

The Lawrence Livermore Test

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The recently published revision of the OSHA respiratory protection standard, 29 CFR 134, has left the issue of assigned protection factors (APF) for different classes of respirators to a separate rulemaking. During the interim period, OSHA still uses the APFs developed by NIOSH in the Respirator Decision Logic (RDL) (NIOSH 1987). In general, there are three types of studies which develop the APFs. These are: quantitative fit testing (QNFT), workplace protection factor (WPF) study, and simulated workplace protection factor (SWPF) study.

Before NIOSH published the RDL, the protection factors (PF) developed by Edwin Hyatt of the Los Alamos Scientific Laboratory (LASL) had been used by OSHA in substance specific standards such as lead, arsenic and benzene (Hyatt, 1976). The APFs developed by Hyatt were based on quantitative fit testing performed on an anthropometric test panel having facial characteristics that are representative of the U.S. work population. The LASL QNFT study was performed with a submicrometer aerosol so that the challenge would penetrate through the face seal. To ensure that the filter leakage was minimal, only high-efficiency particulate air (HEPA) filters were selected for testing air-purifying respirators. Since the filtering facepiece had no HEPA filter media available, the PF for this class of respirators was not included in the Los Alamos study.

In the early eighties, a respirator user registered a complaint to NIOSH regarding the performance of a tight fitting powered air-purifying respirator (PAPR). NIOSH conducted a workplace study to determine the performance of this device (Myers and Peach, 1983). The study indicated that the PAPR did not achieve an APF of 1,000 as indicated in the OSHA standards. NIOSH has conducted additional workplace protection factor studies on negative pressure half-mask respirators, tight fitting, and helmet type PAPRs (Lerhart and Campbell, 1984, Myers *et al.*, 1984 a and b).

The results of these WPF studies indicated that these PAPRs did not achieve an APF of 1,000. Based on the results of these studies, NIOSH assigned tight fitting and loose fitting PAPRs with assigned protection factors of 50 and 25, respectively. Since the certification testing air flow rate of PAPRs is the same as those of continuous flow supplied air respirators (CFSAR) with the same type of inlet covering, NIOSH assigns these SARs the same protection factors as the PAPRs having the same type of inlet covering. These values have been listed in the NIOSH RDL. Since NIOSH has not conducted workplace studies for other types of respirators, the Hyatt APFs have been used to assign protection factors for other types of respirators listed in the RDL. However, one WPF study conducted in an aluminum smelter indicated that the loose fitting helmet type PAPR can achieve a WPF of 275, which is much higher than the NIOSH assigned WPF of 25 (Graboury and Burd, 1993).

The American National Standards Institute Z88.2 Subcommittee was also involved in developing assigned protection factors for various classes of respirators (ANSI 1992). The Z88.2 Subcommittee set a preference for using the workplace protection factors (WPF) obtained from workplace studies to assign protection factors for respirators. The Subcommittee used the same NIOSH studies to develop APFs for half-mask PAPRs, half-mask continuous flow SARs, and the half-mask pressure demand (PD) SAR. However, a higher APF of 100 was assigned to the negative pressure full facepiece respirator in the absence of any WPF study.

Based on the preference of some Subcommittee members, the Z88.2 Subcommittee raised the APF to 1,000 for the full facepiece PAPR and full facepiece CFSAR. However, the only WPF study conducted on the full facepiece PAPR (Myers and Peach, 1983) found a much lower WPF of around 50. The Z88.2 Subcommittee created a new category of loose fitting

PAPR, which is the helmet type PAPR selected by NIOSH and OSHA in their respirator performance studies. This type of PAPR is classified as the loose fitting facepiece PAPR, and an APF of 25 was assigned to this class of PAPRs. Without any supporting WPF data, the ANSI Z88.2 Subcommittee assigned the loose fitting hood and helmet in the PAPR and CFSAR with the same configurations an APF of 1000.

When NIOSH was conducting workplace protection factor (WPF) studies to assign protection factors for respirators, the technical staff of the Occupational Safety and Health Administration believed that, in order to assign protection factors for different types of respirators, the tests should be performed under the same test conditions for a better correlation. Since respirators are often used under stressful working conditions, such as high temperature, high humidity, and heavy work rate, the test conditions should reflect real use situations. The controlled environmental chamber study would be the method of choice to evaluate the respirator performance.

Since all respirators are evaluated under the same test conditions, correlation of protection factors among different classes of respirators is likely. The first OSHA sponsored SWPF study was conducted by the Los Alamos National Laboratory (LANL) (Skaggs *et al.*, 1988). The respirators selected for testing including a half-mask and a full facepiece negative pressure respirators, two helmet type PAPRs, a half-mask PAPR, a helmet type CFSAR, and a PDSAR. The temperature varied between 0°C and 32°C, and the relative humidity varied between 0% and 85% in the environmental test chamber.

The test subjects performed exercises involving stepping, moving oiled gravel between two bins, pounding nails in an overhead position, moving and laying cinder blocks, and pounding a board with a sledge hammer. Each exercise lasted five minutes and the test subject took a five minute break between exercises. The simulated workplace protection factor (SWPF) was measured on each test subject at combinations of different temperature and humidity.

OSHA has sponsored another controlled environmental chamber study to determine the effect of beard growth, air flow, and work rate on the performance of one tight fitting and two loose fitting helmet type inlet covering PAPRs. This study was conducted by the Lawrence Livermore National Laboratory (LLNL) (da Roza *et al.*, 1986). The MSHA/NIOSH certification test air flow requirements are 115

and 170 liters per minute (1pm) for the tight and loose fitting inlet coverings, respectively. The air flow has been increased from 170 to 198 1pm for the tight fitting PAPR, and the air flow has been increased from 170 to 280 1pm for the helmet type loose fitting facepiece PAPR. The test was performed while test subjects walked on a treadmill. The work rate was gradually increased until it reached 80% of the test subject's cardiac reserve. The SWPF for each test subject was measured at different air flow rates. The SWPF was also measured when the test subject was clean shaven, with a 3-day stubble, and with a full beard.

The APFs recommended by Hyatt, NIOSH, and the ANSI Z88.2 Subcommittee are listed in Table 1. The average SWPF for all test subjects in the LANL and the LLNL studies are also presented in Table 1. The SWPFs achieved by the test subjects in the LANL study indicate that the tested respirators can be separated into two distinctive groups. The negative pressure respirators and the helmet type loose fitting facepiece PAPRs have a SWPF around 3,000. The tight fitting PAPR and all SARs have SWPFs above 15,000, which is the value obtained by a positive pressure demand supplied air respirator. The test results confirm Hyatt's PF data that the half-mask PAPR should be classified as a positive pressure device, and it should have the same APF as the full facepiece PAPR. The environmental conditions degrade the performance of tight fitting negative pressure respirators. However, they have little effect on the loose fitting respirators and the tight fitting PAPR and SAR.

The test results of the LLNL study are shown on Table 2. The SWPFs were measured on clean shaven test subjects as they walked on a treadmill at 80% of their heart rate reserve, and under various air flow rates. The results indicate that under the heavy work rate, the tight fitting PAPR can only achieve a positive pressure when the air flow has been increased from the required 115 1pm to 170 1pm. The SWPF for the two helmet type loose fitting facepiece PAPRs is very low. It cannot maintain a positive pressure even when the air flow has been increased to 280 1pm. The LANL and LLNL test results also confirm the WPF findings that the helmet type loose fitting facepiece PAPRs should be assigned a much lower APF than the tight fitting PAPRs.

The LANL study indicates that the helmet type CFSAR can be classified as a positive pressure device with an APF of 1,000. In general, the hood and helmet are lumped together as a single class. How-

Table 1. Comparison of respirator protection factors.

Type of device	Hyatt	NIOSHRDL	ANSI Z88.2	LANL SWPF	LLNL SWPGF
Half-mask	10	10	10	2500	
Filtering facepiece	5	5	10		
Full facepiece	50	50	100	3300	
Loose fitting FF PAPR	1000	25	25	2300/3800	43/15
Hood/helmet PAPR	1000	25	1000		
Half-mask PAPR	1000	50	50	18000	2000
Full facepiece PAPR	1000	50	1000		
Half-mask CFSAR	1000	50	50		
Full facepiece CRSAR	2000	50	1000		
Hood/helmet PDSAR	2000	25	1000	15000	
Half-mask PDSAR	1000	1000	50		
Full facepiece PDSAR	2000	1000	1000	16000	

Table 2. Test results of the Lawrence Livermore PAPR study.

Air flow, lpm	Helmet #1	Helmet #2	Half-mask PAPR
86			1420
115	7	5	2670
144	12		2930
173	19	8	3150
201	88	11	
230	105		
259		20	
288		25	
Mean	43	15	2020

ever, regulatory agencies, such as OSHA and NIOSH have different definitions of hood and helmet (NIOSH 1995 and OSHA 1997).

NIOSH has defined facepiece or mouthpiece, and hood or helmet, in its respirator testing and approval regulations, 42 CFR 84. These definitions follow:

A hood or helmet is a respirator component which covers the wearer's head and neck, or head, neck, and shoulders, and is supplied with incoming respirable air for the wearer to breathe. It may include a head harness and connection for a breathing tube.

A facepiece or mouthpiece is a respirator component designed to provide a gas-tight or dust-tight fit with the face and may include headbands, valves, and connections for canisters, cartridges, filters, or respirable gas source.

OSHA has prescribed definitions for loose fitting inlet covering PAPRs in the standard for respiratory protection, 29 CFR 1910.134. These definitions follow:

Hood means a respiratory inlet covering that completely covers the head and neck and may also cover portions of the shoulders and torso.

Helmet means a rigid respiratory inlet covering that also provides head protection against impact and penetration.

Loose fitting facepiece means a respiratory inlet covering that is designed to form a partial seal with the face.

OSHA considers that a helmet is a device which provides head protection. However, NIOSH does not make any distinction between the hood and the helmet. Since NIOSH does not have a classification of the loose fitting facepiece PAPR, many loose fitting PAPRs with a welding attachment have been approved as a helmet. However, these devices only have a soft head covering and an elastic visor seal which contacts the face. The elastic seal does not form a tight seal around the face to minimize leakage. Other loose fitting inlet covering PAPRs of similar configuration, with or without a head covering, have been approved as full facepiece respirators.

The helmet type CFSAR which provided very high protection in the LANL study has a long shroud

that covers the shoulders and extends to the waist. Other approved hoods or helmets have shorter shroud lengths that can extend to either the upper arms, cover the shoulders, rest above the shoulders, or without any shroud. Under optimum air flow, the longer shroud would minimize air leakage around the seals of the loose fitting PAPR or SAR. One SWPF study of an abrasive blasting helmet type CFSAR conducted by LLNL indicated that the device can achieve a SWPF of 20,000 and retain positive pressure during the test. However, the manufacturer only specified a minimum air flow rate of 170 lpm for testing.

A properly designed helmet with a long shroud can achieve a SWPF at the detection limit of the measuring instrument, at the minimum required flow rate of 170 lpm. Since the helmet type loose fitting facepiece PAPRs do not maintain a tight seal around the visor, it provide very low protection in spite of a high air flow rate at 270 lpm. Also, the weight of the helmet reduces the stability during body movement and increases leakage. It appears that the best and the worst performing loose fitting inlet covering PAPRs and CFSARs have been identified by the simulated workplace protection factor testing. The performance of devices with other configurations would fall somewhat in and between this range. Based on this information, a regulatory agency may wish to classify the performance of hoods or helmets by shroud length. The longer shroud can be assigned a higher APF than a shorter one. But, it is very easy to increase the length of the shroud to meet the specification requirement without improving the protection of the device.

The performance of a loose fitting respirator is determined by a combination of interrelated factors, such as air flow rate, shroud length, and method of seal at potential leak sites. It cannot be classified by specifying some of these factors. PAPRs are positive pressure devices that will maintain a positive pressure inside the inlet covering under any work rate. If the PAPR is properly designed, it will provide positive pressure protection even when it is equipped with a short shroud and operated at the minimum air flow rate. The only method to assign a protection factor to a PAPR is to conduct performance testing. The WPF study is site specific and there is no control over the variables that exist at the workplace. The test results are not representative and cannot be applied to most workplaces. Since the test conditions of the simulated workplace study can be controlled, they can be set to the stringent test conditions that are representative of most

workplaces. The PAPRs test protocol developed by the Lawrence Livermore National Laboratory can determine whether a PAPR can maintain a positive pressure under any test conditions. It should be used

to assign the APF of the PAPRs. If a device passes the Lawrence Livermore test, an APF of 1,000 or higher can be assigned to this device.

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