

Field Test of Powered Air-Purifying Respirators
at a Battery Manufacturing Facility¹

by

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¹ Mention of company names or products does not constitute endorsement by the National Institute for Occupational Safety and Health.

Abstract

We conducted a field study to measure the protection provided by the Racal Airstream AH5 and 3M W-316 powered air-purifying respirators (PAPRs) against airborne lead dust and mist. Both PAPRs were equipped with helmets utilizing MSHA/NIOSH approved dust and mist filters. Performance was assessed by measuring the workplace protection factors provided by the PAPRs during work tasks associated with battery plate pasting. The protocol used for collecting the field samples provided for proper fit, use, wear, and maintenance of the respirators and extensive worker observation. The geometric mean lead concentration measured inside the facepiece of the Racal AH5 was 2.0 yg Pb/m^3 and for the 3M W-316 it was $1.8 \text{ } \mu\text{g Pb/m}^3$. These mean concentrations were not significantly different from one another but both were significantly less than the OSHA Lead Standard PEL of 50 yg Pb/m^3 . The workplace protection factors measured on the Racal AH5 ranged from 23 to 1063 with a geometric mean of 120. The workplace protection factors measured on the 3M W-316 ranged from 31 to 392 with a geometric mean of 135. The mean workplace protection factors measured on the two brands of PAPRs were not significantly different. Our results indicate that the Racal AH5 and 3M W-316 PAPRs, when properly used, maintained and conscientiously worn were able to provide good protection against airborne lead dust and lead mist under the work conditions experienced during this study.

Introduction

Powered air purifying respirators (PAPRs) equipped with dust and mist filters have been given an assigned protection factor of 100 in the 1980 American National Standards Institute (ANSI Z88.2-1980) respirator standard. This assigned protection factor was based primarily upon the assumption that PAPRs are positive-pressure respirators and efficiency of the air purifying element. This assigned protection factor has never been verified by NIOSH field testing. The purpose of this study was to measure the workplace protection factors provided by two MSHA/NIOSH certified PAPRs in selected work activities in a battery plate pasting operation.

The PAPRs chosen for study were the Racal Airstream AH5 and the 3M W-316. Each was equipped with helmet, visor enclosure, and dust and mist filters. Both units are MSHA/NIOSH approved. The performance of the PAPRs in this workplace setting was evaluated when the devices were worn on workers performing their normal work activities and when mounted on stationary manikins.

The specific operation selected for study was the lead acid plate production lines of a specific battery manufacturer. This selection was based upon review of retrospective data on personal exposures to lead. The manufacturing process for this manufacturer involves production of both positive (+) and negative (-) lead acid plates. Double-plate castings, produced in the casting department, are delivered to positive

and negative lead acid plate production lines in the pasting department. The castings are removed from the pallets and stacked on an automatic grid feeder by a pasting machine operator. From there they are fed through the pasting machine where either positive or negative paste, depending on the production line, is forced into the castings.

The positive and negative paste formulations are first prepared by a worker and then mechanically mixed in separate muller (Simpson) type mixers. This process is done on a mezzanine floor located directly above the pasting machines. After mixing is completed the lead acid paste is directly fed by gravity into hoppers which supply paste to the pasting machine. After pasting, the castings are conveyed through a drying oven to remove sufficient moisture to prevent them from sticking together. After passing through the drying oven, the castings are removed from the end of the conveyor belt by slitter operators, who then separate the plates in the casting with vertical band saws. The single lead-acid plates from each line are then stacked by the slitter operators onto separate pallets. The pallets are transported to a holding/storage area until natural curing of the paste is completed. Each production line employs a pasting operator and two slitter operators.

Test Group and Data Collection

The positive and negative pasting operators and their corresponding slitter operators on both the 7 a.m. and the 3 p.m. shifts were selected to participate in the study. No attempt was made to control the facial

size indices of the workers because this is not a significant factor affecting protection for loose-fitting facepiece designs. A total of twelve workers on two production lines were used in the study. Each worker was randomly assigned to wear both models of PAPR twice, however, for the second wearing, he was not given the same specific 3M or Racal PAPR that he wore the first time. The inside and outside facepiece airborne lead samples were collected over the full shift. Time weighted average (TWA) concentrations of lead dust were calculated from the results of air sample analysis. Workplace protection factors (WPF), were then determined from the TWA concentration estimates and were used as a measure of respirator performance.

Statistical Analysis

These data were analyzed using the t-test, analysis of variance (ANOVA) and correlation analysis. These statistical tests all require that the data being analyzed must be normally distributed. However, it is generally believed that environmental occupational exposure data approximately follows a lognormal distribution. Testing of the data collected in this study showed it to be lognormally distributed as expected. A Kolmogorov-Smirnov test was run on randomly selected cells of the ANOVA to check the assumption of normality (Neter et al. 1982). Those results indicated that the log transformed data was far superior to the untransformed data in meeting this assumption. In addition to the Kolmogorov-Smirnov test for the analysis of variance, skewness and kurtosis of each variable distribution was calculated. The skewness is a

description of the asymmetry of a distribution while kurtosis is a measure of the degree of peakedness of a **distribution**. In all **cases**, except as noted, the **log-transformed** data best approximates the normal distribution. Accordingly, the raw concentration data were log transformed and all statistical analyses were performed on the transformed data unless indicated otherwise. In addition to geometric mean, geometric standard deviation and confidence intervals, certain performance aspects of each PAPR are also characterized by tolerance limits. The statistical tolerance limits furnish limits above or below that in which it can be confidently expected to find a prescribed percentage of individual items of the population.

Methods and Materials

Six 3M Model W-316 and six Racal Model AH5 PAPRs were used in this research study. The Racal AH5 PAPR consists of a helmet, a face shield assembly, a dust and mist filter and a fan assembly which is located in the helmet and a belt worn battery pack. Two flexible face seals are attached to the shield assembly to provide a seal between the wearer's face and the shield when it is down. The air provided to the face area is vented through an opening in the faceshield at the chin as previously described by Myers, et al. (1984a). The 3M W-316 PAPR consists of an inner and outer helmet **shell**, a dust and mist filter assembly, a fan assembly located in the helmet, and a belt worn battery pack. A soft, flexible face seal is attached to the faceshield to provide a loose-fitting seal between the **wearer's** face and the faceshield when it

is down. The air provided to the face area is vented through openings in the face seal at the temples (Myers, et al. 1984a).

The **Racal AH5** PAPR and filters were purchased from a commercial source. The **3M W-316** PAPR and filters were purchased from the manufacturer since they had only recently been **MSHA/NIOSH** certified and were not commercially available from suppliers at the start of the study. Within the context of this report facepiece refers to that part of the helmet enclosure that covers the face, often times called the visor, shield or face shield.

I. Laboratory Evaluation

Prior to the collection of any research data, these PAPRs were all visually examined in the laboratory for structural defects. Random selection of filters was obtained from those purchased for field testing. These randomly selected filters were tested for penetration efficiency with silica dust. The silica dust test was done in a chamber according to **NIOSH** certification test procedures contained in the **NIOSH** certification standard (Bureau of Mines, 1972). These examinations and tests are of the type routinely required for PAPRs equipped with dust and mist filters.

II. Field Evaluation

A. PAPR Performance on Workers

Respiratory protection afforded by the 3M W-316 and Racal AH5 PAPR's was determined by simultaneously collecting airborne lead samples inside and outside the facepiece of these units during the course of a complete work shift. Analytical results were used to calculate time-weighted average (TWA) concentrations of lead inside and outside the respirator from which worker exposure and workplace protection factors of the respirator could be estimated.

The workplace protection factor has been defined by Myers et al (1983b) as the TWA estimate of the contaminant concentration which the user would inhale if he were not wearing the respirator (C_u) divided by the TWA estimate of contaminant concentration inside the respirator facepiece (C_I). Samples were collected only while the respirator was properly worn and used during normal work activities. Samples for estimating both C_u and C_I were taken simultaneously.

1. Sampling Technique

For in-facepiece sampling, a modified Luer adapter sampling probe was attached to the face shield with rubber washers and nut to achieve an air tight seal (Liu, et al. 1984). The sampling probe attachment was

on the midline of the face shield of the PAPR approximately 3/4 inch above the lip of the lower face shield frame assembly (Figures 1 and 2). The probe mouth was approximately 1 to 2 inches from the mouth in the horizontal plane. This probe location is somewhat arbitrary; however, it is felt to be a reasonable position from which to estimate the concentration of material a wearer is breathing when the PAPR is worn. The sampling filter cassette was attached directly to the Luer adapter. Some of the potential sources of error for collecting inside facepiece samples on PAPRs have been discussed by Myers and Peach (1983a). The outside facepiece front samples, which constitutes C_o in the workplace protection factor calculation, were taken on the front, lower, right hand side of the face shield assembly. Located in this position the samples would estimate the lead exposure the worker would experience if he were not wearing the respirator. This position did not interfere with the use of the PAPR and it was away from the clean air wash venting from the PAPR (Figures 1 and 2). A second outside facepiece sample identified as outside facepiece-rear was taken near the PAPR filter assemblies. This sample was collected because of concern raised by others in our earlier work that estimates of ambient aerosol concentration challenging the respirator should be taken near the PAPR filters, thus, providing a more accurate reflection of the aerosol concentration challenging the filter component of the PAPR.

Lead exposure sampling requires a total dust **sample**, therefore, all samples were collected as total dust samples. It should be noted that respirable dust samples may give different **results**.

All three lead samples were taken with identical sampling trains. Each sampling train consisted of a **two-piece** closed-face filter cassette with a 37 mm, 0.45 micrometer pore size cellulose ester **Millipore filter** and back up pad connected to a personal air sampling pump by 1/4-inch Tygon^R tubing. The sampling flow rate was approximately 2 L/min for all outside and inside facepiece concentration samples. Individual sample pump flowrates were calibrated by **bubblermeter** in the laboratory with the complete sampling train in place. At the study site, the flowrate calibration of each sampling pump with sampling train was confirmed or **re-established** using a bubblermeter and a Kurz^R flow meter.

The front and rear outside facepiece samples collected during the study were analyzed for lead by atomic absorption spectroscopy according to NIOSH Method No. S-341 with the modification that in the wet ashing step two milliliters of concentrated perchloric acid were used with 4 milliliters of concentrated nitric acid to insure complete oxidation of the organic filter matrix (NIOSH Manual of Analytical Methods, 1977 revised 3/25/81). Final dilution volume was 25 milliliters and absorbances were recorded at 283.3 nm at a scale expansion of 1.000. The limit of detection was 3 micrograms

lead/filter. The total coefficient of variation (CV_T) for the combined sampling and analytical methods based on NIOSH method S-3A1 for lead in the concentration range of .15 - 1.67 mg/m³ is 0.068. Based on retrospective airborne lead concentration data for the battery plate production area it was anticipated that most sample concentrations would be in this range.

The samples collected inside the facepiece were analyzed for lead by a graphite furnace technique similar to that employed in NIOSH Method No. P & CAM 214 with the previously noted modification to method S-341 of using concentrated perchloric acid in the wet ashing step of the analysis (NIOSH Manual of Analytical Methods, 1981). Final sample dilutions were 25 milliliters and absorbances were recorded at 283.3 nm. The limit of detection was 0.3 micrograms lead/filter. The analytical coefficient of variation CV_A for method 214 is 0.057. Assuming a pump sampling coefficient of variation CV_P to be 0.05 then the total coefficient of variation CV_T for the method would be .076 as calculated according to Leidel and Busch (1973). The lead analysis was conducted by Utah Biological Testing Laboratories utilizing their normal in-house analytical quality control procedures.

2. Filter Handling

The filter cassettes to be taken to the field were prepared in the NIOSH Morgantown technical support laboratory using standard

techniques. The cassettes were kept plugged at all times except when being used. During each shift, two filter cassettes were selected as filter blanks. These cassettes were handled identically as the test cassettes except that no air was drawn through them. The blank cassettes were given to the analytical laboratory as blind samples to be analyzed by graphite furnace technique. All blank filters had reported lead concentrations less than the graphite furnace limit of detection of 0.3 μg per filter.

3. Donning, Doffing and Maintenance of the PAPRs

During the field survey the PAPRs were put on and taken off each worker participant by the investigators whenever it was necessary (e.g., start or end of shift, lunch break or personal need). Donning and doffing of the PAPR was always done in a company designated clean area except for those occurrences involved with personal need breaks which were done in the general area of the work site. Workers were instructed to adjust the head harness of their PAPR to provide a snug, comfortable fit. On the Racal PAPR which could be used with large or small face seals, each worker's PAPR was equipped with the face seal that appeared to be the best fitting and most comfortable for him.

After the PAPR was donned and adjusted for comfort, it was turned on first and then the sampling pumps were turned on and adjusted. When

doffing the PAPR, the sampling pumps were turned off before the PAPR was turned **off**. Sampling pumps were always started and stopped **simultaneously**.

The PAPR helmet and visor assembly was cleaned in a detergent solution and rinsed twice with clean water between each use. The units were allowed to air dry after which the face shields and face sealing surfaces were disinfected. All other **manufacturer's** maintenance instructions were followed.

The volumetric air output of each PAPR was checked several times daily. Usually checks were made at the beginning and end of the work shift and at the lunch break. The air flow indicators used were those provided with the PAPR by the **manufacturers**. Batteries were replaced at each **manufacturer's** suggested interval unless a low volumetric air output was found. In which case the battery was replaced **immediately**. Visual inspection of the filters for punctures and tears could not be done easily; therefore, the used filters were replaced after each shift with new filters.

A. Worker Instructions and Monitoring

Prior to participating in the study each worker participant was instructed in the proper use of the PAPR by members of the field study team, who had received training on the use, adjustment and maintenance of the PAPRs from each respective **manufacturer**. Workers

selected for inclusion in the study did not have beards. They were instructed not to remove the PAPR helmet, to lift the face shield, or to handle the air sampling units in any way without first notifying the NIOSH investigators on observation duty. To ensure that these requirements were followed NIOSH investigators observed and assisted workers during periods when the PAPRs were donned or doffed. In addition, workers were monitored at their individual work stations at all times during each workshift each day of the study. Monitoring was done with 2 to 4 NIOSH investigators. This extensive monitoring also allowed very frequent, routine checks to be made on the sampling trains.

B. PAPR Performance on Formed Heads

The PAPRs used by the workers were also tested in a stationary mode on manikins. This testing was done to provide information on how well the filtration systems of the PAPRs would work under the conditions experienced at the plate pasting operation. Stationary PAPRs were located approximately 4 feet from the operations where they were evaluated on worker participants. The height of the tripod was adjusted such that the level of the formed head was approximately that of an adult. Nothing was known to be in the atmosphere that would cause an unusual degradation of the PAPR filters such as oil mist, acid mist, etc.

Testing with the manikins was handled identically in all respects to the testing conducted on workers except that no simulated worker breathing pattern was used and the units were not extensively monitored.

C. Aerosol Characterization

The particle size distribution of suspended lead dust and mist generated from the grid pasting operations was measured with a **Marple** Cascade Impactor. It was operated at a flow rate of 3 L/min. which gave impactor stage 50% effective cut-off diameters of 17, 11, 6.1, 3.0, 1.3 and 0.68 micrometer respectively. Glass coverslides used on each impactor stage were coated with a thin film of APEIZON H grease diluted approximately 7 to 1 with benzene.

Results of impactor sampling indicated that the mass median aerodynamic diameter of the airborne lead aerosol was larger than 17 μm . This suggests that the lead aerosol is comprised predominantly of large particles or agglomerations. This observation is consistent with the processes in the plate production most likely to be the generating source of the airborne lead.

Results and Discussion

The laboratory inspection of the **Racal AH5** and **3M W-316** PAPRs conducted before field testing revealed no visual defects in the units and that all

major component parts of the units were as approved by **MSHA/NIOSH**. Results of performance testing in the silica dust chamber confirmed that the PAPRs and filter assemblies were able to meet the maximum penetration and minimum airflow requirements specified in 30 CFR 11.

The performance data collected on the **Racal AH5** and the **3M W-316** PAPRs from worker participants is presented in Tables 1 and 2. The TWA concentrations measured inside the facepiece of the **Racal AH5** ranged from 0.3 to 12.4 ygPb/m^3 with a geometric mean of 2.0 ygPb/m^3 and a geometric standard deviation of 2.51. The lower and upper 95% confident interval on the mean estimate were respectively 1.3 and 2.9 ygPb/m^3 . Based on the *t*-test the mean was found to be significantly ($P < .01$) lower than the OSHA Lead Standard PEL of 50 ygPb/m^3 . TWA samples collected at the front of the PAPR were used as the estimate of airborne lead exposure that would have occurred if the respirator was not used. The airborne concentrations sampled ranged from 125 ygPb/m^3 to 387 ygPb/m^3 with a geometric mean of 237 ygPb/m^3 and a geometric standard deviation of 1.42. Measurements of the workplace protection factors provided by the **Racal AH5** were made from paired concentration samples obtained inside and outside the facepiece of the PAPR. The workplace protection factors ranged from 23 to 1063. The distribution of workplace protection factors had a geometric mean of 120 with a geometric standard deviation of 2.64. The upper and lower 95% confidence intervals on the estimate of the mean workplace protection factor were respectively

78 and 181. Based on the t-test it was concluded that the mean workplace protection factor provided by the **Racal AH5** was not significantly different ($P < .05$) from the ANSI recommended value of 100.

The TWA concentrations measured from inside of the facepiece of the **3M W-316** PAPR ranged from 0.5 ygPb/m^3 to 5.4 ygPb/m^3 with a geometric mean of 1.8 ygPb/m^3 and a geometric standard deviation of 1.80. Analysis of these data had indicated that the concentration measurement of 38.2 ygPb/m^3 was an outlier therefore it was not used in the data analysis. The upper and lower 95% confidence intervals on the mean estimate were respectively 1.4 and 2.3 ygPb/m^3 . Analysis by t-test indicated that the mean was significantly ($P < .01$) less than the **OSHA** Lead Standard PEL of 50 ygPb/m^3 . Concentration measurements of airborne lead made in front of the **3M W-316** facepiece ranged from 112 ygPb/m^3 to 534 ygPb/m^3 . The distribution had a geometric mean of 236 with a geometric standard deviation of 1.45. The distribution of workplace protection factors measured with the **3M W-316** PAPR ranged from 31 to 392 having a geometric mean of 135 and a geometric standard deviation of 1.89. The upper and lower 95% confidence intervals on the mean workplace protection factor estimate were respectively 102 and 179. The mean workplace protection factor estimate of 135 was not found to be significantly different ($P < .05$) from the ANSI recommended protection factor of 100.

The mean estimates of airborne lead concentration measured at the front of the Racal and 3M PAPR facepieces were respectively 237 and 236 $\mu\text{gPb}/\text{m}^3$. These estimates were not significantly different from which it is concluded that the PAPRs were used in similar concentrations of airborne lead.

Since statistical analysis indicated that the mean estimates of in-facepiece lead concentration and workplace protection factor obtained with the two brands of PAPRs were not significantly different these data were pooled for further analysis. Based on the 47 pooled observations the geometric mean of the in-facepiece exposures was 1.9 ygPb/m^3 with a geometric standard deviation of 2.14. Using the pooled data a probability estimate was made of the percentage of workers having exposures below a certain level. Such an estimate is prudent from the standpoint of worker health because it estimates the potential exposure level of a specified proportion of the population rather than the average exposure level of the entire population. If a 0.95 probability level ($Z_p = 1.96$) is selected it would be concluded that workers in this population or other populations studied under similar conditions, i.e. 236 ygPb/m^3 ambient concentration, would have lead exposures of less than 8.4 $\mu\text{g}/\text{m}^3$. By applying tolerance limits to these same data it is possible to estimate the proportion (p) of lead exposures falling below a certain level at a specified level of confidence (Y). If P and Y are both set at 0.95 then it can be said with 95% confidence that 95% of the workers in this population or other populations studied under similar conditions, i.e., 236 ygPb/m^3 ambient concentration, would

experience lead exposures while wearing these PAPRs of less than 9.3 $\mu\text{g}/\text{m}^3$.

The workplace protection factor distribution obtained from the the pooled PAPR data is presented in Figure 3. This distribution had a geometric mean of 127 and a geometric standard deviation of 2.28. Based on these data and a 0.95 probability level the assigned protection factor (APF), as defined by Myers et al. (1983b), for this class of PAPRs would be 25. This finding is similar to that reported for MSHA/NIOSH certified PAPRs equipped with helmets and high-efficiency particulate filters (Myers, et al. 1984b).

One objective of stationary testing of the PAPRs was to determine if the filter performance of the devices would be similar to that found from the silica dust certification tests specified in 30 CFR 11. The silica dust certification test requires a filter efficiency of 99% or better (equivalent to a PF of 100 or better) against a polydispersed silica dust aerosol having a mean geometric size of 0.4 to 0.6 μm (AMMD of approximately 2.0 - 2.2 μm) and a geometric standard deviation of approximately 2.0. The average filter efficiency found on 22 stationary tests in this workplace was 99.2% ranging from 98.0% to 99.9%. While these results are similar to laboratory test results, one would expect with the much larger particle size in the workplace that the filter efficiency measurements made these would be higher than laboratory

results. One possible explanation of why this was not seen is wind induced leakage through the loose-fitting face seal of these PAPRs. Cecala et al. (1981) have demonstrated the sensitivity of the loose-fitting, helmeted, PAPR to leakage caused by small air velocities directed at the facepiece periphery.

Conclusions:

Based on the results of this study it is concluded that the MSHA/NIOSH certified Racal AH5 and 3M W-316 PAPRs equipped with helmet, face shield and MSHA/NIOSH approved dust and mist filter were able to reduce worker lead exposures to levels that were significantly less than the OSHA Lead Standard PEL of $50 \mu\text{gPb}/\text{m}^3$. It must be emphasized however that these PAPRs were properly fitted, conscientiously worn and used and maintained according to manufacturer's instructions and the contaminant concentration was only 4.7 times the PEL.

The mean workplace protection factors determined on both the 3M and Racal PAPRs were not significantly different from the ANSI assigned protection factor classification of 100 for this type of respirator. While the mean determinations of workplace protection factor do not contradict the ANSI recommended protection factor of 100, a more prudent estimate of workplace protection would be made using the assigned protection factor method defined by Myers, et al. (1983b). Based on the data presented in this study and a 0.95 probability level the assigned protection factor for these PAPRs would be calculated to be 25.

The results of this study coupled with the results of Cecala, et al. (1981), Myers and Peach (1983a), Myers, et al. (1984b), and Dixon, et al. (1984) strongly suggest that the respirator user community not view current generation powered air-purifying respirators equipped with helmets as positive pressure respiratory devices.

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TABLE 1

Lead Concentration and Workplace Protection Factor Data
Obtained With The Racal Model AH5 PAPR.

Day/Shift	Work Activity*	Concentration $\mu\text{g}/\text{m}^3$			Workplace t Protection Factor
		Inside Facepiece	Outside Front	Facepiece Rear	
1 - a.m.	A	1.4	281	176	200
	B	4.7	374	140	80
	B	1.6	308	127	81
1 - p.m.	A	3.0	208	128	69
	B	2.0	174	171	89
	B	1.5	222	194	146
2 - a.m.	A	1.5	150	103	99
	B	0.3	319	96	912
	B	1.0	138	106	144
2 - p.m.	A	1.3	134	105	100
	B	1.2	341	194	291
	B	2.2	344	265	158
3 - a.m.	A	12.4	280	96	23
	B	4.9	264	167	54
	B	4.7	125	193	27
3 - p.m.	A	1.1	165	118	150
	B	2.1	180	173	88
	B	0.9	265	127	300
4 - a.m.	A	3.1	217	136	71
	B	1.8	387	427	214
	B	0.3	309	310	1063
4 - p.m.	A	3.1	194	99	63
	B	2.5	355	314	144
	B	12.0	291	320	24
Geometric Mean		2.0	237	162	120
Geometric Std. Dev.		2.51	1.42	1.54	2.66

* A - Positive and Negative Pasting Operator;
B - Positive and Negative Slitter Operators

† Calculated before inside facepiece concentration values were rounded to the nearest tenth and the outside facepiece concentration rounded to the nearest whole number.

TABLE 2

Lead Concentrations and Workplace Protection Factor Data.
Obtained With The 3M Model W-316 PAPK.

Day/Shift	Work Activity*	Concentration $\mu\text{g}/\text{m}^3$			Workplace † Protection Factor
		Inside Facepiece	Outside Front	Facepiece Rear	
1 - a.m.	A	2.8	338	135	120
	B	2.8	150	231	54
	B	1.5	218	142	143
1 - p.m.	A	3.2	168	171	53
	B	1.6	193	130	121
	B	1.8	342	134	194
2 - a.m.	A	0.5	170	101	320
	B	1.1	112	112	100
	B	0.9	164	91	1,84
2 - p.m.	A	1.9	534	99	282
	B	0.7	275	192	392
	B	1.3	340	-	255
3 - a.m.	A	2.1	275	96	131
	B	3.1	279	197	91
	B	2.7	335	321	126
3 - p.m.	A	1.4	169	150	118
	B	2.2	-	354	-
	B	1.8	342	401	186
4 - a.m.	A	38.2**	154	-	
	B	5.4	170	157	31
	B	4.6	295	489	64
4 - p.m.	A	2.5	312	114	124
	B	1.6	237	209	146
	B	0.8	226	222	300
Geometric Mean		1.8	236	171	135
Geometric Std. Dev.		1.80	1.45	1.62	1.89

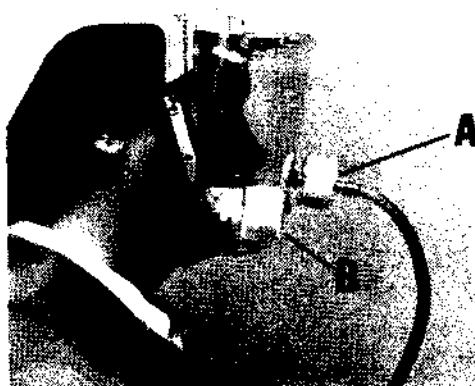
* A - Positive and Negative Pasting Operator;
B - Positive and Negative Slitter Operator

** Outlier value not used in data analysis

† Calculated before inside facepiece concentration values were rounded to the nearest tenth and the outside facepiece concentration rounded to the nearest whole number.

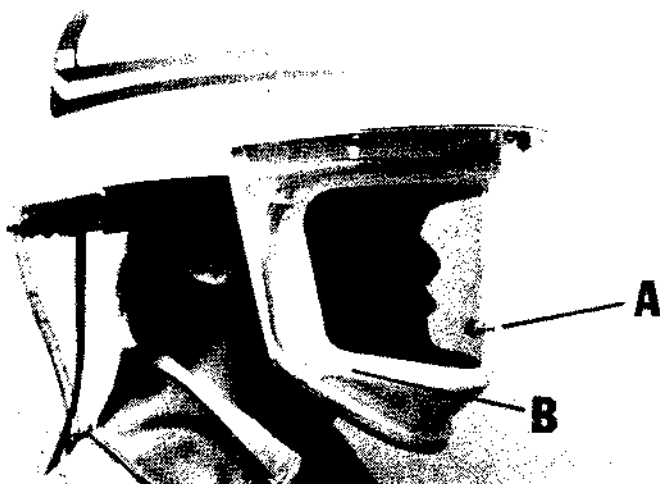


Photograph 1

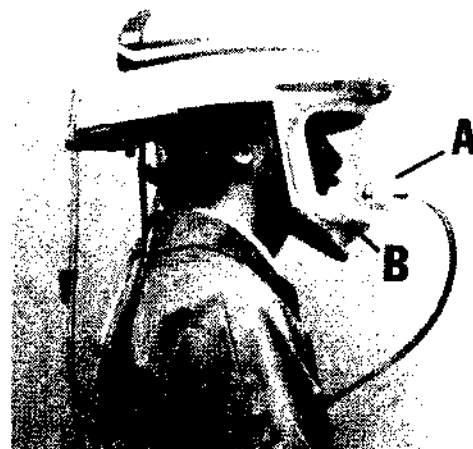


Photograph 2

Figure 1. In-facepiece and outside facepiece sampling locations used with the **Racal AH5** powered air-purifying respirator. Photograph 1: A - in-facepiece sampling probe location; B - outside facepiece sampling location. Photograph 2: A and B filter cassette attachment and sampling lines.



Photograph 1



Photograph 2

Figure 2. In-facepiece and outside facepiece sampling locations used with the 3M W-316 powered air-purifying respirator. Photograph 1: A - in-facepiece sampling probe location; B - outside facepiece sampling location. Photograph 2: A and B filter cassette attachment and sampling lines.

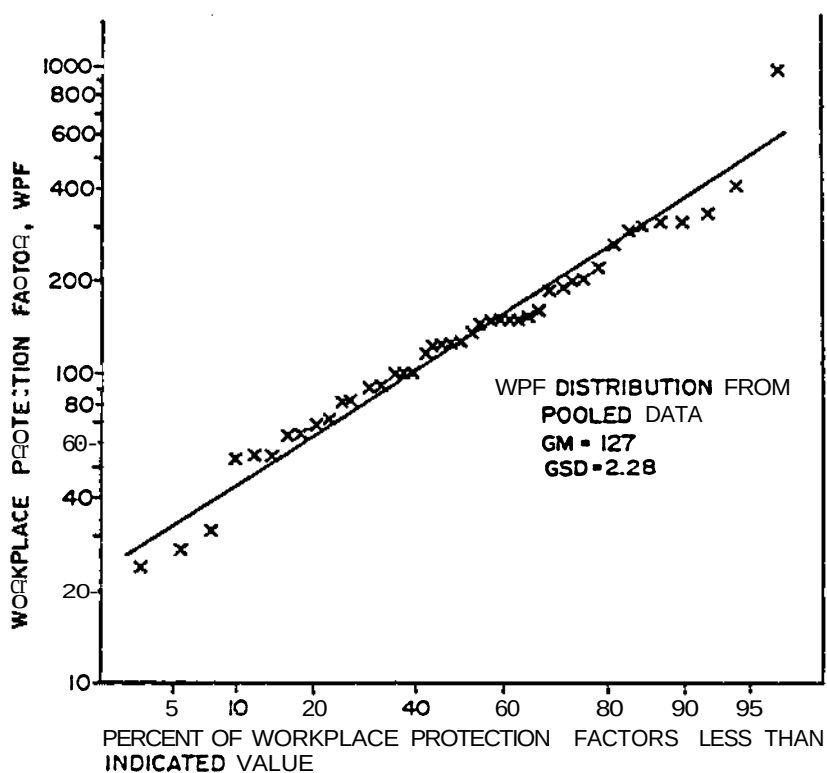


FIGURE 3. LOG PROBABILITY PLOT OF THE POOLED WORKPLACE PROTECTION FACTOR DATA FOR THE RACAL AH5 AND 3M W-316 PAPRS.

Figure 3. Log probability plot of the pooled workplace protection factor data for the Racal AH5 and 3M W-316 PAPRs.