

DETERMINING AND VALIDATING THE ADEQUACY OF AIR-PURIFYING RESPIRATORS USED IN INDUSTRY

Part I—Evaluating the Performance of a Disposable Respirator for Protection Against Mercury Vapor

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Abstract

A prototype disposable air-purifying respirator designed for protection against mercury vapor was field-tested at a chlorine-producing plant. Seven employees wore the respirator for short periods of time, ranging from 10-30 minutes, while performing routine maintenance operations. While the subject wore the respirator, workplace protection factors were obtained by simultaneously sampling air inside the respirator and outside the respirator in the worker's breathing zone. A total of 26 workplace protection factors were calculated from the results, which ranged from 9-63 with a mean value of 30. A number of factors that need to be examined are raised by this study regarding the interpretation of workplace protection factors. The efficiency of the air-sampling train used to monitor contaminants inside the facepiece should be validated because of the high humidity and temperature of exhaled breath being sampled. Also, attempts to adjust workplace protection factors because of lung retention of the contaminant is difficult when sampling for vapors and gases and probably cannot be done with a single correction factor. There also appears to be the potential for contamination of the inside of a respirator facepiece if an employee has been exposed to a gas or vapor contaminant, prior to donning the respirator.

Introduction

In recent years Olin Corporation, along with other large industrial users of respirators, has increased the emphasis on the quality of its respiratory protection programs. This has typically included improving its training, medical monitoring, and fit-testing programs. Olin has also taken steps to validate the effectiveness of the respirators that their employees use, and to conduct research into ways of improving respirators. This includes deter-

mining the service life of air-purifying cartridges under representative temperature, humidity and concentration conditions which exist at its facilities, developing a novel respirator fit test, evaluating experimental respirator sorbents, and determining the actual protection afforded by respirators when worn by employees under normal working conditions.

Part I describes our efforts to conduct a study at a chlorine-producing facility to determine the performance of a prototype disposable mercury* respirator. Olin has a number of chlorine-producing facilities which use electrolytic cells containing mercury. Through the use of engineering controls, mercury exposure of production employees is kept below the OSHA Permissible Exposure Level of 100 micrograms per cubic meter. However, a number of employees who perform routine maintenance of the electrolytic cells need to intermittently wear respirators while performing certain operations. Respirators are typically worn for between 10-30 minutes at a time, two to four times a day.

OSHA, in its respirator regulations (1970), generally requires employers to furnish their workers with NIOSH/MSHA certified respirators.

NIOSH has no testing and certification schedule for approving respirators for protection against mercury exposure (1972). However, a number of respirator manufacturers sell either disposable or reusable respirators for protection against mercury.

Olin's employees use disposable air-purifying respirators when protection against mercury exposure is required. Employees prefer the lightweight feature of these devices for comfort and because they interfere less with certain required maintenance operations. Management prefers the disposable respirator since it eliminates concern over the daily decontamination of the respirator, if it were of a reusable design. Disposable respirators are discarded daily, regardless as to how often they are used during an eight-hour shift.

Materials and Methods

The purpose of this study was to document how well a prototype disposable respirator performed when worn by employees during routine maintenance operations. Employees indicated, through the use of questionnaires, that the addition of an exhalation valve and cotton adjustable headstraps would improve the comfort of their disposable respirators. Disposable mercury respirators were supplied by 3M modified with the addition of an exhalation valve and cotton adjustable headstraps. In addition, 3M inserted probes into the respirator which allowed air to be sampled from inside the facepiece.

Seven cell room maintenance employees volunteered to participate in this study. No special training was given to employees prior to testing. All volunteers received a single-size device and no fit testing was done, since there were no established procedures for fit testing this type of respirator at the time of this study. Testing occurred over a three-day period. Employees performed their normal scheduled maintenance activity. When they needed to don a respirator, they entered a supervisor's office adjacent to the electrolytic cell area, put on a probed respirator attached to an air-sampling train,

and proceeded to do their job. When the task was completed, they returned to the supervisor's office, the sampling train was shut off, and the respirator was taken off. Typical sampling times ranged from 10-30 minutes. Employees were observed wearing respirators for the entire sampling period.

The sampling train used was similar to that described by Rathje (1974) and is shown in Fig. 1. It consisted of a personal air-sampling pump run at 1-1.5 liters per minute with an SKC™ mercury adsorbent tube attached. Two identical sampling trains were used: one attached to the lapel of the worker outside the respirator, and one attached to the sampling probe used to measure mercury contamination inside the respirator. Sampling pumps were calibrated before and after each sample using a precision rotometer which had been calibrated by a soap film flowmeter. The adsorbent tube used to measure mercury inside the respirator was connected directly to the probe to minimize any possible loss of mercury prior to the tube. All tubes were analyzed by Olin's Environmental Hygiene Laboratory, an AIHA accredited industrial hygiene lab, using a modified Rathje procedure (1974).

Results

The results of 26 pairs of air samples taken inside and outside the respirator are displayed in Table 1. Workplace protection factors (WPFs), a

*The term mercury throughout the text refers to elemental mercury.

measure of the effectiveness of the respirator when worn by an employee during routine operations, were calculated two ways: corrected and uncorrected for lung retention. The following formulae were used in calculating the WPFs:

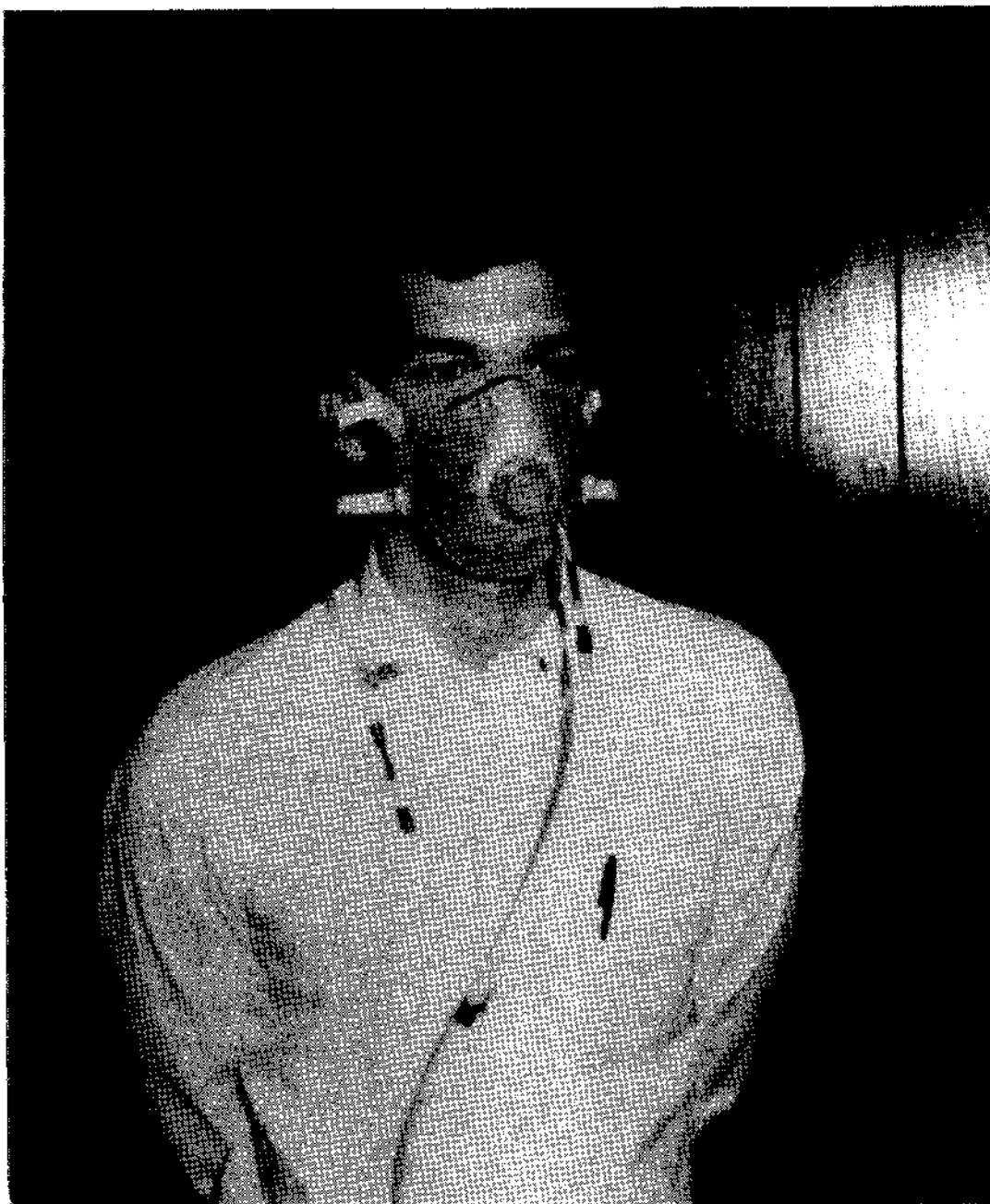


Fig. 1 —Test subject wearing probed respirator with sampling train.

WPF Uncorrected =

$$\frac{\text{Mercury Concentration Outside the Respirator (Co)}}{\text{Mercury Concentration Inside the Respirator (Ci)}}$$

$$\text{WPF Corrected} = (0.63) (\text{WPF Uncorrected})$$

The 63% correction formula is based on a 74% average mercury lung-retention value reported by

Hursh et al. (1976) and assumes an equal mix inside the facepiece between freshly inspired air and exhaled breath.

A probability plot of the data is displayed in Fig. 2. The plot indicates 95% of the WPFs are above 5. One disconcerting aspect of the data is the lack of any high WPFs (above 100). We expected our results to be geometrically distributed with both high and low WPFs. The lack of high WPFs

TABLE I
RESULTS OF RESPIRATOR FIELD TESTS

<u>EMPLOYEE</u>	<u>MERCURY CONCENTRATION IN UG/M³</u>		<u>WPF</u>	
	<u>OUTSIDE</u>	<u>INSIDE</u>	<u>UNCORRECTED</u>	<u>CORRECTED</u>
A	81.8	5.7	14.4	9.1
	168.9	7.9	21.4	13.5
	55.0	2.3	23.9	15.1
B	218.6	11.4	19.2	12.1
	147.9	4.8	30.8	19.4
	183.8	5.3	34.7	21.9
	316.5	5.4	58.6	36.9
C	136.9	16.0	8.6	5.4
	230.0	15.2	15.1	9.5
	170.8	5.7	30.0	18.9
	180.2	3.2	56.3	35.5
D	125.9	12.6	10.0	6.3
	178.5	7.8	22.9	14.4
	114.9	4.8	23.9	15.1
	146.6	5.3	27.7	17.5
E	142.5	4.9	29.1	18.3
	271.1	6.5	41.7	26.2
	281.2	6.8	41.4	26.0
	251.6	4.0	62.9	39.6
F	197.6	14.0	14.1	8.9
	78.8	2.0	39.4	24.8
	214.5	4.3	49.9	31.4
	1096.3	20.9	52.5	33.1
G	127.1	13.5	9.4	5.9
	99.2	8.5	11.7	7.4
	130.8	3.7	35.4	22.3
Total	Range: 55.0-1096.3	2.0-20.9	8.6-62.9	5.4-39.6
n = 26		Geometric mean =	25.8	16.2

*Based on a lung retention of 74% for elemental mercury

could be the result of either the limited performance characteristics of the respirator, a low-level contamination of mercury inside the respirator, or contamination of the air-sampling sorbent tubes. To examine the possibility of a contamination problem, the mercury concentration outside the respirator was plotted against the resultant workplace protection factor. The results are shown in Fig. 3. Regression analysis of the data indicates an increasing trend with a coefficient of correlation (r) of 0.55. This strongly suggests constant contamination of mercury inside the facepiece occurred during our testing.

One theory for having a constant low level of mercury inside the respirator is that employees working in low concentrations of mercury (10-60 micrograms per cubic meter), prior to donning the respirator, absorb a sufficient quantity of mercury to have a partial pressure of mercury in their lungs, resulting in a measurable quantity of mercury in their exhaled breath. To test this theory, we had three maintenance employees perform normal work in a mercury contaminated environment, which did not require the use of a respirator. After working for 30-60 minutes, the employees then entered a relatively clean environment, and donned

a probed respirator with the previously described mercury air-sampling train. Employees wore the respirator for 30 minutes and air was simultaneously sampled from inside the room. Results indicated 2-5 micrograms of mercury per cubic meter of air higher inside their respirators than would have been predicted had the respirators offered a protection factor of only ten.

The data obtained from the WPF study was then corrected for mercury in exhaled breath. When two micrograms of mercury per cubic meter of air (a conservative estimate based on results from the exhaled breath study) was subtracted from air sampled inside the respirator, substantially higher WPFs resulted. The range of WPFs corrected for exhaled breath went from 5-41 to 7-491, and the geometric mean of the WPFs from 16 to 28. Regression analysis indicated the relationship between mercury concentration outside the respirator and WPFs was nearly eliminated with a coefficient of correlation (r) of 0.14. A probability plot of WPFs corrected for both lung retention and exhaled mercury is shown in Fig. 4. The plot suggests that 95% of the workers who use this respirator should achieve WPFs above 5.

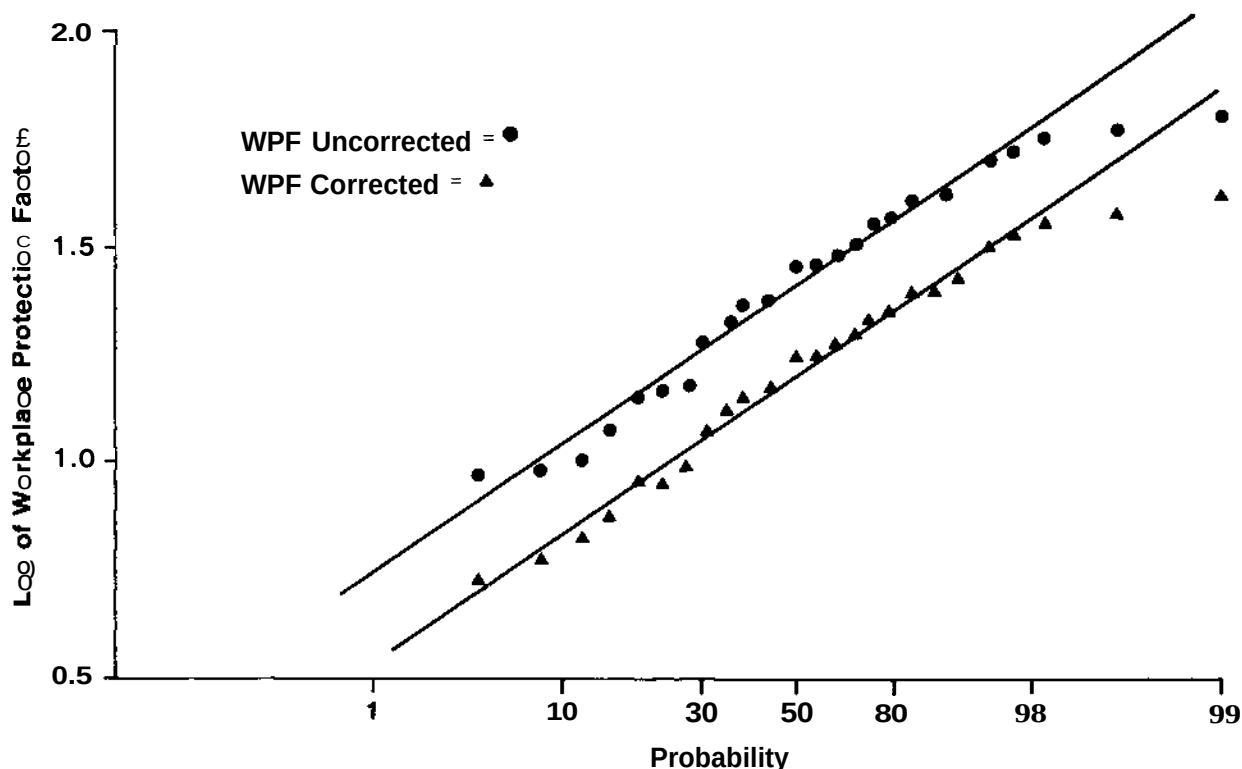


Fig. 2—Probability plot of workplace protection factors.

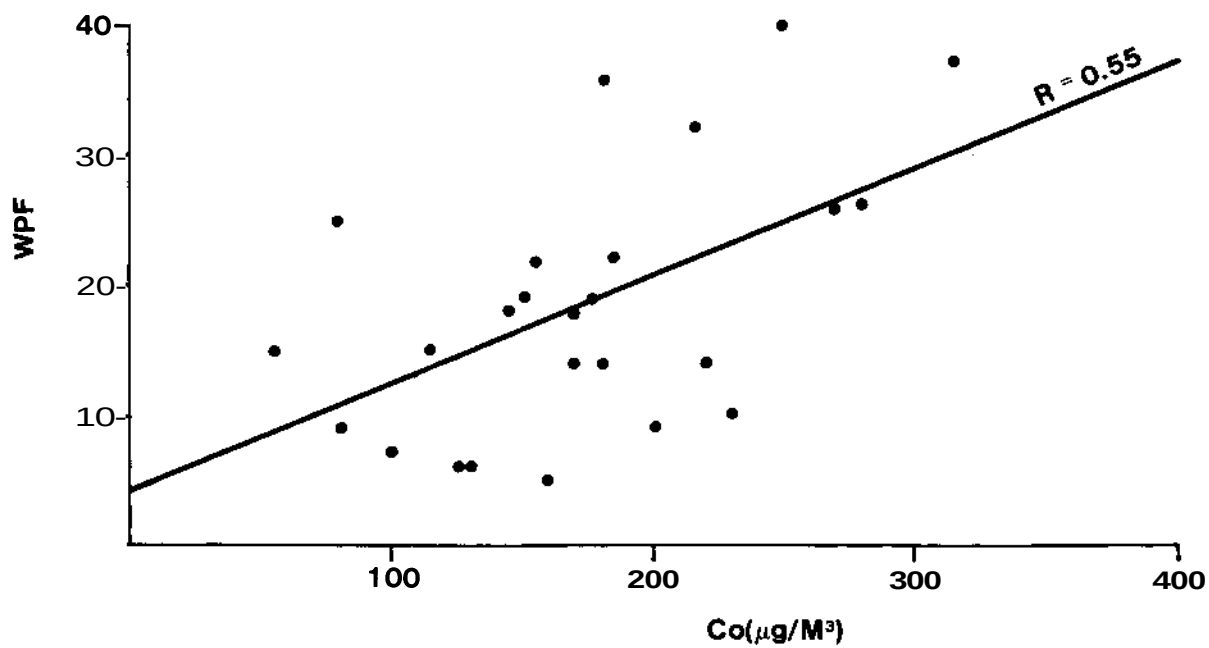


Fig. 3 —Plot of workplace protection factors vs. challenge concentration.

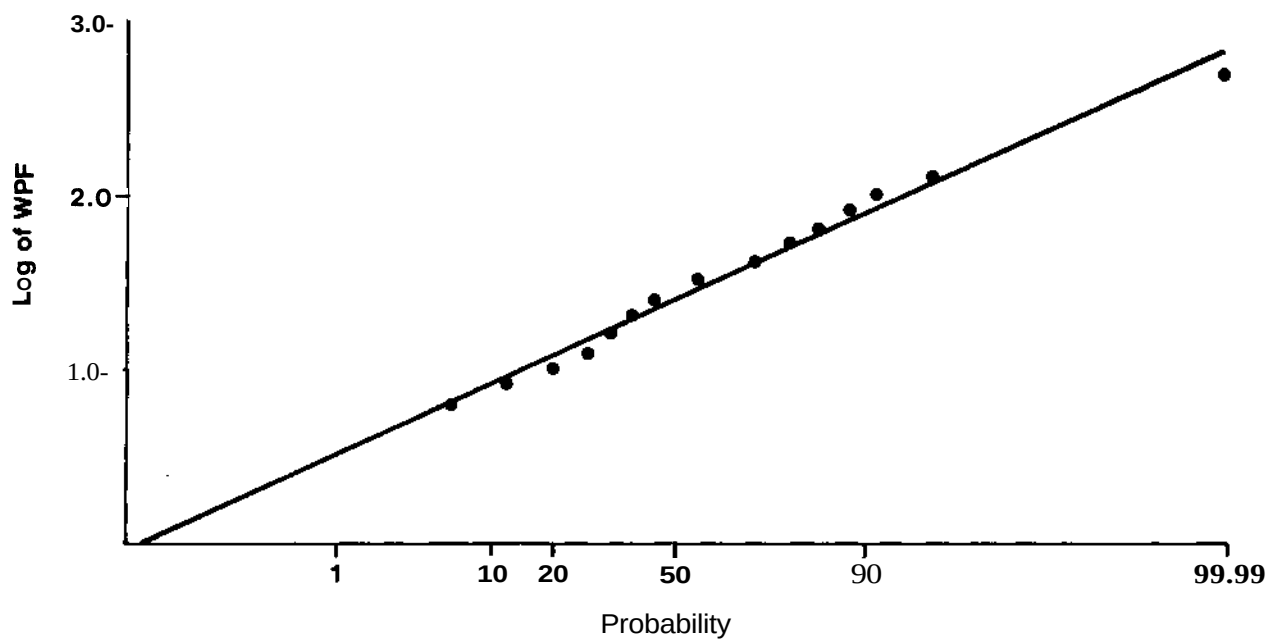


Fig. 4 —Probability plot of **WPFs** corrected for lung retention and exhaled mercury.

Discussion

A number of studies have been published which attempted to evaluate the performance of a respirator during normal usage in the work environment. Harris et al. (1974) examined the performance afforded by dust respirators used by coal miners. Effective protection factors (EPF), which are a combination of the efficiency of the device and how frequently it was used, ranged from 1-34. Smith et al. (1980) reported the results of a respirator study conducted with workers exposed to cadmium oxide. Effective protection factors ranged from 1-146 with a geometric mean of 6. Neither study described whether employees had been pre-screened using qualitative or quantitative fit tests. Also, it was difficult to distinguish in these studies between respirator performance and respirator usage, since air was always sampled from inside the respirators, whether it was worn on an employee's face or hung around his neck.

A study by Moore and Smith (1976) reported the results of workplace protection factors obtained from employees who were exposed to sulfur dioxide while working in a copper smelter. Mean protection factors for three different types of half-mask chemical cartridge respirators varied from 11-23. The authors noted a highly significant ($p < 0.001$) relationship and increasing trend between the concentration of sulfur dioxide outside the respirator and the resultant workplace protection factor. This relationship, like the one described in our study, may be due to the subject's inadvertent contamination of the inside of the facepiece caused by exhaling sulfur dioxide resulting from a prior exposure.

A recently published study by Que Hee and Lawrence (1983) examined the effective protection factor of respirators used by brass foundry employees exposed to lead. EPFs of 1 to >97 were recorded for employees using powered air-purifying respirators equipped with high-efficiency particulate filters. The authors attempted to relate resultant EPFs to facepiece leakage measured with a hot wire anemometer. One interesting aspect of the study was the results of multiple analyses for zinc, copper, and lead obtained from identical samples. In three of the six samples reported, the EPFs for exposure to zinc were significantly higher than the EPFs for copper or lead. This suggests that protection factors and facepiece leakage could be dependent upon the nature of the challenge test agent. The extent of contaminant influence on WPFs may limit the usefulness of interpreting the results from quantitative-fit-test data using a standard size and type of aerosol.

Most of the studies conducted to date have examined the effective protection factor of a respirator. Typically, very low values have been reported since this technique not only measures respirator performance but also respirator usage. None of the studies to date have seriously examined factors which can influence the measured effective or workplace protection factors. This study has focused solely on the performance of a respirator and not the usage which relates both to a specific work environment and the effectiveness of a respirator program. The major contribution of this study is in its attempt to discuss variables which influence both the performance of a respirator and the ability to accurately measure respirator performance.

It would be useful if large industrial employers would conduct workplace protection factor studies whenever their employees routinely rely on respirators for protection against a toxic contaminant. However, a number of questions surround the ability of these studies to accurately measure respirator performance. Standard air sampling trains used to monitor the work environment for a particular contaminant may have a far different efficiency when sampling inside a respirator facepiece worn by an employee. We noticed the sorbent tube attached to the respirator to frequently be saturated with water vapor coming from the exhaled breath of the test subject. The effect of this on the efficiency of the sampling train is unknown. Clearly, efforts to validate sampling trains used in these studies must be considered in the future. One possible solution would be to test the air sampling method in a laboratory by generating known concentrations of the contaminant under humidity (95%) and temperature (37°C) conditions which are similar to that found inside a respirator facepiece. Another possibility would be to remove the cartridge from a reusable respirator and have the test subject work in a lightly contaminated environment. Any difference between an air sample taken inside the facepiece and outside the respirator could result in a correction factor to be used when calculating workplace protection factors.

Another problem is how to correct properly for lung retention of a contaminant. Contaminants inside the respirator are constantly being scrubbed by the wearer's lungs. Attempting to correct this problem with a gaseous contaminant is very difficult. In our study, we used a correction factor based on a reported 74% retention of mercury in the lungs. The figure is dependent, however, on the partial pressure of the contaminant in the lungs. Consider an example where an employee is exposed

to mercury levels of 10 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) and then dons a respirator. If the respirator were to offer a protection factor of 10, a concentration of one $\mu\text{g}/\text{m}^3$ would be expected inside the facepiece. However, little or none of this would be absorbed by the lungs because of the partial pressure of mercury in the lungs which exists from the employee's exposure prior to donning the respirator. Clearly, no single correction factor can consider all the possibilities, and the correction factor used in this study was an oversimplification of the problem.

Another factor to consider when monitoring for a gas or vapor, is whether an employee exposure prior to wearing a respirator may result in exhaled air contaminating the inside of the respirator. This may be extremely critical when evaluating protection factors above 100. A correction factor of 2 $\mu\text{g}/\text{m}^3$ was subtracted from air sampling data obtained from inside the respirator to compensate for this problem in this study. This number appears conservative based on a limited study of the exhaled

breath of our maintenance workers which showed levels of 2-5 $\mu\text{g}/\text{m}^3$. However, no one correction factor can adequately take into consideration the varying conditions to which an employee was previously exposed. The exact correction factor needed is a function of the contaminant concentration to which an employee was exposed and the duration of the exposure. Also, the longer the sampling time, the smaller the effect of a prior exposure on the results.

One constant criticism of quantitative-fit tests is the artificial condition in which respirator performance is measured. However, even with workplace protection factor studies, the nature of the sampling equipment which must be worn by the test subject and the constant vigilance required by whomever conducts the study, makes these studies only a simulation of real work conditions. Therefore, a conservative approach should be taken in interpreting the results from these studies. This is especially true if subjects have been pre-screened or undergone special training prior to the study,

Conclusions

The air-purifying respirator tested in this study appears to offer excellent protection for employees exposed to mercury concentrations up to 500 micrograms per cubic meter. Typical cell maintenance work for chlorine producing plants does not appear to exceed the level based on this study. When results are corrected both for lung retention of mercury as well as mercury contamination caused from a prior exposure, workplace protection factors ranged from 7-567 with a geometric mean of 41.

A number of problems must be addressed and solved if accurate estimates of respirator per-

formance based on workplace protection factors are to be made. Methods to validate the air-sampling train used to sample air from inside the respirator need to be explored. Also, the affects of lung retention and exhalation of previously breathed contaminants must be more accurately defined for particulates, gases and vapors. Ultimately, obtaining workplace protection factors must be made relatively simple and inexpensive to encourage many companies to examine how well the respirators worn by their employees are working.

Acknowledgments

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References

- Bureau of Mines (1972), "Respiratory Protective Devices Tests for Permissibility," *30 Code of Federal Regulations*, Part 11.
- Harris, H. E., W. C. DeSieghardt, W. A. Burgess, and P. C. Reist (1974), "Respirator Usage and Effectiveness in Bituminous Coal Mining Operations," *Am. Ind. Hyg. Assoc.* 35:159-164.
- Hursh, J. B., T. W. Clarkson, M. G. Cherian, J. J. Vostal, and R. V. Mallie (1976), "Clearance of Mercury Vapor Inhaled by Human Subjects," *Arch. Environ. Health*, 31:302.
- Hyatt, E. C. (1976), *Respirator Protection Factors*, Los Alamos National Laboratory, Los Alamos, NM, LA-6084-MS.
- Moore, D. E. and T. J. Smith (1976), "Measurement of Protection Factors of Chemical Cartridge, Half-Mask Respirators Under Working Conditions in a Copper Smelter," *Am. Ind. Hyg. Assoc. J.*, 37:453-458.
- Occupational Safety and Health Administration (1970), "Respirator Regulations": *29 Code of Federal Regulations*, Part 1910.134.
- Que Hee, S. S. and P. Lawrence (1983) "Inhalation Exposure of Lead in Brass Foundry Workers: The Evaluation of the Effectiveness of a Powered Air-Purifying Respirator and Engineering Controls," *Am. Ind. Hyg. Assoc. J.*, 44:746-751.
- Rathje, A. D., and D. C. Marcero (1974), "Improved Hopcalite Procedure for the Determination of Mercury Vapor in Air by Flameless Atomic Absorption," *Am. Ind. Hyg. Assoc. J.*, 35:571-580.
- Revoir, W. H. (1974), "Respirators for Protection against Cotton Dust," *Am. Ind. Hyg. Assoc. J.*, 35:503-510.