Am. Ind. Hyg. Assoc. J. 49(4):199 204 (1988)

Facial Hair and Respirator Fit: A Review of the Literature

TERRENCE J. STOBBE[A], ROBERT A. daROZA[B] and MARGO A. WATKINS[C]

[A]Department of Industrial Engineering, West Virginia University, P.O. Box 6101, Morgantown, WV 26506; [B]Lawrence Livermore National Laboratory, L-386, P.O. Box 5505, Livermore, CA 94550; [C]Sandia Scientific Sales, 7801 Pioneer Trail, Albuquerque, NM 87109

The effect of facial hair on the quality of fit obtained while wearing a tight-fitting respirator has been and continues to be a controversial subject. Many people hold strong opinions on both sides of the issue, but it is not opinion that is needed. Rather what is needed is quantitative study of the situation to determine precisely what effect facial hair has on respirator fit. The results of fourteen studies of the facial hair leakage question have been summarized. All but two of the fourteen studies found that in the presence of facial hair, face seal leakage increases from 20 times to 1000 times. In addition both intersubject and interrespirator face seal leakage variability increased when facial hair was present. In the other two studies, one completed with positive pressure SCBAs and the other completed in the workplace, no statistically significant leakage differences were found.

Introduction

Respiratory protection has a single purpose: to reduce the wearer's exposure to airborne contaminants. One of the prime factors determining the effectiveness of the respirator is the seal between the edge of the respirator and the facial skin. Anything that interferes with this seal reduces the effectiveness of the respirator. Facial hair (beard, sideburns, mustache, goatee, stubble, *etc.*) is one item which breaks the face seal. The questions are how much leakage results from the face seal break, and does it materially affect the protection afforded by the respirator.

In our society, with its emphasis on personal freedom, these questions demand accurate and honest answers. These answers can come only from scientifically valid studies designed to evaluate the leakage question. A number of studies have been published, and the purpose of this paper is to summarize their results.

Concern over the fit and effectiveness of respirators probably dates to their original users 2000 years ago. Hounam[1] discusses some of these early papers which expressed concern about respirator fit, but a true evaluation of the fit question was dependent on the development of quantitative methods of measuring fit. Burgess[2] and Letts[3] developed the first quantitative fit testing (QNFT) methods. These early QNFT methods were somewhat crude, but they provided a basis for Hounam's[1] pioneering study of the effects of beard growth on negative pressure full-facepiece respirators. Since then there have been at least twelve studies of the problem, the results of which are readily available to the health and safety community. The results of these studies are summarized in Table I.

Table I is explained as follows. The column headings, author, year, respirator type or types tested, and challenge materials are self explanatory. The test equipment column describes the test environment (booth, room, workplace, *etc.*) and the analytical method used. The testing protocol column describes the test method used (*i.e.*, same group clean-shaven and then tested periodically while beards grew) to evaluate leakage. The fit adjust column indicates whether the fit test results were collected after using a pretest to ensure a good fit. The exercises or speech column indicates whether one or both were done during the data collection period. The number of subjects, facial hair description and time columns also are self-explanatory. The facial characteristics column shows whether facial scars, wrinkles, facial shape, denture condition, *etc.*, were considered in the selection of subjects. The leakage expression method column indicates how the results are stated (*i.e.*, challenge material concentration, percent leakage, or protection factor calculated as the outside to inside concentration ratio). The results column shows the relative leakage differential between subjects with and without facial hair. The last column, significance, shows whether or not the results were statistically tested to determine their significance.

Results and Discussion

Twelve studies that reported data during 1964–1987 were reviewed. Of these, six[1,4-8] studied negative pressure half-mask and/or full-face respirators; six[5,8-12] studied full-face supplied air respirators; one[13] studied half-mask disposable dust respirators; and one[14] studied aviator's oxygen masks. In some studies more than one type of respirator was examined. Twelve other studies[15-25] were reviewed that contained background material that was highly relevant to the topic but which did not report leakage data *per se*.

The challenge materials used in the studies were di-octylphthalate (used in six studies), sodium chloride aerosol (two studies), air (one study), argon (one study), corn oil (one study), sulfur hexafluoride (one study), polyethylene glycol (one study), dichlorodifluoromethane (one study), or workplace dust (one study). The air and argon were analyzed using a mass spectrometer. The corn oil, poly-

TABLE
Summary of Key Respirator Leakage

Author	Year	Respirator Types Tested	Challenge Material	Test Equipment	Testing Protocol	Fit Adjusted Before Data Collection	Exercises or Speech Used
Hounam[1]	1964	Full-face negative pressure	NaCl	Plastic hood, flame photometer	Test clean-shaven and then daily while beard grew up to 2 weeks	Yes	Not stated
Griffin[10]	1971	Full-face air-supplied	Argon	Plastic tent mass-spectrometer	Bearded persons were tested and then retested after shaving	Yes	Both
Hyatt[3][a]	1973	Half-mask and full-face, negative pressure	DOP NaCl	Chamber, light scattering and flame photometers	Test clean-shaven and then daily for 8 days while beard grew	Yes	Both
Stamperius[12]	1974	Full-face, air-supplied, demand	DOP	Small room, optical light scattering	Subjects had 3 or 4 trials/test—some tested both ways; some tested only clean-shaven or only bearded	Yes	Exercise on bicycle ergometers
deSteiguer[11]	1979	Aviator's O_2 mask	Normal air as contaminant in mask	Mass-spectrometer	Tested each subject twice with beard and twice after shaving	Yes	Both
Welch[7]	1979	Half-mask negative pressure	Not stated; DOP assumed	Dynatech-Frontier QFT Booth	Test clean-shaven and then 9 more times over next 41 days	Yes	Both
Jonsson[5]	1980	Half-mask and full-face negative pressure, full-face air-supplied	DOP	Plastic tent, light scattering aerosol photometer	Test clean-shaven and 8, 16, 24, 96 hr afterward; also tested 20 full beards	Yes	Both but only resting data reported
McGee[11]	1983	Full-face closed circuit pressure-demand	DOP	Dynatech-Frontier QFT Booth	Test clean-shaven and every 2 weeks for 8 weeks; 3 trials/test period	Yes	Both
Skretvedt[6]	1984	Half-mask and full-face negative pressure	DOP	Dynatech-Frontier QFT Booth	Large population of clean-shaven and bearded subjects tested separately	Yes	Both
Fergin[4,b]	1984	3 types of half-mask negative pressure disposable with and without adjustment straps	Workplace dust and alumina	Comparison of inside/outside respirator dust concentrations	Measured bearded and clean-shaven separately while both worked for 2 hr	No	Yes—as required by job
Bentley[9]	1984	SCBA open-circuit positive pressure	Sulfur hexafluoride (SF_6)	Analytical Instruments "Leakmeter"	Tested subject with 3-day beard growth	Yes	Exercise on treadmill, head movements and speech used
daRoza[8]	1986	SCBA open-circuit positive pressure	Polyethylene glycol aerosol, Freon	Chamber, forward-light scattering photometer, Miran® IA IR	Tested clean-shaven; daily for 1 week, weekly for 1 month, and at 2-month beard growth	Yes	Exercise on treadmill
daRoza[8]	1986	Ultra-twin, full-face piece, negative pressure	Polyethylene glycol aerosol	Chamber, forward-light scattering photometer	Tested clean-shaven; daily for 1 week, weekly for 1 month, and at 2-month beard growth	Yes	Exercise on treadmill

[a]S.S. = statistical significance.
[b]Hyatt also reported some unique facial characteristic data. He tested 12 people with full beards and 4 with Van Dykes and/or sideburns. For each person he reported
[c]Effect of beard growth on leakage significance ($P = 0.0001$).
[d]12 clean-shaven and 3 bearded were tested on 2 occasions. Total tested, 50 clean-shaven and 25 bearded.

tors in the Studies Reviewed

No. Subjects in Each Category	Facial Hair Description	Length of Time of Beard Growth	Facial Characteristics Considered	Method of Leakage Expression	Results	S.S.[A]
Same 7 tested clean-shaven and bearded	Stubble	0 to 14 days	Subjects with obvious scars not tested	% penetration	Mean % leakage day by day Day 0 1 2 3 4 5 9 % 0.001 0.5 2.5 4.0 1.5 4.5 10.0	N/A
12 tested before shaving; 10 retested after shaving	Full beard	15 to 30 days; 2 with permanent beards	Not stated	ppm of argon in exhaled air	Subject had 50 to 100 X's more leakage with beards	N/A
Same 4 people clean-shaven and bearded	Stubble to well established beards	0 to 8 days	Facial shapes categorized	% penetration	Data for full-facepiece only; Mean % leakage day by day Day 0 1 2 3 4 5 8 % 0.05 0.37 0.44 0.34 0.5 0.47 0.6	N/A
3 both ways; 2 beard only; 2 shaven only; 1 mustache only	Full beard	Permanent beard	Not stated	% leakage	Subjects had 100 to 1000 X's more leakage with beards	N/A
Same 4 people bearded and clean-shaven	Full beard	Stated as 2 to 10 cm of beard length	Not stated	Change in O_2 partial pressure	More leakage occurred with beards; test-retest variance higher with beards	N/A
1 person all tests	Not stated	0 to 41 days	Not stated	Protection factor	PF was 10 000 to start, 175 after 5 days, 10 after 10 days, and 10 at 41 days	N/A
31 clean-shaven and bearded; 20 beards only	Stubble to full beard	0 to 96 hr, and permanent beards	Not stated	% leakage	8 masks tested—considerable results variance from mask to mask; subjects went from mean leakage of less than 0.01 to 0.1% at start to 0.1 to 1% in 24 hr, to 10% in 96 hr; found increased leakage on old faces due to wrinkles	N/A
Same 8 tested clean-shaven and bearded	Full beard	0 to 8 weeks	Stated as within LASL normal range	Protection factor	Protection factor by week Week 0 2 4 6 8 PF 5k-20 450-20k 50-3k 22-2k 15-1k	Yes[C]
303 clean-shaven; 67 bearded	Full beard	Permanent beard	Not stated	Protection factor	Half-mask: Clean-shaven, Sample Size 188, Fit Factor Median 2950, Minimum 95, Maximum >10 000; Bearded, 54, 12, 12, 185 Full-facepiece: Clean-shaven, 115, >10 000, 95, >10 000; Bearded, 13, 30, 5, 75	N/A
38 clean-shaven; 12 bearded	Full beard	Permanent beard	Not stated	Protection factor	No significant difference between bearded and clean-shaven subjects; geometric mean protection factors for 3 respirators' tests varied as: Clean-shaven: Range 16 to 161, Median 25 Bearded: Range 16 to 183, Median 26	Yes
1	Not stated	3 days	Not stated	ppm leakage	Leakage varied from 0% to 1.2% depending on the respirator used and exercise done	N/A
10	Not stated	0 to 2 months	Not stated	% penetration	Percent penetration was not affected by beard growth	0.05
10	Not stated	0 to 2 months	Not stated	% penetration	Average of all subjects shows 90 X's more leakage with beards	N/A

ength, texture and average of the facial hair.

ethylene glycol aerosol and most of the DOP tests used a light scattering photometer. The sodium chloride was done with a flame photometer, the dichlorodifluoromethane with the Miran® 1A 1R (The Foxboro Company, Foxboro, Mass.), and the sulfur hexafluoride with an electron capture detector. Subjects were housed in a small booth or tent, in a small chamber, or in a room. These settings allowed for easy control of the external concentration of challenge material. The workplace dust was studied under real, on-the-job conditions, with the analysis being done gravimetrically.

The testing protocols were highly variable. In six studies[1,4,5,7,8,11] subjects were tested while clean-shaven and then retested at various intervals to determine the progressive effects of facial hair growth on leakage. In three studies[10,12,14] the protocol was reversed—subjects with varying degrees of beard growth were tested, they shaved, and then they were retested. In one study[8] bearded subjects were tested, then shaved and retested, and then periodically tested during the next two months. In these studies the subjects served as their own controls. In four studies[5,6,12,13] two separate groups were tested, one with facial hair and one without. In these studies the results could be due to differences between the groups as well as the effects of facial hair. In all but one study,[13] the protocol insured a good respirator fit by pretesting the subject's fit using qualitative or quantitative fit tests until a good fit was obtained and then collecting the leakage data. During data collection seven of the studies[4,6,7,9-11,13] used both test exercises (head movement, *etc.*) and speech to simulate actual use. One study[5] involved resting subjects only, one[12] involved vigorous exercise on a bicycle ergometer, and two[8,9] involved exercise on a treadmill.

The number of subjects tested varied from one to over three hundred. Facial hair condition varied from clean-shaven, to various degrees of stubble, to full beards several inches in length. Facial hair measurements were taken from one day to eight weeks after the clean-shaven measurements. In the case of established full beards, several months of growth may have been represented. Subjects with obvious scars were excluded in only one study.[1] Facial shape characteristics were classified in two studies.[4,11] Leakage results were expressed in terms of protection factor in four studies,[6,7,11,13] percent leakage (penetration) in five studies,[1,4,5,8,12] ppm leakage in two studies,[9,10] and partial pressure of oxygen in one study.[14] The statistical significance of the results was reported in only three studies.[8,11,13]

The results of the controlled studies were generally consistent, with all but one showing that the presence of facial hair produced leakage that was 50 to 1000 times greater than that found with clean-shaven persons. Leakage generally increased as the facial hair length increased, and fit variability was greater in the presence of a beard. In the one exception, a positive pressure respirator, no trends toward increased leakage with beard growth were found, and a statistical comparison of the bearded versus clean-shaven leakage measurements showed no significant difference in leakage.[8] Comparisons between studies are difficult because of protocol differences such as the length of time the beard grew between measurements, the choice of respirators tested and whether the same or different persons were used for the clean-shaven and bearded conditions. With these general factors in mind, the authors examined the results specific to a given respirator type in more detail.

Negative pressure, half-mask air purifying respirators provided the least protection. Studies that tested both full- and half-face units reported half-mask leakage as being two to five times greater than that found in negative pressure, air purifying full-face units.[4-6] The performance decrement associated with beard growth appeared to be about the same for both types of negative pressure respirators. What is perhaps more important is the fact that, for a given subject, the effect of a beard was highly variable from respirator to respirator. Similarly, for a given respirator, the facial hair effect was highly variable from subject to subject. For a given subject, respirator to respirator leakage varied by factors of four to ten, while for a given respirator the intersubject variability varied by factors of one to twenty and up. Similar patterns existed for both types of negative pressure respirators. The study by Jonnson[5] provides summary data showing the differential effects of beard growth (over a ninety-six hour period) from respirator to respirator. His graphs indicate that, for his test group, some respirators were more seriously affected by facial hair growth. He provided no individual data, thus the effects on individuals cannot be assessed.

A number of studies evaluated the effect of facial hair growth time on negative pressure respirator fit.[1,4,5,7,8,11] Clean-shaven people generally begin with 0.01% or less leakage; leakage increases rapidly during the first 2 or 3 days, stabilizes through day 5 or 6, increases again by day 8 or 9, and then appears to stabilize again. From this point forward, day to day variability is high but no worse than day 9. The leakage increases varied from 50 times to 1000 times greater between day 0 (clean-shaven) and day 9 of facial hair growth.

The use of full-face, negative pressure supplied-air respirators sometimes has been suggested as a solution to facial hair leakage, with the concept apparently being that the compressed air supply would overcome the face seal leakage. Three studies[5,11,12] addressed this question, and one other[14] dealt with supplied-air aviator's oxygen masks. These studies clearly demonstrated that negative pressure supplied-air respirators suffer from the same relative decrement in performance that was observed in the negative pressure respirators: leakage with facial hair was found to be greater by factors ranging from 20 to 1000. With respect to these respirators, two points should be noted: even with facial hair, full-face, air-supplied units generally provided more protection than negative pressure units; and beards may pose a greater hazard in the use of these units because these units typically are used in immediately dangerous to life or health (IDLH) situations where contaminant exposure may be fatal.

Two studies[8,9] addressed facial hair induced leakage during the use of positive pressure, full-face SCBAs. The study by Bentley[9] included only one subject with a three-day beard growth. The subject's facial dimensions (length and width) were such that they were not included in the range described by the 25-man fit panel used by the Los Alamos

National Laboratory (LANL) and the National Institute for Occupational Safety and Health (NIOSH). Facial length was exceptionally small, and the worst fit was obtained during the "look up/down" exercise. In spite of this, the subject had significant leakage on that one exercise with only one of the five facepieces tested. It is doubtful that the beard caused the leakage during the exercise, since the extent of the negative pressure within the mask was inconsistent with the differential pressure patterns typically caused by beards.

In the second study, daRoza[8] used both a gas and an aerosol in the evaluation. The measurements were made while subjects walked on a treadmill. The exercise, which was conducted at 80% of the subject's maximum heart rate (3.3 MPH on an 8% to 17% grade), produced breathing deep enough to cause very brief measureable negative pressure within the face mask (overbreathing). In spite of this, no facial hair growth trends related to leakage were observed, and no statistically significant difference in leakage between the with- and without-facial hair conditions was found.

The study by Fergin[13] is unique in that it was done in the workplace. Data were collected on 3 models of half-mask disposable dust respirators worn by workers doing their regular jobs for a 2-hr period. No premeasurement fit test was done, and the workers wore a single size of respirator. Sample analysis was gravimetric. Workplace protection factors were found to vary from 1 to 1041 when 75 measurements were made. Only 6 workers had protection factors below 5, and of these, 5 were clean-shaven. Overall, the results of this study found no statistically significant difference between the protection factors achieved by the bearded and clean-shaven workers.

While this result has not been explained, two possibilities have been suggested. The first is that the results simply reflect the inconsistency with which single-use respirators actually are worn and/or fit in a real workplace. Furthermore, this type of respirator is prone to face seal leakage around the nose. When this leakage is significant, the additional leakage caused by a beard may not be readily measureable. The second possibility is that the challenge aerosol (airborne aluminum smelter dust, in this case) is aerodynamically large compared to the typical laboratory challenge aerosol. The significance of the challenge aerosol's size distribution and its relevance in evaluating the effect of facial hair on respirator fit have not been fully evaluated.

Conclusions

The research reviewed for this paper leads to the following conclusions.

1. Negative Pressure Respirator. When a health hazard exists or is likely to exist, facial hair along or in the face seal area should not be permitted—*i.e.*, no beards.
2. Positive Pressure Respirator. For modern, full-facepiece positive pressure respirators, the answer remains ambiguous. Only two positive pressure studies were found, and their results were inconclusive. Unless future research proves that a positive pressure system overcomes the leakage effects of facial hair, prudent work practice dictates that facial hair should not be worn with positive pressure respirators.
3. Convenience Use of Respirators. There is no simple answer to the problem of respirator use when respirators are not required for job-related exposures but are requested by employees to control odors, tastes, *etc.*, associated with their workplace. Respirator use under these conditions will not increase the employee's exposure—the research cited herein suggests that even for an employee with a beard, respirators provide significant protection—but it may lead to sloppy respirator use practices or other administrative problems. The authors' opinion is that when a competent industrial hygiene evaluation has demonstrated that no health hazard exists or is likely to exist, the situation requires the exercise of professional judgment. Under these conditions respirator use with facial hair may pose a number of administrative problems and risks, the significance of which must be balanced carefully against the restrictions on personal freedom associated with a ban on facial hair. In any case, the conditions under which facial hair could be allowed are quite restrictive, and they presume that all other aspects of a complete respirator program will continue to be met. Training in particular is important because a bearded respirator user cannot safely enter an area where respirator use is required.

References

1. **Hounam, R.F., O.J. Morgan, D.T. O'Conner and R.J. Sherwood:** The Evaluation of Protection Provided by Respirators. *Ann. Occup. Hyg. 4*:353-363 (1964).
2. **Burgess, W.A., L. Silverman and F. Stein:** A New Technique for Evaluating Respirator Performance. *Am. Ind. Hyg. Assoc. J. 22*:422-429 (1961).
3. **Letts, H.J.R.:** The Limitations of Gas Masks as a Means of Protection against Occupational Hazards. *Design and Use of Respirators*, edited by C. Davies. Oxford: Pergamon Press, 1962.
4. **Hyatt, E.C., J.A. Pritchard, C.P. Richards and L.A. Geoffrion:** Effect of Facial Hair on Respirator Performance. *Am. Ind. Hyg. Assoc. J. 34*:135-142 (1973).
5. **Jonsson, P.G.:** *The Influence of Beard, Beard-Stubble, and Age Wrinkles on the Adjustment of Protective Masks* (Technical Report #W410). Umea, Sweden: Defense Research Council, Department 4, 1980.
6. **Skretvedt, O.T. and J.G. Loschiavo:** Effect of Facial Hair on the Face Seal of Negative Pressure Respirators. *Am. Ind. Hyg. Assoc. J. 63-66 (1984).*
7. **Welch, B.:** *Dynatech Fronteir Corporation In-House Study on the Effects of Facial Hair on Respiratory Protection Factors with Reference to 29 CFR 1910.136.* April 1979.
8. **daRoza, R.A., C.A. Cadena-Fix and J.E. Kramer:** *The Effect of Beard Growth on Respiratory Protection: SCBAs and Air Purifying Respirators under Simulated Work Conditions.* Lawrence Livermore National Laboratory, P.O. Box 5505, L-386, Livermore, CA 94550 (1986). Presented at the American Industrial Hygiene Conference. 1987.
9. **Bentley, R.A., G.J. Bostock, D.J. Longson and M.W. Roff:** Determination of the Quantitative Fit Factors of Various Types of Respiratory Protective Equipment. *J. International Society Respiratory Protection 2(4)*:313-337 (1984).

10. **Griffin, O.G. and D.J. Longson:** Influence of Facemask Design on Operational Performance. *Fire Command. September*:18–23 (1971).
11. **McGee, M.K. and R.K. Oestenstad:** Effect of the Growth of Facial Hair on Protection Factors for One Model of Closed-Circuit, Pressure-Demand, SCBA. *Am. Ind. Hyg. Assoc. J. 44*:480–484 (1983).
12. **Stamperius, P.C. and R.E.W. Husmann:** Effect of Facial Hair on Leakage of the Face Piece in Individuals Wearing Compressed Air Masks. *De Veiligheid. 50(12)*:499–502 (1974).
13. **Fergin, G.S.:** Respirator Evaluation for Carbon Setters with Beards. *Am. Ind. Hyg. Assoc. J. 45*:533–537 (1984).
14. **deSteiguer, D. and K.E. Hudson:** "The Influence of Beards on the Efficiency of Aviators' Oxygen Masks." Paper presented at the *Survival and Flight Equipment Symposium*. Las Vegas, Nevada, December 2–6, 1979.
15. **Brown, C.E.:** Respiratory Protective Devices. *J. Ind. Hyg. Toxicol. 19*:95 (1937).
16. **Davies, C.N.:** "Fibrous Filters for Dust and Smoke." In *Proceedings of the Ninth International Congress of Industrial Medicine*, edited by John Wright. Bristol, England: (1949).
17. **Eulenberg, P.:** Tightness of Protective Masks in Users with Beards or Long Whiskers. *Brandschultz Deutsche Feuerwehr Zeitung. 8*:238–245 (1975).
18. **U.S. Army, Aberdeen Proving Ground:** *Individual Respiratory Protection against Chemical and Biological Agents* (Report #84DDEL) by M. Goldberg. Edgewood Arsenal, 1966.
19. **Held, B.J.:** Facial Hair and Breathing Protection. *Int. Fire Chief. December*:24–28 (1980).
20. **Hyatt, E.C.:** Air Purifying Respirators for Protection against Airborne Radioactive Contaminants. *Health Phys. 9*:425–432 (1963).
21. **Naber, D.C.:** *Effects of Facial Hair in Oxygen Masks* (NADC-7221-CS). 1972.
22. **Persson, G.:** Alarming Figures. *Brandforsvar.* 5:41–42 (1971).
23. **Stojack, W.B. and P.B. Raven:** *Development of Quantitative Fit Testing Program for the Clark County Fire Department.* Clark County, Nevada, May 1982. [Technical Report].
24. **Warncke, C. and W. Schipke:** Investigations into the Sealing Effect of Face Masks. *Draeger Rev. 38*: (1976).
25. **White, J.M. and R.J. Beal:** The Measurement of Leakage of Respirators. *Am. Ind. Hyg. Assoc. J.* 27:239–242 (1966).

22 June 1987; Revised 11 February 1988