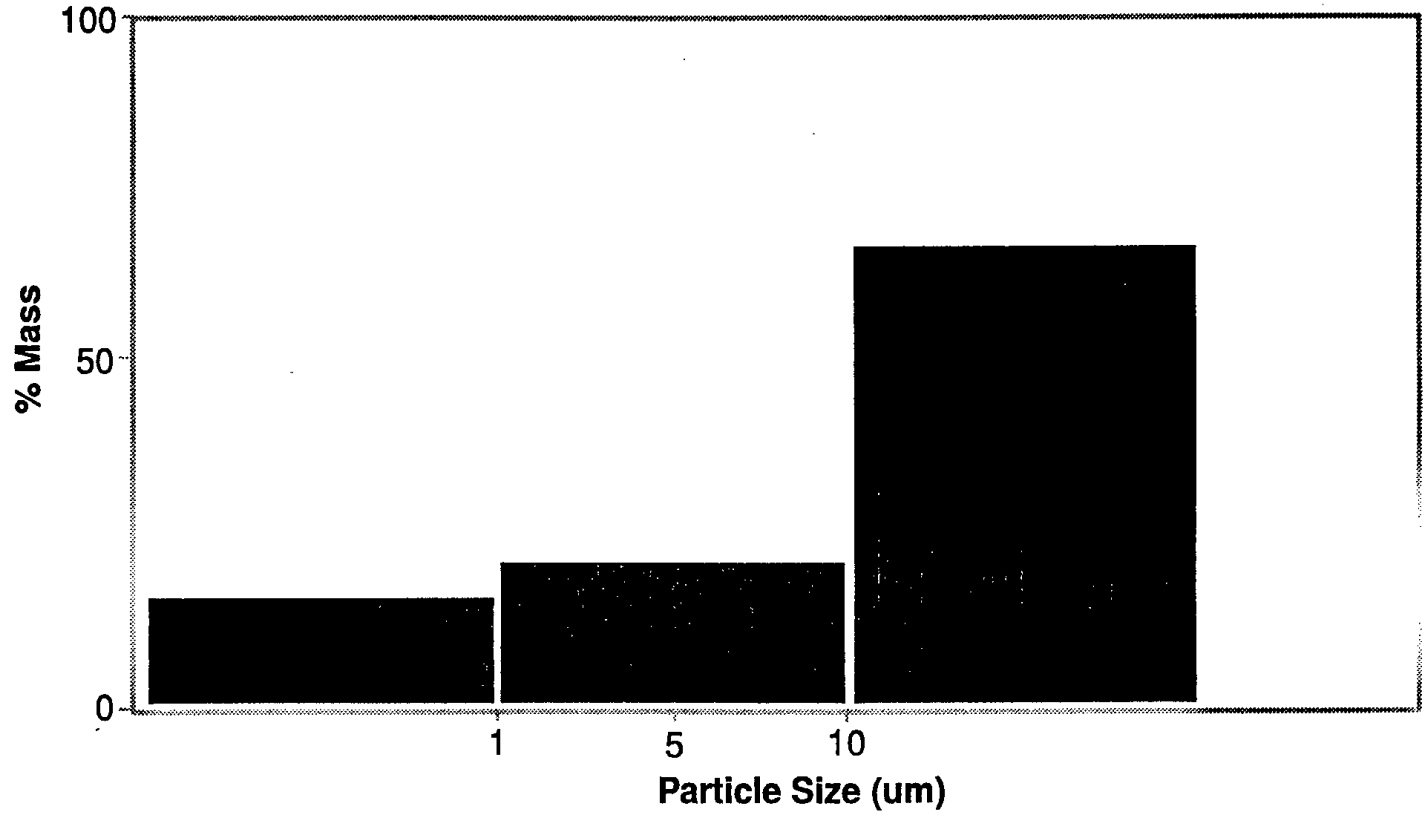
COLTO22A

Workplace Protection Factor vs. Quantitative Fit Factor



COLTONC

Particle Size Distribution of Lead Aerosol in Secondary Lead Smelter



COLTON25

Conclusions

- Assigned protection factor of full facepiece respirator ~100 against lead dust and fumes.
- All lead concentrations measured inside the respirator were less than the OSHA PEL.
- Quantitative fit factors did not predict workplace protection factors.