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RESULTS OF WORKPLACE PROTECTION FACTOR STUDIES

1. Asbestos Environment
2. Loose Fitting Facepiece PAPR
3. Abrasive Blasting Airline Respirator
4. General Purpose Airline Respirator
5. Disposable Dust/Mist Respirator
6. Full Facepiece with HEPA Filters
7. PAPR with Full Facepiece and HEPA Filters
8. Disposable Dust/Mist Respirator in an Aluminum Smelter
9. Disposable High Efficiency Filter Respirator

Presented by C. E. Colton on behalf of the Industrial Safety Equipment Association(ISEA) for NIOSH Technical Conference on Assessment of Performance Levels for Industrial Respirators on January 10, 1991.

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ABSTRACT

A study was conducted at a foundry to evaluate the workplace performance of a supplied air respirator. Workplace protection factors were determined for six workers performing grinding operations. The workers were observed at all times to help ensure sample validity. Samples were analyzed for metal dusts using proton induced x-ray emission analysis. Results showed an important relationship between outside filter weight (loading) and workplace protection factors. This relationship demonstrates that the true performance capability of respirators may not be accurately reflected by data generated from sample sets with low outside filter weights. This relationship needs to be considered when designing workplace protection factor studies and analyzing and interpreting results.

WORKPLACE PROTECTION FACTOR STUDY ON A SUPPLIED AIR RESPIRATOR

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(SLIDE 1 -- TITLE SLIDE)

INTRODUCTION

Protection factors assigned to various types of respirators have historically been based primarily on laboratory evaluations of respirator performance.

(SLIDE 2 -- COMPOSITE PHOTO OF RESPIRATOR BEING TESTED IN WORKPLACE)

As respirator standards are updated, there is an increasing desire to see workplace evaluations of respirators play a more important role setting these numbers. The ANSI Z88.2 subcommittee carefully considered workplace test results when updating assigned protection factor recommendations for their revised standard on respiratory protection, which was sent out for comments earlier this year. NIOSH has also been reviewing workplace testing. In fact, the proposed rule on respirator certification they issued in 1987 included provisions for workplace or simulated workplace testing.

The NIOSH proposal generated a lot of controversy--not necessarily because of the concept of workplace testing, but because key issues such as how such testing should be conducted and evaluated were not addressed. The concept of testing respirators in the workplace is rather simple. The implementation of such testing is not. Although well over a dozen workplace studies have been conducted, and considerable laboratory experimentation has been done in support of these studies, a consensus has still not been reached on the best protocol to follow, the best sampling and analytical methods to use, and the most accurate way to analyze the resulting data.

(SLIDE 3 -- PROTECTION FACTOR TERMS DEFINED BY AIHA RESP. COMM.) One problem has been resolved. Researchers have standardized on terminology to follow when designing study objectives and reporting results. The AIHA Respirator Committee and NIOSH have assembled very similar protection factor definitions to help clarify the type of measurements actually being made.

I am not going to go through all of the definitions, but just to make sure you are all aware of the different terms in use, there are assigned protection factors, effective protection factors, program protection factors, workplace protection factors, and simulated workplace protection factors. Since the purpose of the study I am reporting on today was to generate workplace protection factors, I do want to define that term.

(SLIDE 4 -- AIHA WPF DEFINITION). In the AIHA Respirator Committee's words, a workplace protection factor 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 5 -- AIHA DEFINTION CONTINUED, FORMULA FOR CALCULATION). It is defined as the workplace contaminant concentration which the user would inhale if not wearing the respirator (Co) divided by the workplace contaminant concentration inside the respirator facepiece

(Ci). Both Co and Ci are determined from samples taken simultaneously, only while the respirator is properly worn and used during during normal work activities."

This definition clearly sets the scope of workplace protection factor studies, and our objective was to generate results that would meet this definition. However, basic definitions of protection factors do not include guidance on how to ensure sampling protocols are valid or that results obtained are representative of a respirator's performance capability. That is the subject I would like to address today. As you review the available data, I think you will agree that we still have some things to learn about how to best set up workplace protection factor studies and interpret results.

BACKGROUND INFORMATION

(SLIDE 6 -- PHOTO FROM WPF STUDY ON WCII ABRASIVE BLASTING HELMET). At the conference in 1987, we presented a poster session paper on a workplace protection factor study conducted on a continuous flow abrasive blasting supplied air respirator. To the best of my knowledge, this is the only other supplied air respirator study in which the objective was to determine workplace protection factors. Other studies on this type of equipment have been done, but they have either been in the laboratory, or have measured effective protection factors (i.e., they involved sampling during periods of respirator use, as well as during periods of non-wear time).

(SLIDE 7 -- PHOTO FROM 8715 WPF STUDY). We presented a second paper in 1987 on results of a workplace study on an air purifying respirator. In this study, as well as the supplied air respirator study, a relationship was observed between the amount of contaminant loading on ambient samples from worker lapels and workplace protection factors that resulted. In general, the higher the outside filter loading, the higher the protection factor. I want want to briefly review this data, because it is important to the interpretation of the data from our current study.

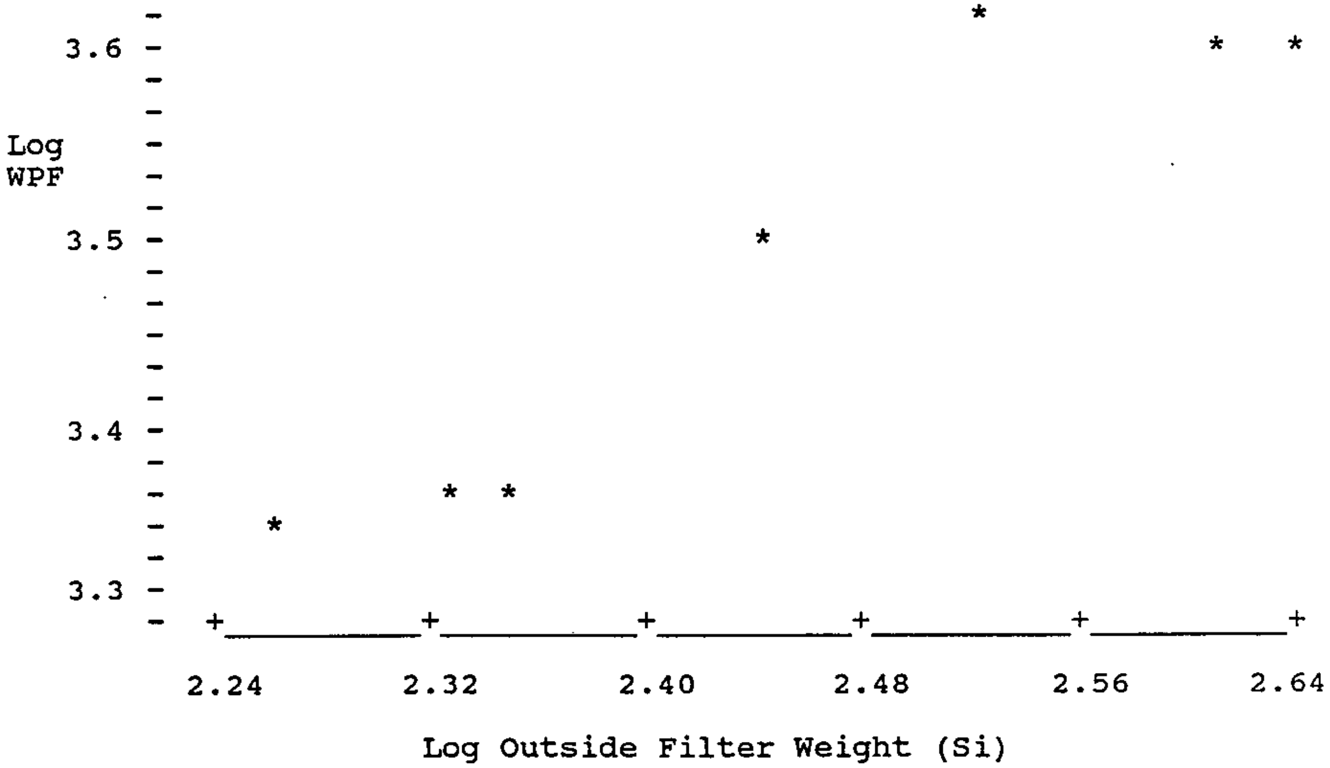
(SLIDE 8 -- DATA FROM WCII STUDY AS SUMMARIZED BELOW). In the supplied air respirator study, we had a working data base of 37 sample sets. When we looked at sub-sets of the data having increasing amounts of outside sample loading, we found a correlation between filter loading and protection factor. The sub-sets were defined by using multiples of the mean background contamination level found on field blanks collected. The multiples used, along with the number of samples in each sub-set and the geometric mean workplace protection factors observed can be summarized as follows:

OUTSIDE FILTER WEIGHT VERSUS WORKPLACE PROTECTION FACTOR SUPPLIED AIR ABRASIVE BLASTING RESPIRATOR

Multiple of Field Blank	N	Xg WPF
> 10X	37	2143
>200X	32	2340
>400X	28	3135
>600X	22	4150
>800X	19	4243
>1000X	17	4076
>1200X	15	4023

(SLIDE 9 -- LOG-LOG PLOT OF WPF VS FILTER WEIGHT FOR WCII A/B STUDY).

LOG WORKPLACE PROTECTION FACTOR VS LOG OUTSIDE FILTER WEIGHT SUPPLIED AIR ABRASIVE BLASTING RESPIRATOR



A log-log plot of mean filter weight versus mean workplace protection factor for these sub-sets looks like this. The plot has an r-squared value of 90.2%, indicating a significant correlation. If you look at the curve, it appears to start leveling off somewhere between the 600X and 1000X the blank area. And in fact if you look at the 10X-600X data and the 600X-1200X data separately, you find R-squared values of 96% and 35%, respectively. This indicates that there is a very strong correlation on the lower end of the curve and no significant correlation on the upper end of the curve. This is a very important finding. It appears to indicate that even if you set up a sample collection protocol that will allow calculation of workplace protection factors in accorcance with the accepted definition, those calculations may not accurately reflect the respirator's performance capability. If the samples you collect happen to fall in the area of the curve where protection factors remain highly correlated with outside filter weight (i.e., low contaminant loadings), you are likely to be assessing sampling and analytical limitations, rather than respirator performance.

(SLIDE 10 -- DATA FROM WC II STUDY -- AS SUMMARIZED BELOW). The geometric standard deviations and fifth percentiles calculated for the data sub-sets provide further support for this conclusion. They were as follows:

FIFTH PERCENTILE WPF'S AND STANDARD DEVIATIONS FOR WCII ABRASIVE BLASTING RESPIRATOR STUDY

Multiple of Blank	N	Sg	5th Percentile
> 10X	37	3.6	259
>200X	32	3.5	324
>400X	28	2.5	673
>600X	22	2.2	1167
>1000X	17	2.3	1038
>1200X	15	2.2	1096

As you can see, despite a gradual decrease in sample size for the sub-sets, the geometric standard deviation also decreased. This is believed to reflect a reduced contribution to variability from non-respirator factors, such as sampling and analytical methods.

(SLIDE 11 -- SLIDE SUMMARIZING >1000X DATA FROM WCII STUDY).

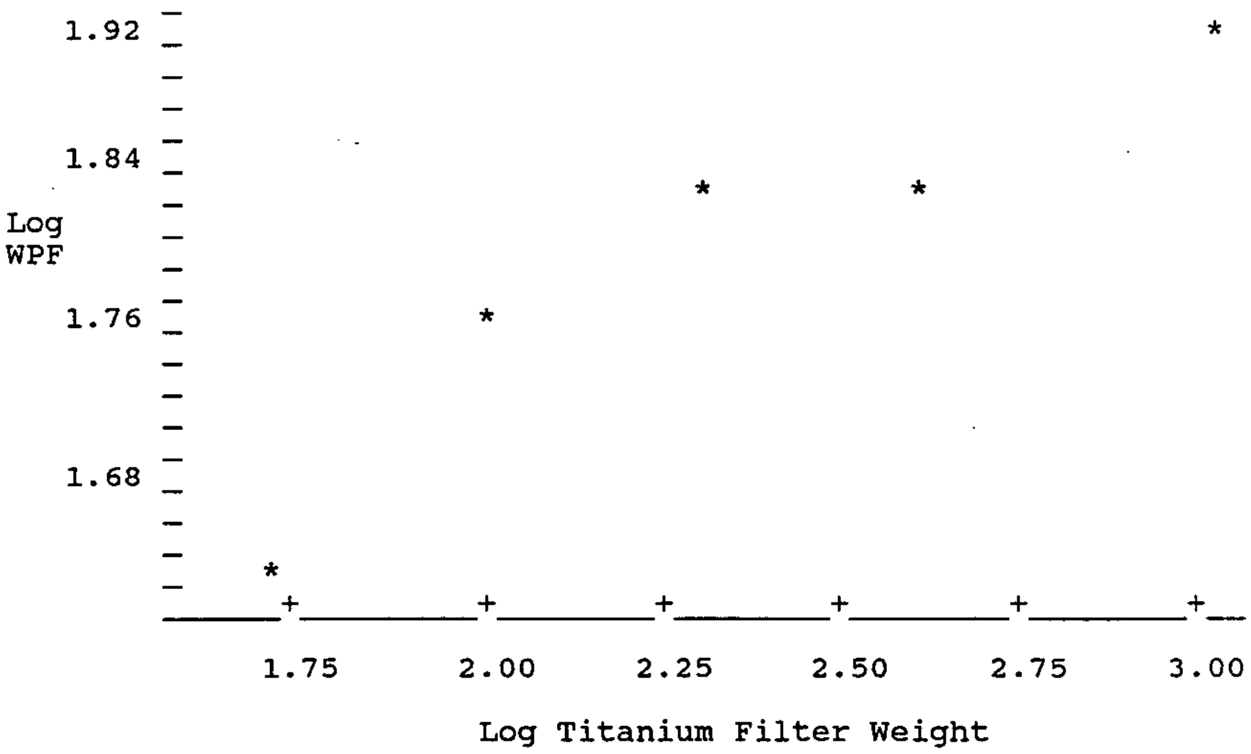
As a result of these findings, it was concluded that the data best suited for estimating the capabilities of the respirator evaluated in this study were those in the >1000X the blank area. These data no longer showed a significant correlation between outside filter weight and protection factor. Thus, they were believed to more accurately reflect the WPF's provided by the respirator. Of interest is the fact that the 5th percentile WPF for the >1000X data supports the assigned protection factor of 1000 for loose fitting, continuous flow supplied air hoods and helmets recently suggested by the ANSI Z88.2 subcommittee.

(SLIDE 12 -- COMPOSITE PHOTO FROM OTHER WPF STUDIES).

To verify that this outside filter weight versus workplace protection factor relationship was not just a function of this particu- respirator, this particular study, the protocol we had used, or the analytical method, we reviewed several other studies to determine if the same correlation between outside filter weight and workplace protection factors existed. The air purifying respirator study we reported on in 1987 also showed a filter weight versus protection factor correlation.

(SLIDE 13 -- LOG-LOG PLOT OF FILTER WEIGHT VS WPF FROM 8715 STUDY). Log-log plots of mean filter weight versus mean workplace protection factor for titanium, silicon, and aluminum dusts showed r-squared values of 76%, 90%, and 82%, respectively.

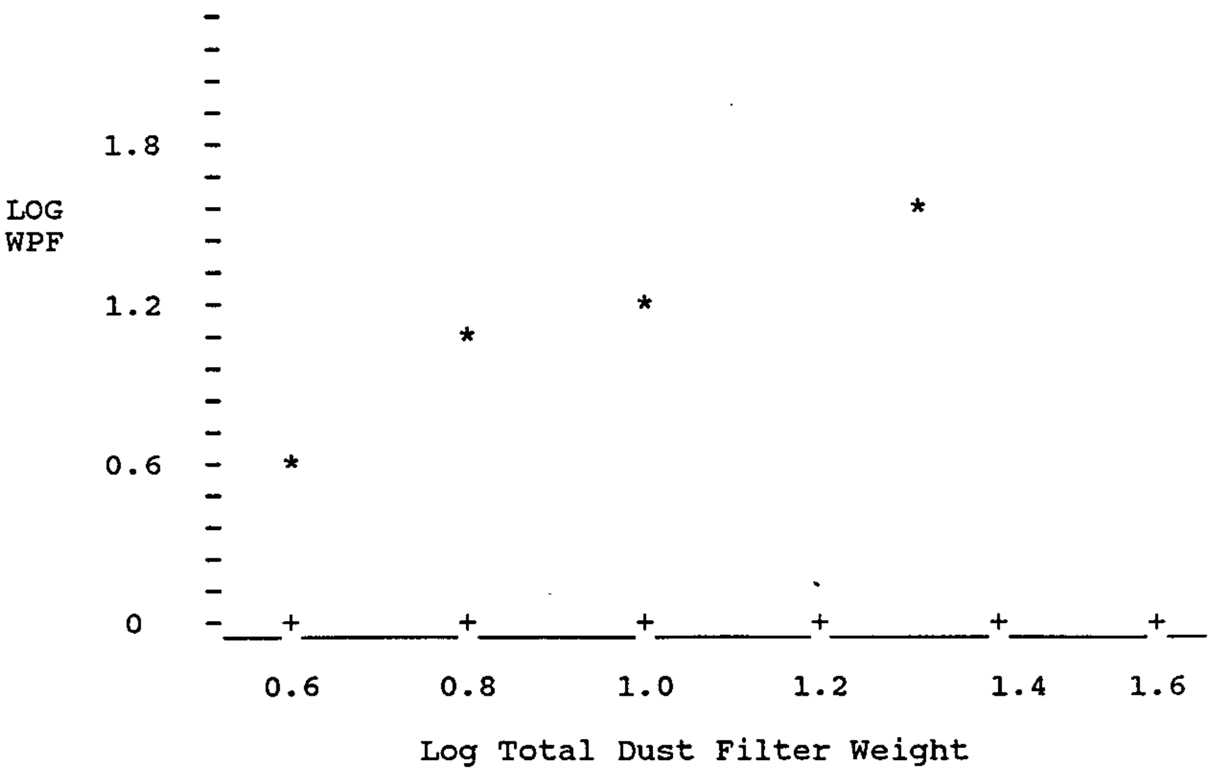
PROTECTION FACTOR VS OUTSIDE FILTER LOADING
TITANIUM DUST -- 8715 RESPIRATOR



(SLIDE 14 -- LOG-LOG PLOT OF 9910 DATA FROM NIOSH STUDY).

Data from a NIOSH study on a similar half mask respirator were analyzed in the same fashion and found to show the same correlation between mean outside filter weight and workplace protection factors. In this case, the log-log plot of filter weight vs. WPF had an r-squared value of 89%. The NIOSH report did not address this relationship or its possible impact on interpretation of the study results, but I think it is clear that this issue needs to be considered.

PROTECTION FACTOR VS OUTSIDE FILTER LOADING
TOTAL DUST -- NIOSH STUDY ON 3M 9910



(SLIDE 15 -- COMPOSITE PHOTO OF WPF STUDIES EVALUATED TO DATE). All of the studies we have reviewed so far, which includes two on supplied air respirators, three on half-mask air purifying respirators, and one an a PAPR, have shown outside filter weight--WPF correlations. The significance of this is that data which show a strong correlation (i.e., data from sample sets with lower outside filter loadings) may not be providing representative workplace protection factors for the respirator under study.

FOUNDRY STUDY

(SLIDE 16 -- PHOTO OF WCII GENERAL PURPOSE SYSTEM STUDIED). I would like to use the recent foundry study we conducted with a supplied air respirator to further illustrate this point. In this study, the respirator evaluated was a 3M Brand W-8000 Whitecap II General Purpose Helmet equipped with a W-5114 Breathing Tube, either a W-2862 Vortex Cooling Assembly or a W-2907 Air Regulating Valve, and a W-9435 Compressed Air Hose. The system with the Vortex cooling valve has NIOSH/MSHA approval No. TC-19C-70. The system with the air regulating valve has approval No. TC-19C-69.

Airflow to the helmets was maintained at approximately 6.7 cfm throughout the test by maintaining the appropriate air supply pressure with a W-2806 Filter and Compressed Air Regulator Panel (60 psi with the Vortex and 25 psi with the ARV).

(SLIDE 17 -- CLOSE UP PHOTO SHOWING PROBE). In order to sample inside the helmets, their faceshields were modified by installation of a sampling probe. The probe developed by Dr. Liu at the University of Minnesota was used. It was was positioned approximately midway between the nose and the mouth of the test subjects, with the inlet portion extending only a few millimeters into the helmet.

(SLIDE 18 -- PHOTO OF WORKER ACTIVITY).
Test subjects included six different workers involved with grinding of iron parts. One observer was present for each subject to ensure sample validity and record comments about conditions present. Air samples were collected outside and inside the respirators using 0.8 micron pore size polycarbonate filters in 25 mm cassettes. The outside samples were collected with MSA or Bendix cyclone assemblies to restrict protection factor determinations to respirable dust only. Area samples were also collected for particle size analysis, using cellulose acetate filters. For both area and personal sampling, Spectrex Model 2000 Personal Air Sampling pumps were used. They were set at 1.7 Lpm for the cyclone samples and at approximately 2.0 Lpm for the inside samples and area samples. The pumps were calibrated at least 3 times daily with a TSI Model 67 mass flow meter.

Before the pumps were turned on, air supply pressure and air control valve settings were checked and integrity of hose connections, respirators, and sampling trains verified. Sampling pumps were shut off before airflow to the helmets was stopped. Workers were then asked to step into a clean area for removal of the samples. If a sampling pump failure was experienced, an inside sample came loose from the probe, a respirator was removed prior to terminaation of sampling, or similar problems were exerienced, the sample set involved was invalidated and another pair of samples set up. To estimate contamination due to sample handling, a number of 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.

(SLIDE 19 -- PIXE DATA SUMMARIZED IN FOLLOWING PARAGRAPH).
The samples were analyzed via proton induced x-ray emission, an extremely sensitive surface analysis technique. The primary contaminants of concern were iron and silicon dusts. Detectable amounts of iron and silicon were found on the field blanks, thus the mean value of the blanks was used to correct inside and outside sample weights. Resulting outside sample concentrations averaged approximately 1500 ug/m3 for iron dust, with a range from <100 - 2800 ug/m3. Outside concentrations of silicon averaged about 1000 ug/m3, with a range from <100 - 1500 ug/m3. Corresponding inside concentrations were at or near the detection limit for both elements, ranging from about 0.2 - 8 ug/m3 for iron and about 1 - 5 ug/m3 for silicon. The area samples were analyzed via optical microscopy methods. The mean particle size found in six different samples ranged from 1.27 - 2.55 microns.

(SLIDE 20 -- DATA SLIDE -- 1ST 3 COLUMNS FROM FOLLOWING TABLE).

When the outside filter weight versus protection factor relationship was examined, a correlation was again found. The results were for iron dust were as follows:

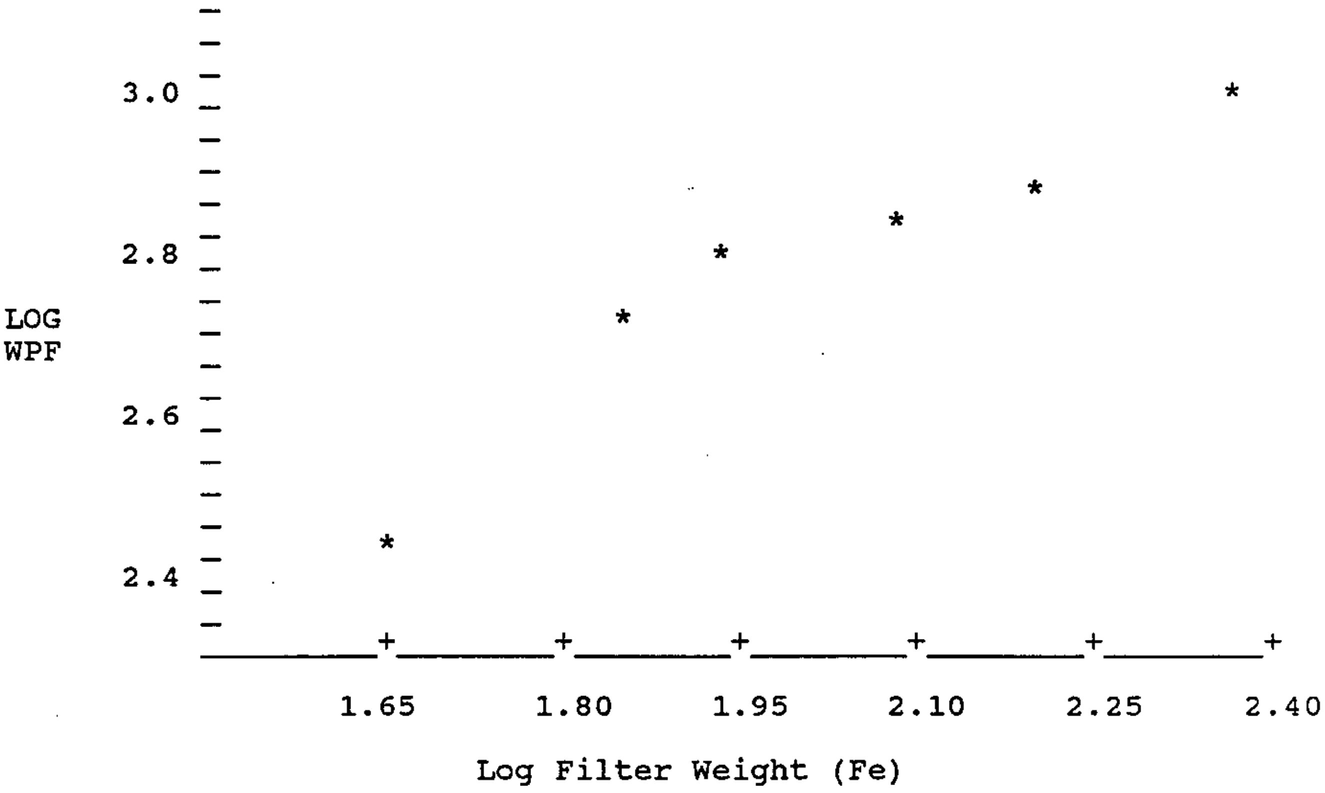
OUTSIDE FILTER WEIGHT VS WORKPLACE PROTECTION FACTOR FOR GENERAL PURPOSE SUPPLIED AIR RESPIRATOR (IRON DUST DATA)

Multiple of Field Blank	N	Xg WPF	Sg	5th Percentile
>25X	39	273	5.7	39
>100X	30	518	4.2	50
>200X	24	612	3.9	64
>300X	15	770	3.0	125
>500X	12	837	3.4	110
>750X	8	1012	2.6	199

(SLIDE 21 -- LOG-LOG PLOT OF DATA FROM SLIDE 20).

A log-log plot of the mean filter weights versus WPF's showed a regression equation of: Log WPF = 1.23 + 0.78 Log FWT. It had an r-squared value of 91%, indicating a significant correlation. However, unlike the situation observed for the supplied air respirator study referenced earlier, the correlation did not drop off at the higher filter loadings. This was believed due to the fact that outside contaminant loadings were simply too low to allow that to happen.

PROTECTION FACTOR VS OUTSIDE FILTER LOADING
WCII GENERAL PURPOSE HELMET -- IRON DUST



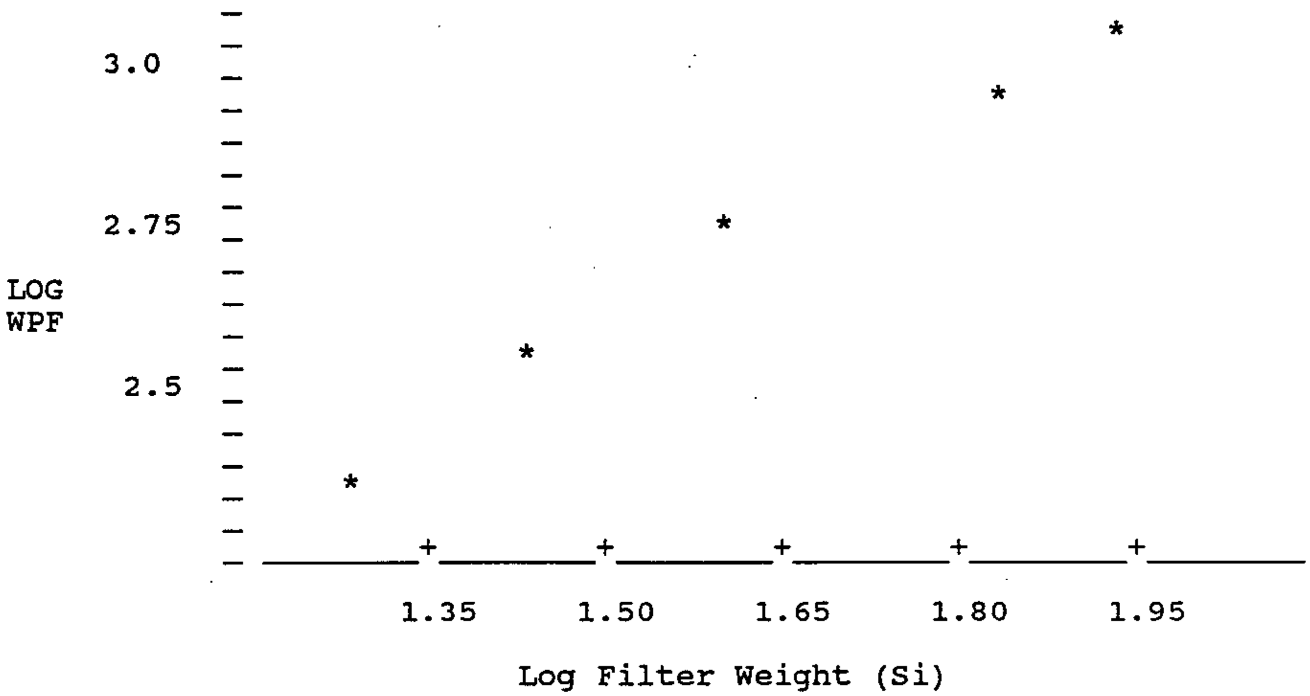
(SLIDE 22 -- DATA SLIDE -- 1ST 3 COLUMNS FROM FOLLOWING TABLE). The silicon (Si) data showed similar results. But, in this case, outside concentrations were even lower, as evidenced by the relatively modest multiples by which the outside filter loadings exceeded background contamination levels on the field blanks. As a result, the correlation between outside filter weight and WPF was even stronger for silicon than it was for iron.

OUTSIDE FILTER WEIGHT VS WORKPLACE PROTECTION FACTOR FOR GENERAL PURPOSE SUPPLIED AIR RESPIRATOR
(SILICON DUST DATA)

Multiple of Blank Loading	N	Xg WPF	Sg	5th Percentile
>10X	32	220	5.3	14
>25X	24	360	4.6	29
>50X	18	482	3.1	75
>100X	14	904	2.6	186
>200X	10	1142	3.0	187
>300X	8	1417	3.0	224

(SLIDE 23 -- LOG-LOG PLOT OF ABOVE DATA). A log-log plot of the Si data showed a regression equation of: Log WPF = 0.94 + 1.09 Log Outside Filter Weight, an r-squared value of 99.4%, and again no drop off in correlation between these two variables at the upper end of the curve. We quite simply never reached a region in which the protection factors start to become independent of outside filter weight.

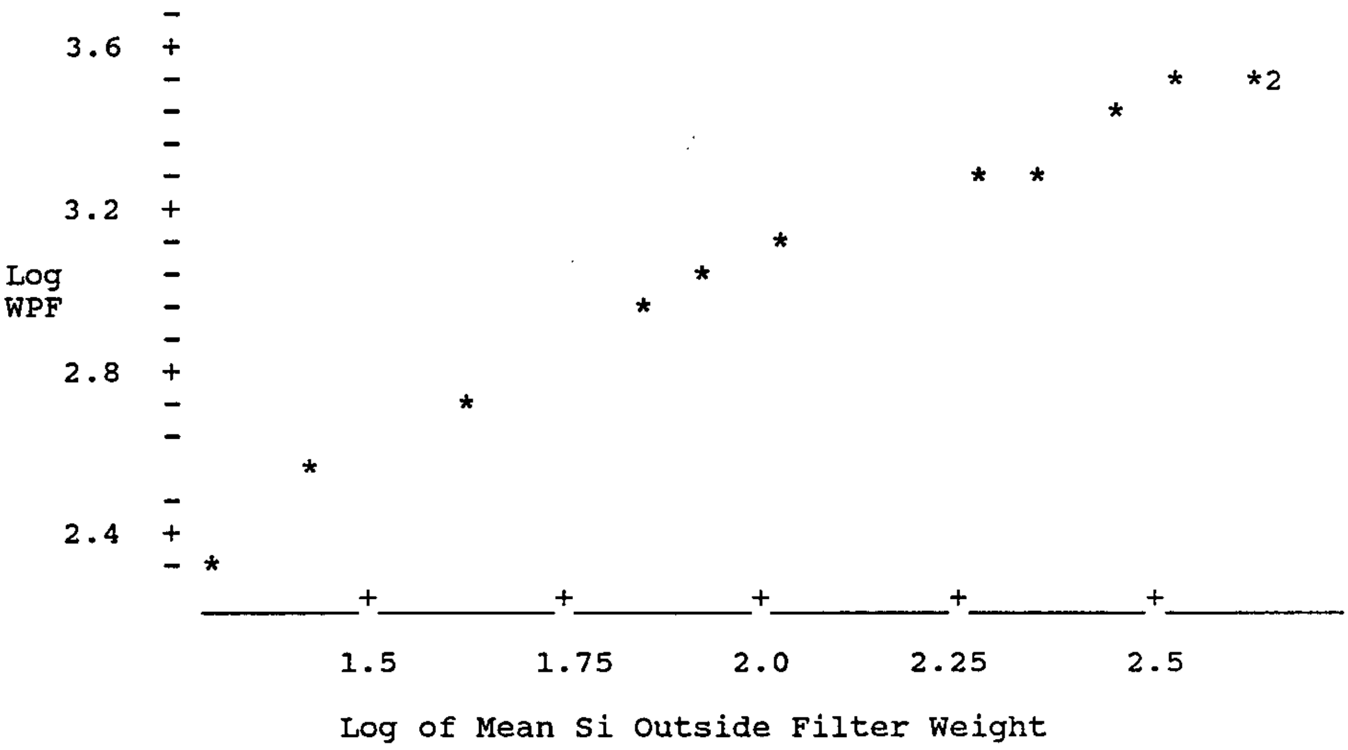
PROTECTION FACTOR VS OUTSIDE FILTER WEIGHT
WCII GENERAL PURPOSE HELMET -- SILICON DUST



As a result, despite similarities in sampling methods, analytical methods, respirator airflows, and particle size distributions, the workplace protection factor estimates obtained from this study were drastically different from those obtained in the abrasive blasting respirator study I referred to earlier. When the data from the two studies are combined, the reason for the difference is quite obvious. Although this study was set up to generate measurements that would meet the accepted definition of workplace protection factors, because of the relatively low sample loadings, the WPF numbers obtained significantly underestimate the performance capability of the respirator.

(SLIDE 24 -- PLOT OF COMBINED A/B AND FOUNDRY STUDIES, Si DATA) This is a log-log plot of the silicon data from the two supplied air respirator studies. The data from the abrasive blasting study fall into the upper end of the plot. The data from the foundry study fall into the lower end of the plot. Two conclusions are immediately apparent: (1) The geometric mean outside filter weight (ug Si) for the lowest weight sub-set of data from the abrasive blasting respirator study is higher than the geometric mean outside filter weight for the largest weight sub-set of data from the foundry study; and (2) The workplace protection factors obtained from the foundry study could have been predicted with good accuracy by the data from the abrasive blasting respirator study. The foundry data have a slope of about 1 (Log WPF = 0.91 + 1.11 Log Si FWT) and a correlation coefficient of 0.997. In comparison, the lower part of the curve for the abrasive blasting study data also has a slope of about 1 (Log Wpf = 1.22 + 0.932 Log SiFwt), with a correlation coefficient of 0.972.

WORKPLACE PROTECTION FACTOR VS. FILTER WEIGHT
COMBINED DATA FROM 2 STUDIES



Another interesting finding is that despite the large variability in the data for these two studies, a worker overexposure was never observed. In cases where lower protection factors were found, low protection factors were all that was needed. The protection factors observed were ALWAYS sufficient to prevent worker overexposures. This is certainly not a random occurence.

(SLIDE 24 -- BLANK).

These types of findings make it clear that measurement of representative performance of respirators in the workplace is not necessarily simple or straightforward. In the case of supplied air respirators, in order to maximize the value of workplace data we generate, we should attempt to target outside sample loadings of at least 1000X the anticipated analytical detection limit. If we do not, the data we get is likely to reflect limitations of our sampling and analysis procedures, rather than the respirators we are testing.

Workplace Protection Factor Study on a Supplied Air Respirator

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H.E. Mullins, and C.R. Rhoe

WCII Foundry Study

- Iron (Fe) Dust Concentrations -

Outside Samples–<100 - 2800 ug/m^3
Inside Samples–0.2 - 8 ug/m

- Silicon (Si) Dust Concentrations -

Outside Samples–<100 - 1500 ug/m^3
Inside Samples–0.1 - 5 ug/m

Protection Factors

- Workplace Protection Factor (WPF)
- Effective Protection Factor (EPF)
- Program Protection Factor (PPF)
- Assigned Protection Factor (APF)

Workplace Protection Factor

$$\text{WPF} = \frac{\text{Outside Concentration}}{\text{Inside Concentration}}$$

Both concentrations are determined simultaneously while respirator is worn.

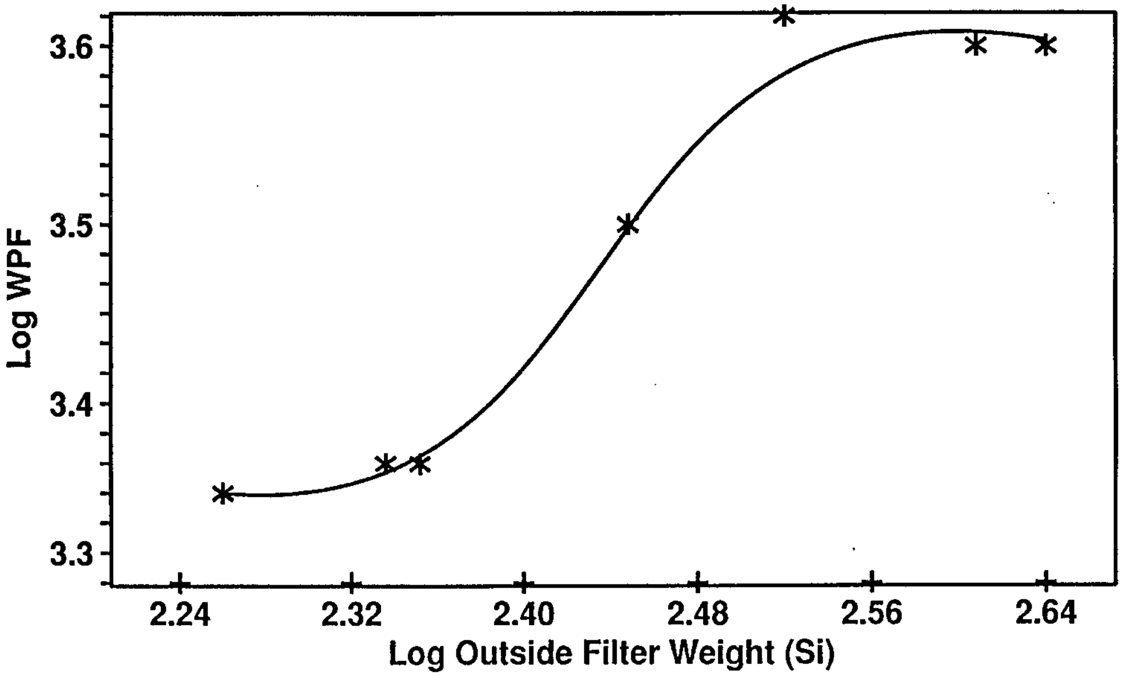
Outside Filter Weight Vs. Workplace Protection Factor

WCII Abrasive Blasting Study

Multiple of Blank	N	WPF
> 10X	37	2143
> 200X	32	2340
> 400X	28	3135
> 600X	22	4150
> 800X	19	4243
> 1000X	17	4076
> 1200X	15	4023

Workplace Protection Factor Vs. Outside Filter Weight

WCII Abrasive Blasting Study



Outside Filter Weight Vs. 5th Percentile WPF

WCII Abrasive Blasting Study

Multiple of Blank	N	Sg	5th Percentile
> 10X	37	3.6	259
> 200X	32	3.5	324
> 400X	28	2.5	673
> 600X	22	2.2	1167
> 1000X	17	2.3	1038
> 1200X	15	2.2	1096

WPF Statistics for >1000X Blank Sub-set

WCII Abrasive Blasting Study

$n = 17$

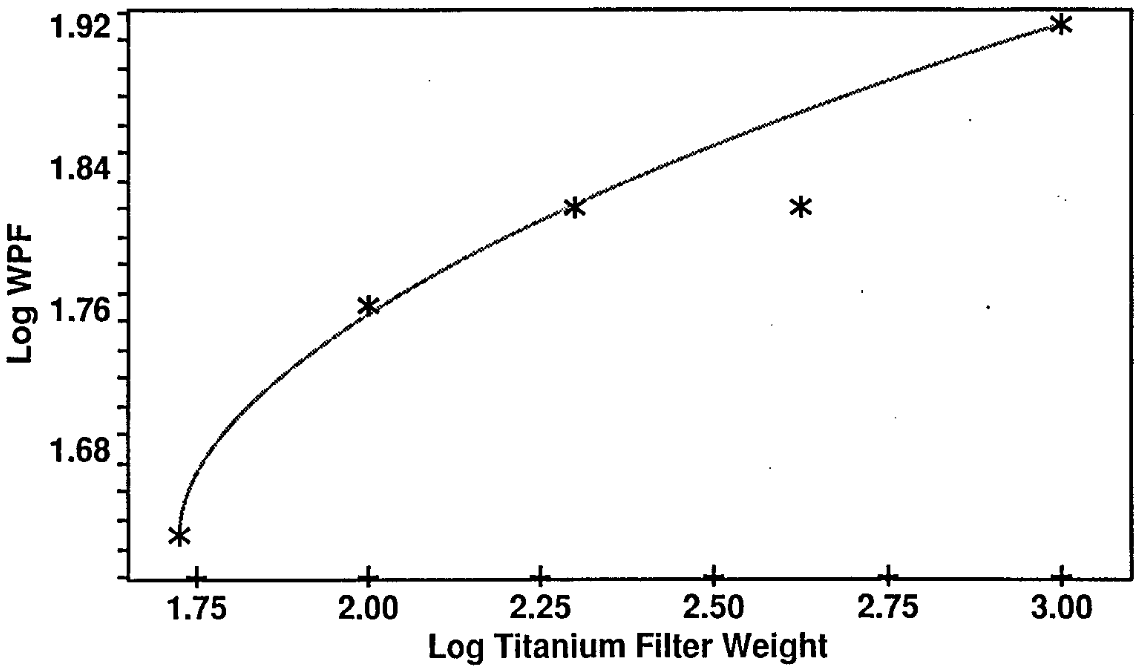
$\bar{X}g = 4076$

$\sigma g = 2.3$

5th = 1038

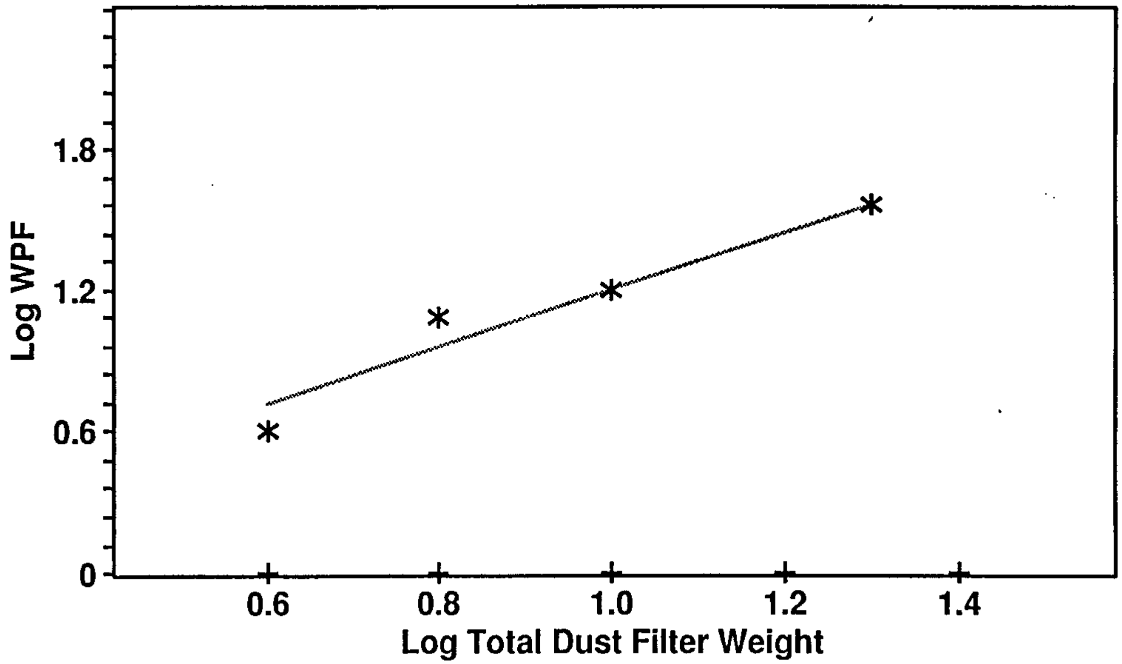
Outside Filter Weight (Ti) Vs. WPF

8715 Grinding/Polishing Study



Outside Filter Weight (Total Dust) Vs. WPF

NIOSH Study on 9910



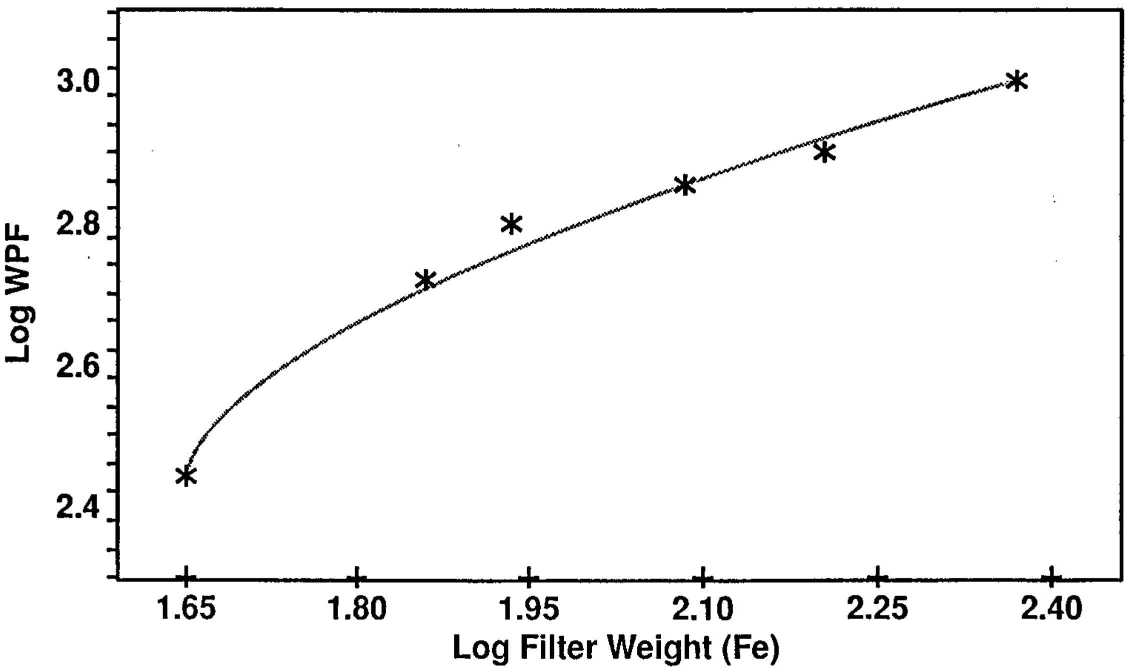
Outside Filter Weight (Fe) Vs. WPF

WCII Foundry Study

Multiple of Field Blank	N	$\overline{X}g$ WPF
> 25X	39	273
> 100X	30	518
> 200X	24	612
> 300X	15	770
> 500X	12	837
> 750X	8	1012

Outside Filter Weight (Si) Vs. WPF

WC II Foundry Study



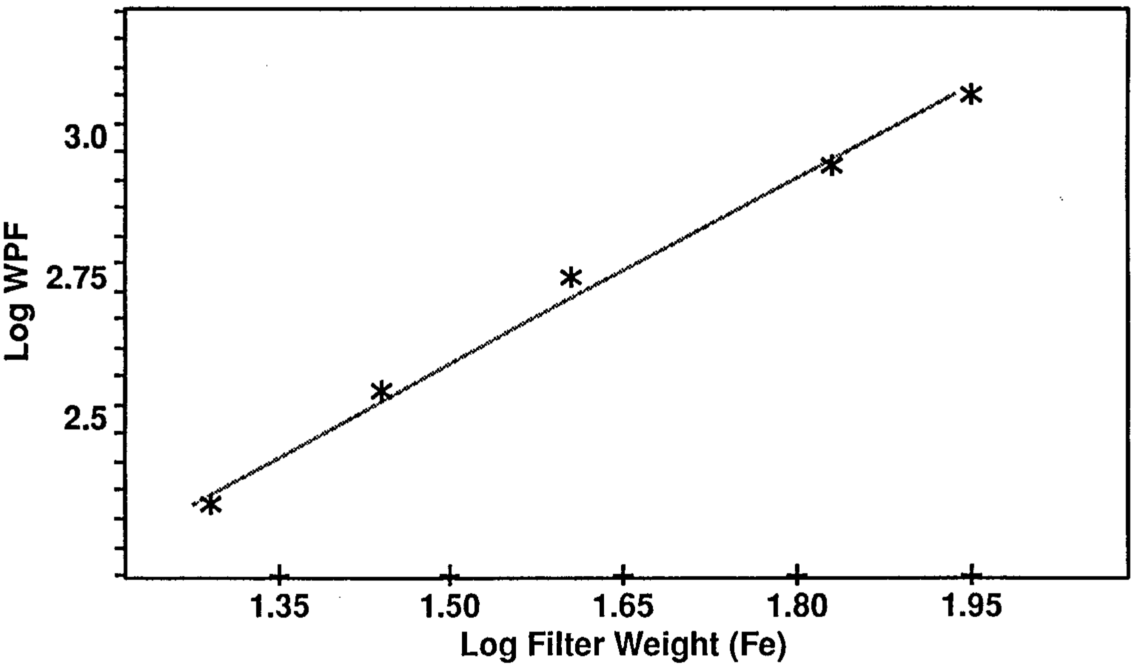
Outside Filter Weight (Si) Vs. WPF

WCII Foundry Study

Multiple of Field Blank	N	$\overline{X}g$ WPF
> 10X	32	220
> 25X	24	360
> 50X	18	482
> 100X	14	904
> 200X	10	1142
> 300X	8	1417

Outside Filter Weight (Si) Vs. WPF

WC II Foundry Study



Workplace Protection Factor Vs. Outside Filter Weight

Two Different Supplied Air Respirator Studies