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RESPIRATORS:

HOW WELL DO THEY REALLY PROTECT?

By

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INTRODUCTION

We have learned how well respirators perform in the laboratory, but do we know how well they really protect the wearer from long exposures during routine shift work or from short exposures during maintenance or intermittent jobs? During the past 20 years, many investigators in several countries have reported results of laboratory quantitative fit tests and performance procedures for all types of respirators, including air-purifying respirators, supplied-air respirators, and self-contained breathing apparatus (SCBA). More than 50 years ago, Bloomfield and Greenberg¹ investigated the efficiency of continuous flow supplied-air helmets during laboratory sandblasting in a chamber using quantitative measurements of the silica dust leakage into the wearer's breathing zone.

Advances in respirator technology have provided new laboratory data indicating that it is possible and feasible to provide very high levels of respiratory protection with positive pressure atmosphere-supplying respirators if they are used and maintained properly. Pressure-demand SCBA and supplied-air respirators provide the highest overall protection levels with fit factors of 10,000 and higher. These levels have been verified and documented by investigators in the last 20 years with laboratory tests.

Investigators generally agree that any respiratory protective device operated with a negative pressure in the facepiece during inhalation provides a low level of protection when compared to positive pressure devices. Although several laboratory quantitative fit test studies with negative pressure respirators have reported moderately high protection factors, these are, in fact, laboratory fit factors. These results may be the basis for the OSHA proposed rule making published in February, 1983, when they asked for comments on the use of respirators and engineering controls for air contaminants. The notice stated that OSHA's policy (requiring feasible engineering controls) has been criticized as being too inflexible, not cost-effective, and often unnecessary for health protection. This prompted my choice of the title of this paper. Some illustrations and examples will help answer

the question "How well do respirators really protect the wearer at work?" I believe that, except in non-routine or emergency situations, respirators simply cannot protect workers as well as properly designed and operated engineering controls.

BACKGROUND

Although respiratory protective devices are probably the oldest method of controlling occupational diseases, health and safety professionals, including Industrial Hygienists are sometimes less informed about their applications and limitations than about any other particular field in health and safety.

In 1947 Brandt² made an important point. He stated that "Respiratory protective devices have a distinct place in the field of industrial health engineering. That they are a last line of defense can hardly be denied. Nevertheless, where they should be used, how they should be selected, and how they should be used and maintained is understood adequately by only a small number of industrial hygiene engineers. Owing to a relatively low cost as compared to most other control methods, and the fact that they can be employed on shorter notice than most other control measures, they are very much misused." I believe this problem still exists in the 1980's: Respiratory protective devices in industry are often improperly selected, used, and maintained.

The many new and unusual occupational diseases resulting from industrial processes in the atomic and space ages have created a demand for respirators with a high degree of protection against specific contaminants. However, the state of development of these devices exceeds the state of their selection and use by health and safety professionals and by wearers of the devices. In fact, our knowledge of their performance under known exposure situations is better than the use we make of them.

I believe the guidance in the Respiratory Protective Devices Manual³, published in 1963 by AIHA and ACGIH, relating to the control of airborne contaminants is one that still applies today. The manual states that "in the control of those occupational diseases caused by breathing air contaminated with harmful dusts, fumes, mists, gases, or vapors, the primary objective should be to prevent the air from becoming contaminated. This is accomplished, as far as possible, by accepted engineering control measures; However, although one may wish to be idealistic in applying these procedures, there will always be circumstances in which, for one reason or another, the procedures will be uneconomical, inapplicable, impractical, or ineffective. Protective respirators will be needed for these situations, either as a primary means or as an adjunct or supplement to other primary control measures."

SUPPLIED-AIR RESPIRATORS

The very high level of protection provided by continuous supplied-air helmets during sandblasting was reported by Bloomfield and Greenberg in 1933. During actual sandblasting in a laboratory chamber, they collected silica dust samples from the breathing zone of the blasters inside the hood and from the challenge concentration of silica dust outside the hood at air flow rates to the hood ranging from 0 to 6 cfm. At an air flow of 6 cfm during sandblasting at three levels of dustiness, they reported leakages into the helmet ranging from 0.03 to 0.08%, a protection factor range from 1,250 to 2,000 (See Table I). This test was adopted and used by the Bureau of Mines in Schedule 19⁴ for the approval of Type CE abrasive blasting helmets.

Forty-five years after the first study, Douglas⁵ at Los Alamos measured the efficiency of approved abrasive blasting helmets using a DOP challenge atmosphere. Douglas reported PF's of 10,000 when at least 6 cfm of air was supplied to the helmet. Hoods 2A and 3 indicated PF's below 10,000 when operated at the recommended minimum air pressure approved that produced air flows of 119 and 91 lpm. When Douglas obtained minimum air flows below 170 lpm and PF's below 10,000, he adjusted the air flow upward toward the required minimum 170 lpm and repeated the test. For hood 2A the adjusted air flow of 166 lpm gave average PF's from 500 to 4,000. The adjusted air flow of 161 lpm for Hood B gave protection factors on three subjects of 10,000 (See Table II).

Such high levels of protection verified and reported in the open literature should have assured us that sandblasters would not develop silicosis during the period since the Bureau of Mines approved the first abrasive blasting helmet in 1938, assuming the helmets were used in the approved manner. Unfortunately, this is not the situation. There are hundreds of silicosis cases among sandblasters in the United States today. In 1978, for example, Weill⁶ et al at Tulane University Medical School reported more than 130 cases of silicosis in Louisiana. They found that with an average exposure to free silica of ten years, sandblasters developed silicosis and suffered a mortality rate of approximately 25%. The British data⁷ of 1936 indicated that sandblasters had an average employment duration of 10.3 years before death from silicosis.

NIOSH has sponsored studies to determine the level of respiratory protection provided during abrasive blasting in various operations at many U.S. locations. In 1974 Blair⁸ reported the results of his representative study of the abrasive blasting industry in the United States from 1971 through 1973 (See Table III). Blair reported protection factors ranging from 10 to 3,750 when Bureau of Mines approved abrasive blasting hoods or helmets were used. The mean PF's obtained with the six approved hoods tested ranged from 49 to

980. Hoods 2B and 4 used full facepieces under hoods or helmets which were firmly attached to the facepiece. Blair noted the maximum PF of 3,750 was obtained when the air flow to the hood was 18 cfm (500 lpm). The maximum PF's do not always occur at 18 cfm in hoods. Blair concluded that the remarkable range is due to the condition or misuse of equipment rather than to any particular brand superiority.

Studies of the efficiency of abrasive blasting hoods made in two New Orleans fabrication yards by Tulane University investigators⁹ indicated a low level of protection. They reported that well-maintained and properly worn approved abrasive blasting hoods 1A and 3 offered fair protection during blasting. The sandblasters, they found, were exposed to an average level of silica dust several times greater than the permissible level of the threshold limit value (TLV). Protection levels were generally low and dust levels were high because the sandblasters were wearing worn out and defective hoods, operations were faulty or careless, and silica dust was being transmitted from adjacent blasting sites during nonblasting periods when the sandblasters were unhooded.

In the third NIOSH-sponsored study, an A.D. Little¹⁰ report published in 1974 indicated that state-of-the-art protective equipment generally does not provide the degree of protection required for complete security of the worker during sandblasting. The A.D. Little investigators found that in most cases the respiratory protective equipment, as available, is badly maintained and frequently abused by the operator himself.

Unfortunately, the three NIOSH-sponsored studies verified the use of worn out and defective hoods, the faulty or careless use of approved abrasive blasting helmets, and in many cases, an improper selection of respirators such as the use of half-mask dust respirators with or without unapproved, non-air-fed ricochet hoods, which results in overexposure of the user. It is worth noting that Blair concluded in his study that the average sandblaster depends on the local protective equipment salespersons for advice on selection, fit, use, maintenance, and all aspects of respiratory protection. In other words, the sales person is the consultant. I will further address this point later.

SELF-CONTAINED BREATHING APPARATUS

Several investigators¹¹⁻¹⁴ have measured the level of protection provided by both pressure-demand and demand SCBA in the laboratory. The results show the demand negative pressure SCBA generally provides less protection than that provided by positive pressure type. In several reported cases, firemen have been overexposed while wearing demand SCBA during industrial and residential fires; These overexposures have resulted in hospitalization and some fatalities. One study¹⁵ published in 1969 determined the level of protection provided

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by demand SCBA and carbon monoxide gas masks used during exposures from staged fires in a Quonset Hut. The International Association of Fire Fighters sponsored a project conducted with volunteers from the Denver Fire Department to determine the effectiveness of the demand SCBA and CO gas masks used then during fire fighting. The level of protection provided by these devices during use was estimated by measuring the blood levels of carboxy hemoglobin (COHB) at various intervals after exposure to the fires. During the six stated fires, 72 firemen were exposed; of these 24 wore demand SCBA, 24 wore gas masks, and 24 wore no masks; Exposure time for those wearing no masks was 5 to 8 minutes; for those wearing SCBA and gas masks it was 20 to 25 minutes (See Table iv).

Normal COHB levels are frequently less than 4%. A level of 10% or higher is taken to be evidence of carbon monoxide intoxication in cases involving industrial workers. A heavy cigarette smoker who inhales will often exhibit a COHB level of 6 to 8%. The authors of this study reported maximum COHB levels in ranges from 0 to 4%, 5 to 9%, 10 to 14%, and up to 40% in increments of 5%. Of the 24 firemen wearing the demand SCBA, 2 had COHB levels from 10 to 14%, 5 had levels from 5 to 9%, while 17 had levels from 0 to 4%. Of the 24 wearing gas masks, 4 had COHB levels greater than 10%. Of the 24 wearing no masks, 21 had COHB levels greater than 10%. The authors concluded that the abnormal COHB levels developed by those wearing masks is best explained by the use of faulty equipment. I believe the main fault was probably leakage around the full facepiece.

In the United States, most fire departments now use pressure-demand SCBA or other devices that maintain a positive pressure in the facepiece at all times. Thus any overexposures with pressure-demand SCBA were probably from poor maintenance, lack of training or improper use by the wearer, poor quality control, or poor design by the manufacturer of the SCBA. Some fatal exposures reported in this country were probably caused by one of these problems. NIOSH has required manufacturers to correct deficiencies. However, in some fire departments and in industry, improper use and poor maintenance continue to affect the level of protection provided by pressure-demand SCBA).

AIR-PURIFYING RESPIRATORS

PERFORMANCE EVALUATION BY BIO-ASSAY

In a few operations with contaminants, the performance of respirators during actual use can be determined by bio-assay, and the unintentional exposures may be estimated, but only after the exposure has been received. Reliable bio-assay methods exist for lead, carbon monoxide, and radioactive materials such as plutonium, uranium, and tritium. Bio-assay procedures can include analysis of blood, urine, feces, and breath. I believe the following examples show how well

respirators protect against these contaminants.

Lead Exposures

Workmen using flame cutting torches on lead-painted steel during the demolition of the Boston elevated train structure were provided with negative pressure air-purifying respirators approved by the Bureau of Mines for protection against lead fumes. Tabershaw¹⁶ et al reported in 1943 that many of the men exposed to lead fumes during torch cutting had absorbed excessive amounts of lead as evidenced by analysis of lead in urine samples. They concluded that the approved lead fume respirator did not provide adequate protection and suggested that air-line respirators be used. In the absence of other information such as particle size and concentration of the lead fume, the most logical explanation for the lack of protection, is that the negative pressure air-purifying respirators weren't able to provide a good facefit or that they weren't properly donned.

An inquiry into how half-mask particulate respirators fit faces was reported by Thompson¹⁷ et al during exposure to lead dust and fumes in an Australian smelter in 1961. Three months after the new and modern plant began production, it became evident to the medical officer that better respiratory protection was necessary. In the fourth month approximately 24 of the men directly concerned with lead production had reached a level of lead absorption approaching the maximum accepted level. Either these men were not wearing the respirators, or the respirators were not fitted adequately. Hughes¹⁸ of the Division of Occupational Health helped the safety officers to conduct fitting tests on the respirators being used and on several other types. This fitting study revealed that a large percentage of the men were not obtaining a satisfactory fit as determined with the isoamyl acetate fitting test. According to follow-up bio-assay samples, the properly fitted respirators provided good protections.

Radioactive Exposures

One of the first instances when workers wearing respirators were overexposed to radioactive contaminants followed the NRX reactor accident at the Chalk River Atomic Installation in Canada in 1952. Overexposures were estimated by bio-assay. The investigation reported by White and Tait¹⁹ indicated the main reason the masks did not provide adequate protection during use was that the wearers had not worn their masks properly. The solution was to appoint a full-time respirator officer who periodically checked every employee who always kept his respirator near his work station to determine if he knew how to wear the mask properly and how to obtain a satisfactory fit.

Atomic Energy establishments where some workers may be

exposed to plutonium during maintenance or transfer operations provide workers with high-efficiency full-facepiece filter respirators for protection. During regular work the workers are protected by extensive engineering controls, primarily glove boxes used for all plutonium work. During the period that workers use respirators, air samples are collected. The level of protection is indicated by bio-assay of urine samples collected after the operation is completed. Bio-assay results of Los Alamos workers using high-efficiency full-facepiece filter respirators, since individual fitting was started in 1956, indicate that the workers have been well protected. The Los Alamos respirator program incorporated both drills and training in proper use as well as proper fitting with an appropriate respirator.

PERFORMANCE EVALUATION DURING ACTUAL USE

Several methods of measuring respirator efficiency in actual working conditions have been reported. All of these field methods involve measuring both the ambient contaminant concentration challenging the workers and the contaminant concentrations in the breathing zone inside the facepiece, hood, or helmet. In 1968 Los Alamos and New Mexico Health Department Investigators²⁰ reported the efficiency of dust respirators worn by trained uranium miners, who were observed to ensure proper donning technique. The respirator wearer was equipped with two personal samplers mounted on his belt; one leading to the label sampler used to measure the ambient radon daughter concentration and the other to the probe on the facepiece, which measures the concentration in the user's breathing zone. By equipping the half-mask or quarter-mask respirator with wool or fume filters, we obtained average respirator efficiencies ranging from 88 to 98 during a 5-minute to 1-hour sampling period against exposures to selected high radon daughters concentrations (See Table v).

There were 26 man tests made with English wool batt filter media mounted in holders on 2 brands of U.S.A. half-mask facepieces. The respirator efficiency ranged from 93 to 99%, equivalent to a PF range of 15 to 100. A quarter-mask facepiece equipped with the same English Wool batt filter medium showed approximately the same results. We had found during filter efficiency measurements, with four brands of English wool batt media from England and Australia, that all were approximately 99% + efficient against radon daughters. The U.S. fume filter media was equally good and did not degrade or lose efficiency in the high humidity in the uranium mines, generally over 90% relative humidity.

In the early 1970's NIOSH sponsored two studies to measure respirator efficiency under actual working conditions in coal mines and during paint spray operations. The study of dust respirator efficiency in coal mines was reported by Harris²¹ in 1974. The Harris method used to measure efficiency consisted

of collecting respirable dust samples from the facepiece and challenge concentration samples from the miner's lapel. The respirable dust sample was collected continuously both while the respirator was worn and when it was removed for short periods of time (See Table VI). Using this method, Harris reported that the mean average effective protection factor obtained for six types of approved dust respirators worn for the entire shift was 4.0 and ranged from 3.8 to 4.6. Harris also collected some 10-minute samples when the respirator was worn continuously and reported his mean average true protection factor was 9.3 and ranged from 9.0 to 11.4 on five types of dust respirators commonly used in the coal mines.

The NIOSH study on the efficiency of respirators worn during paint spray operations consisted of collecting simultaneous samples to measure two concentrations, solvent vapor and particulate, in both the facepiece and the challenge concentration. Toney²² reported that, in general, the only time he measured protection factors greater than 10, was when approved half-mask spray paint respirators in good condition were used and when the painter had been properly trained and fitted before painting. For example, the average protection factor under these conditions was 6.4 for solvents and 24 for aerosols. However, for all air purifying respirators (approved and unapproved) the average protection factor was 4.8 for solvents and 8.3 for aerosols. He accredited most of the low protection factors he measured to improper employee training, incorrect use of equipment, and poor maintenance.

In 1973 Revoir²³ measured the efficiency of three types of disposable, valveless dust respirators for protection against cotton dust. He reported protection factors ranging from 5 to 20 on these respirators and claimed good correlation with his laboratory coal dust quantitative fit tests. Approved single-use dust respirator B shows 5 persons of 5 tested obtaining a PF of 20 (See Table VII).

CONCLUSIONS AND RECOMMENDATIONS

Some respirators do not protect workers well because of improper selection, incorrect use, and poor maintenance. I believe most respirators used in small plants are selected by purchasing agents or operators after consultation with local respirator suppliers or, sometimes, with the manufacturer. This method of selection increases the responsibility of suppliers, salespersons, and plant employees and suggests the need for improved training. I know of one major manufacturer who has periodically trained all its field salespersons for over 25 years and also conducted periodic regional respirator training courses for users before NIOSH and AIHA initiated their formal training courses for users a few years ago. Thus, the small plant still depends on suppliers for advice on selection and use of respirators. Several US manufacturers sell their respirators through safety equipment supplies. Some

of them belong to the Safety Equipment Distributors Association, which put on 3-day training courses for salespersons at several locations from 1979 to 1981. Besides the obvious concern about the variable quality of advice from sellers, we should be concerned about employers who may not be living up to their responsibilities of implementing a quality respiratory protection program.

We also need more professional or technical industrial hygiene guidance at plant sites. Federal and State health and safety agencies provide some consultation service, but more is needed, especially on the selection, use, and maintenance of respirators. Manufacturers, for example, should provide more adequate information on use and limitations to accompany the respirators they sell.

Practicing industrial hygienist should observe several precautions to obtain better respirator protection. For example, respirator fit factors determined in the laboratory are not equivalent to the level of protection afforded in the workplace, even when a good respirator program (per ANSI Z88.2-1980) is in use. Human factors affect the level of protection. I recommend that we apply a minimum safety factor of 10 to protection factors measured in the laboratory. For example, if the laboratory protection factor achieved by a worker during a quantitative fit test is 1000 for a full-facepiece respirator, we should allow the worker to wear it for protection up to only 100 times TLV. This is generally consistent with our experience at Los Alamos, and the Protection Factor Guidance which I recommended for full facepiece masks in 1971.

Industrial Hygienists also should recognize that the following factors are important and necessary:

- o Proper Respirator Selection
- o Improved training for users and supervisors
- o Increased surveillance or audit of respirator use
- o Proper maintenance and storage of respirators
- o Increased management support

SUMMARY

When a pressure-demand SCBA is properly used and maintained by well-trained wearers, it provides a very high level of protection for emergency and other use. This also applies to pressure-demand supplied-air respirators. However, if future field tests indicate poor maintenance and improper use, as the three NIOSH studies in the early 1970's found common for continuous flow supplied-air abrasive blasting hoods, we must recognize that the level of protection will be much lower than predicted.

The very limited field tests of air-purifying respirator

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performance in the workplace show that respirators may perform far less well under actual use conditions than is indicated by laboratory fit factors. We are not yet able to predict the level of protection accurately; it will vary from person to person, and it may also vary from one use to the next for the same individual. In contrast, we can predict the effectiveness of engineering controls, and we can monitor their performance with commercially available state-of-the-art devices.

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Table I. Evaluation of sand-blasting helmet at 6 cfm under normal working conditions (Bloomfield and Greenberg, 1933).

Concentration		% Leakage	PF
in room air ^a	inside helmet ^a		
4,000	3.1	0.08	1250
3,000	1.0	0.03	3333
1,000	0.5	0.05	2000

^aMillions of particles per cubic foot.

Table II. Los Alamos abrasive blasting hood tests.

B of Type	M Approved CE Hood	Test Flow Rate ^a (L/Min)		PF Range Thousands
		Min.	Adjust ^b Max.	
	1B	118	350	10 +
	2A	119		0.3 - 4
			116	0.5 - 4
			234	8 - 10
	3	91		1 - 10
			161	10 +
			225	10 +
	5	192		10 +
			316	10 +
	6	167	350	10 +

^aMin recommended = 170 LPM (6 cfm).
Max recommended = 354 LPM.

^bIf min. below 170 LPM and PF < 10,000, airflow adjusted upward toward 170 LPM and hood was retested.

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Table III. Results of NIOSH-sponsored studies of respiratory protection used during abrasive blasting (1974 report by Blair).

Type	B of M Approved CE Hood	Protection Factors In Field		
		# Tests	Range	Mean
1A		2	75-94	85
1B		8	10-3750	980
2A		5	12-275	104
2 ^a		7	10-1096	264
3		2	13-85	49
4 ^a		2	16-360	188

^aHood over full facepiece type.

Table IV. Results of 6 staged fires with Denver fire department volunteers.

COH ₂ Max. %	Demand SCBA	CO Gas Mask	No Mask
0 to 4	17	12	0
5 to 9	5	8	3
10 to 14	2	3	7
15 to 19	0	1	8
20 to 39	0	0	6
No. Exposures	24	24	24
Exposure Time, Min.	20 to 25	20 to 25	5 to 8

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Table V. Results^a of field man tests^b in five N. M. uranium mines with dust respirators.

Facepiece Type	Type Filter	No. Tests	Respirator Deficiency (%)	
			Range	Average
1/2	E Wool	18	93-99	98
1/2	E Wool	8	94-99	96
1/4	E Wool	16	95-99	96
1/4	E Wool	20	92-98	96
1/2	Fume	6	93-98	96
1/4	Dust	3	80-92	88

^a1967 Joint study by LASL and N. M. health department.

^bTime tested ranged from 5 to 50 minutes.

Table VI. NIOSH field study of dust respirators performance used in coal mines.

	Mean Average of 6 Respirators	Mean Average All Respirators
Effective PF	3.8 to 4.6	4.0
True PF	9.0 to 11.4	9.3

Table VII. Performance of three single-use dust respirators, each worn in cotton textile plant by five workers (1973 study by Revoir).

Respirator	Number Obtaining PF of	
	20	10
A	0/5	4/5
B	5/5	5/5
C	3/5	5/5