

Leakage Measurements on Wearers of Respiratory Protective Equipment with Facial Hair/Beards/Spectacles:

Summary of a Literature Search

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Abstract

The efficiency of certain types of facepiece relies to a large extent on the face-to-facepiece seal. On examination, the results of a literature search overwhelmingly concluded that facial hair and spectacle side arms have a detrimental effect on faceseal leakage. What also became clear was that the extent of the effect varies considerably and that the effect of beards and spectacles cannot be taken in isolation; other factors, such as fitting and movement must also be taken into account. It is assumed by some that the use of positive-pressure equipment will solve the problem, but the evidence suggests that this is not the case and that inward leakage still occurs. Comparisons between individual studies reviewed are difficult because of the differences in the test/measuring equipment used and the test subjects.

Introduction

A literature search has been carried out to obtain information on the effect of facial hair or spectacles on the faceseal leakage of respiratory protective equipment (RPE). The original remit was with particular reference to positive-pressure devices, but other types of RPE were often discussed in the literature, so a wider picture has been obtained. It is clear from the literature that

a number of factors affect faceseal leakage. Whilst the effect of facial hair/spectacles could be shown by some authors, it is difficult to isolate it from, or ignore, those other factors such as fitting of the mask; facial dimension and type of mask; movement of the wearer; and outward leakage, which all have an effect on the performance of the equipment. These points are discussed below.

Effect of Different Factors on Faceseal Leakage

Fitting

Balieu and Spindler (1978) conducted tests on 49 firemen wearing negative-demand compressed-air breathing apparatus and carrying out various exercises such as running, head movements, and talking. Each fireman fitted his own mask, and the inward leakage results taken immediately showed that 16 had "nominal protection factors" (NPF) below 2000. After visual inspection and readjustment, all the NPFs were above 2000, with one exception which was 1400. It was possible to identify several factors that contributed to the lower protection factors. The main ones were the wearing of beards or sideburns and extreme anthropometric measurements.

The firemen benefited from taking part in the tests in that they came to understand the problems. With training and experience, problems could be identified and in some cases solved.

Hounam et al. (1964) also found that initial fittings of full-facepiece respirators could be improved by careful fitting. Out of 113 respirators tested for penetration, many achieved better results after adjustment. For example, where 65% of tests gave protection factors of less than 1000 on the initial fitting, after adjustment this was reduced to 20%. These tests were carried out on clean-shaven men before the effect of beard growth was studied.

Luria and Dougherty (1984) noted that subjects wearing spectacles paid more attention to fitting and tightening the straps than they did when not wearing spectacles. Several types of spectacles were tested. These ranged from the type that are designed to fit completely inside the mask and do not have temple bars to ordinary spectacles with temple bars. He did not state whether this applied to bearded and/or clean-shaven subjects.

Warncke and Schipke (1976) conducted tests on six subjects, wearing full facemasks. The head straps were tightened by the subject according to "feel" for the first test and were tightened by an unbiased person to a defined tension for the second test, without removal of the mask. In all cases the leakage was higher when the straps were tightened by the subject and in two cases was "eliminated" when adjusted to the defined tension.

Facial Dimensions and Type of Mask

It is unlikely that one size and type of facepiece will adequately fit all wearers over the range of facial dimensions that might exist. Fernandes and Reid (1987) found when fit testing that women, Asians and men with unusual facial configurations (broken noses, scars, missing dentures, etc.) all gave low fit factors. Adley and Uhle (1970) noted a wide variation of protection for individual subjects (clean shaven, with and without spectacles) and identified small facial dimensions, narrow chins and short faces as being problem areas.

Balieu and Spindler (1978) measured the facial dimensions of subjects with poor initial fittings (of negative-pressure compressed-air breathing apparatus) that had improved during exercises. For those without facial hair it appeared that the explanation could be in the anthropometric data. They concluded that special attention should be paid to subjects with extreme anthropometric measurements, i.e., particular dimensions found for less than 10% of the population in general. Hounam et al. (1964) accepted that an adequate standard of protection could not be achieved for some people because the shape of their faces prevented a seal being obtained. These tests were carried out on negative-pressure full- and half-mask respirators.

Jonsson (1980) tested a panel of older people with five negative-pressure respirators. He found that the differences between men and women, and older men and younger men were considerable. Two of the masks were only available in one size and were too large for the women. For the older men individual differences and age wrinkles may have been reasons for the higher results as well as factors such as the wearing of dentures.

In some cases only one size will be available for one type of facepiece. It is therefore important to try different types of facepiece to obtain the best possible fit. The type of faceseal may also affect the faceseal leakage. Griffin and Longson (1971) found that a pneumatic seal gave much lower leakage figures than revert and plain seal full-face masks even when facial hair was present.

A statistical evaluation of inward leakage results on several types of full facepiece seal

carried out by Warncke and Schipke (1976), Engineers at Drägerwerk AG, Lübeck, found that a double edged seal gave the best results although a pneumatic seal was not included in this particular set of tests. Subjects were clean shaven and bearded and carried out exercises such as talking and climbing a ladder. Twelve subjects were tested and all gave inward leakage figures of less than 10.2 % except for one bearded subject who was above this level.

Movement

Balieu and Spindler (1978) found that in a few cases where initial fitting of the mask of a negative-demand compressed-air breathing apparatus was poor, improved fit was obtained during head movements for men both with and without facial hair. However, overall maximum protection factors were obtained with subjects standing at ease and inward leakage generally increased during exercises, partly due to increased breathing rate, partly due to mask slippage caused by sweating. Hyatt et al. (1973) found a temporary improvement when a subject moved his head up and down indicating that the respirator was working its way into the beard. The tests were carried out on half-mask and full-facepiece respirators.

Outward Leakage

Test data collected by Naber (1972) showed no conclusive evidence that beards or facial hair cause serious injury (such as breathing difficulties caused by hair segments becoming lodged in the mask valves) or fire when worn with oxygen masks, but did conclude that a potential hazard exists. Griffin and Longson (1971) carried out a series of experiments where hair cuttings were placed around the edges of a mask which was fitted to a dummy head. When a controlled leak of oxygen around the faceseal exceeded 0.25 l/min both the hair cuttings and mask rim could be ignited using a glowing splint.

McGee and Oestensstad (1983) discussed the effect on the service time (effective duration) of positive-pressure equipment due to outward leakage caused by beard growth. They surmised that the service time would be reduced but did not take any measurements to confirm this. Stamperius (1976) carried out tests on compressed-air breathing apparatus with a positive-pressure

facility and noted that a higher consumption of air accompanied increased protection in the positive-pressure situation due to escape of air via leakage sites. All the test subjects had large beards.

Facial Hair

It is generally accepted by most authors that anything which passes between the sealing edge of a facepiece and the face will have a detrimental effect on the faceseal leakage. From the 24 references obtained (all of which refer to work carried out on wearers with facial hair or spectacles) only two claimed that facial hair had no effect. Fergin (1984) studied several types of filtering facepieces worn by carbon setters in a prebake aluminium reduction plant. Seventy-five tests were carried out on 38 nonbearded and 22 bearded workers using gravimetric sampling. A statistical comparison of respirator performance showed that protection factors were not significantly different for bearded or non-bearded workers in that particular working environment. The range of protection factors was 1-1041 for non-bearded and 4391 for bearded workers. The statistical analysis gave a respirator efficiency of 97.3% for non-bearded and 97.4% for bearded. Da Roza et al. (1990) concluded that facial hair has little effect on faceseal leakage into a powered half mask as long as the flow rate is high enough. In addition, no effect was seen on helmet type powered respirators. This was thought to be because the face-to-facepiece seal is so poor that the effect of the addition of a beard cannot be detected. However da Roza's tests on a powered half mask on the same subjects and with the subject working at 80% of his maximum showed that the NIOSH required flow rate of 113 l/min (4 cfm) could not cope with peak inhalations and that positive pressure was only maintained for 50% of the time.

In most cases the presence of facial hair could be shown to have a detrimental effect on faceseal leakage. Griffin and Longson (1972) reported an overall average faceseal leakage of 237 ppm for clean-shaven to over 7000 ppm for bearded subjects when tested wearing a full facemask and inhaling from a lung-governed oxygen supply, i.e., bearded subjects experienced approximately 30 times the inward leakage of clean-shaven subjects. Tests carried out by de Steiguer and Hudson (1979) on aviators' oxygen masks showed that the presence of beards had a detrimental effect on the mask efficiency, which was influenced by type and

length of beard, type of mask, and the level of exercise. Jonsson (1980) reported a tendency for inward leakage to increase with increasing stubble growth. Tests were carried out on 31 subjects and 8 different types of half mask and full facemask. Ninety percent of tests on 20 full bearded subjects gave penetration results of above 10%. Even with positive-pressure equipment over half were above this level.

A literature search carried out by Stobbe et al. (1988) on facial hair and respirator fit, concluded that for negative pressure respirators facial hair in the seal area should not be permitted. He found only two positive-pressure studies and found their results inconclusive. Held (1980) and Evans and Leinster (1984) point out the reasons for not using respirators when wearing beards. Both conclude that in atmospheres immediately dangerous to life or health, beards or facial hair should not be worn, but that in other circumstances common sense must prevail and adequate training, etc., must be provided.

Other hazards caused by beards have also been found by Hyatt et al. (1973) where in tests a two-inch Van Dyke beard blocked the operation of the inhalation valves holding them closed. It is also possible for beards to hold exhalation valves open, allowing leakage during inhalation. As stated by

Skretvedt and Loschiavo (1984), a beard also accumulates moisture, oils, and debris and is a dynamically changing thing, length and orientation changing daily. Even if an adequate fit can be obtained one day it may be different the next and this coupled with the fit variability from donning to donning will probably mean that an individual will not receive the required protection.

Spectacles

All the work carried out to assess the effect of spectacles on faceseal leakage arrived at the same conclusion. Reed and Moore (1985), Luria and Dougherty (1984), Hounam et al. (1964), Adley and Uhle (1970), and Hyatt (1963) all found that facemasks with specially designed spectacles that fitted completely inside the mask or had very thin, flat temple bars could give leakage figures that were similar to results obtained when no spectacles were worn. (It should be noted that spectacles which fit entirely within the mask would not normally be expected to affect the face seal). Anything else would result in some leakage, and in one case with ordinary spectacle frames Luria and Dougherty (1984) recorded a 100% leakage. These tests were carried out on the full facemask from an oxygen breathing apparatus.

Positive Pressure

Nine positive-pressure studies were found. Five studied the effect of facial hair, two studied the effect of spectacles, one studied both effects, and the last used an artificial leak created by a piece of tubing to simulate a poor faceseal. The studies are summarised in Table 1. All observed that whilst positive pressure was an improvement over negative pressure, leakage could still be detected when beards or spectacles were worn.

Stamperius et al. (1974, 1976), in tests conducted on compressed-air breathing apparatus, found that beards could cause a hundred to a thousand times greater leakage. Adley and Uhle

(1970) and McGee and Oestenstad (1983) also reported similar results on self-contained breathing apparatus. The latest study conducted by da Roza et al. (1990) on subjects who were tested clean shaven, then with three days' stubble and then with a two month beard growth found that so called "positive-pressure respirators" could not maintain positive pressure at higher work rates and that the difference in the performance of, for example, a half mask and a helmet is so great that they should be in different categories when assigning protection factors and that true "positive pressure" is a myth.

Table 1 Summary of studies of inward leakage measured on positive pressure equipment on wearers with facial hair spectacles.

REFERENCE	TEST AGENT	TYPE OF RPE/BA	EQUIPMENT	FLOW RATE OF TEST AGENT & CONC.	SAMPLE FROM MASK	TYPE OF TEST ENCLOSURE	OTHER	EXERCISES
Adley & Uhle 1970	FREON 12	Self-contained compressed air breathing apparatus (SCCABA)	Davis Halide Meter	3 cfm 100% FREON	1/8" OD S Steel Tube	Wood (Blouse Type)	Exhaled air piped away to stop dilution of test cloud	Yes
Reed & Moore 1985	DEHS	Positive pressure (4) & negative pressure (5)	Los Alamos 691 Photometer	Aerosol 4 cfm. Flow rate into chamber 100 cfm 25 mg/m ³ ± 5	Latex sample line to probe in breathing zone	16 m ³ chamber	Chamber conc. was diluted by exhaled air from powered air purifying respirator	Yes
Lurie & Dougherty 1983	Helium	Oxygen BA	Perkin Elmer Medical gas analyser model 1100	4% Helium	Sample port flush with visor	Hood (close fitting)	Inhale and exhale to ambient	Not stated
McGee & Oesterstad 1983	DOP	Closed circuit self-contained BA	Dynatech frontier (FE 2594) high aerosol flow rate DOP test instrument (generator/photometer)	20 mg/m ³	Flush with inner mask 4.5 l/min	Booth 1.83 x 1.22 x 2.29 m		Yes
Stamperius & Husmann 1974	DOP	CABA Compressed air BA (CABA)	Optical light scattering photometer	185 mg/m ³		1.5 x 1.0 x 2 m chamber	Great care taken with donning — made to measure straps. In valve opened at 20–30 mm wk mask pressure	Yes
da Roza et al. 1990	PEG 400	Half mask Helmet A Helmet B	Forward light scattering photometer		Sample taken from near upper lip of subjects	Large fit test chamber		Yes
Stamperius 1976	DOP	Compressed air BA. Neg. pressure with pos. pressure facility	Optical light scattering photometer	185 mg/m ³		3 m ³ chamber	Leak measured in positive mode 1st then negative	Yes
Dahlback & Novak 1983	SF ₆	Positive pressure BA with full face mask	Electron capture device	10% SF ₆ in air		Hood	Exhaled air exhausted. Sample during inhalation only to bladder. Artificial leak created with tube under face seal	Yes
Jonsson 1960	DOP	2 Halfmasks 5 Fullmasks 2 Positive pressure full masks	Sinclair Phoenix aerosol photometer	115 l/min 100 mg/m ³	20 l/min	Tent 0.75 m diameter	Test panel inexperienced as test subjects	No

Table 1 (cont.)

TOTAL NO. OF SUBJECTS	CLEAN SHAVEN	BEARD	GLASSES	NO GLASSES	RESULTS/CONCLUSIONS
9	9	0	9	9	Range of protection of self-contained BA can be wide protection factor (PF) 500 with glasses, 29,000 without
Phase I 25 II 10	0	0	25 UNMOD 10 MOD	25 UNMOD 10 MOD	Glasses used were specially designed with very thin straps PI (control) 166 Quantitative fit test on SCBA 3 PF under 10,000 2 with specs, 1 without 54 Quantitative fit test on PAPR 2 PF under 10,000 (could show possible reasons for all low PF, e.g., low flow rate, facial contours, etc.) PII 71 Quantitative fit test on SCBA, 20 on PAPR— all above 10,000 (PI 1 result showed decrease in cylinder life when wearing specs)
8	4	4	8 5 types of glasses	8	No specs, clean shaven 1%, bearded 1.35%. 1 type of frame gave 100% leakage, next highest was 1.5% clean shaven, 27% bearded. Type of mask, comfort and facial dimensions have an effect and how the mask is fitted subjects took more care fitting mask when specs were worn
8	8 (plus control)	8 at 2 wks 4) growth 6) 8)	0	8	Protection factor decreased as time went on - best case 20,000 -> 852 worst 20,000 -> 31. Beard growth had a profound adverse effect on the protection afforded by 1 type of CC SC BA. It is possible that it would cause a similar result in other types
8	2+3	5 (3 then shaved) 1 moustache only	0	8	Those with beards had higher leakage. When shaved inward leakage was reduced e.g., Subject 1 $1-4.9\% \rightarrow 6 \times 10^{-4}$ Subject 2 $0.94-4.1 \rightarrow 3.3 \times 10^{-2}$ (Beards 100-1,000 x greater leakage) Subject 3 $0.25-3.6 \rightarrow 1.2-7.8 \times 10^{-2}$
6	6	6 at 3 days & 2/3 months	0	6	Half mask — Inward leakage (IL) remained OK with decrease in flow or increase in work rate while shaven — Inward leakage (IL) increased with stubble and beard at lower flow rates For both helmets IL increased with decrease in flow and increase in workrate. Stubble or beard may not affect protection factor of half mask if flow is high enough. It will affect helmets but this will depend on type of seal— some are so bad that beard effect will not be detected. Helmet A (increased work rate) 10^{-4} to 0.1%. Helmet B 10^{-6} to 0.01% — tend same with stubble/beard. Helmets should not be regarded as positive pressure respirators. Positive pressure respirators are a myth.
6	0	6 (larger than average)	0	6	60% of positive pressure measurements were less than 0.001%, in 25% it was just possible to observe the leakage i.e., 0.001%. Highest was 0.017%. In negative pressure mode leakage up to 5.5% were measured, lowest 0.036%. Negative → positive can increase protection factor by a factor of 1,000 but is accompanied by a higher consumption of air
2	2	0	0	2	When a positive pressure was maintained inside the mask no leakage was detected even with tube inserted (i.e., less than 0.0001%). At 300W work (exhaustion) inhalation was 450 l/min (peak) created a negative pressure of 1k Pa and a leakage above 0.3 ppm was detected (above measuring range). (At 300 l/min leakage could be detected (above 0.3 ppm.) (Without leak but with negative pressure — no leak sometimes, probably because of heavy facial sweating)
Stubble 31 Beards 20	31 0	31 at 8, 24, 48, 96 hours growth 20	0 0	31 20	Tests varied considerably. Some masks were affected by 8 hrs stubble, others unaffected by 1-2 days stubble. Overall tendency is for penetration to increase as stubble grows. With positive pressure tendency is same but deterioration is slower. For bearded wearers 90% had penetration above 10%. For positive pressure 50% were above 10%.

Conclusion

It is unlikely that faceseal leakage can be attributed only to one factor but will be a combination of two or more. For example, movement of the head, particularly nodding, may create a leak but the extent of the leak will depend on facial dimensions, how well the facepiece fits or was fitted, etc. Facial hair or spectacle side arms will undoubtedly affect the faceseal efficiency but to what degree will depend on the wearer, the type of mask, the work situation, and the airborne contaminant. The use of positive-pressure equipment may in some circumstances solve the problem, but it would be dangerous to be lulled into a false sense of security. The dangers of inward leakage may still be present under certain circumstances; for example, at high breathing rates positive pressure is not always maintained.

The conclusions reached in the information obtained from the literature search overwhelmingly support the view that facial hair will have a detrimental effect on the faceseal efficiency. Comparisons between individual studies are

difficult because of the range of test aerosols, detection equipment, equipment type, and test subjects. None of the papers give enough detail of the test method used to assess its accuracy, suitability, or the relationship to methods of test currently employed by CEN (Comite Europeen de Normalisation) standards.

The present Health and Safety Executive (HSE) guidance (1990) on facial hair, i.e., that it is not compatible with respiratory protective equipment that relies on a faceseal is confirmed by this literature search. Whether or not some types of loose-fitting hoods should be considered adequate substitutes may be a matter for further work or a better definition of the term "loose fitting hoods."

Wearers of breathing apparatus should be made aware of the possibility, even with "positive-pressure" equipment, of the facepiece pressure going negative in certain circumstances and of the factors that could exacerbate the situation, e.g., facial hair or spectacle side arms.

References

- Adley F E, and Uhle R J, "Protection Factors of Self-Contained Compressed Air Breathing Apparatus," *J. Amer. Soc. Safety Eng.*, pp. 7–10 (1970).
- Balieu E, and Spindler L, "Performance Testing for Improving the Level of Respiratory Protection in a Fire Brigade," *Ann. Occup. Hyg.* (21), pp. 351–361 (1978).
- Dahlback G O, and Novak L, "Do Pressure-Demand Breathing Systems Safeguard Against Inward Leakage?" *Amer. Ind. Hyg. Assoc. J.* (44), pp. 336–340 (1983).
- da Roza R A, Cadena-Fix C A, and Kramer J E, "Powered-Air Purifying Respirator Study," *JISRP*, pp. 15–36 (1990).
- de Steiguer D, and Hudson K E, "The Influence of Beards on the Efficiency of Aviators' Oxygen Masks," presented at the Survival and Flight Equipment Symposium, Las Vegas, NV, Dec 2–6, 1979.
- Evans M J, and Leinster P, "Personal Protection (Part 2) Respirators–I," *Quarterly Bulletin on Health, Safety and the Environment* (10) (1984).
- Fergin G S, "Respirator Evaluation for Carbon Setters with Beards," *Amer. Ind. Hyg. Assoc. J.*, (45), pp. 533–537 (1984).
- Fernandes M P, and Reid A S, "Personalized Respiratory Protection at an Aluminium Smelter," in *Light Metals: Proceedings of Sessions, AIME Annual Meeting* (Warrendale, PA, 1987); published by Metallurgical Soc. of AIME, USA, pp. 633–638 (1987).

- Griffin O G, and Longson D J, "Influence of Facemask Design on Operational Performance," Second Conference on Portable Life Support Systems, NASA, pp. 325-333 (1971).
- Griffin O G, and Longson D J, "The Effects of Beard Growth on the Inward Leakage of Gas into a Full Facemask," *Fire*, pp. 433-434 (1972).
- Held B J, "Facial Hair and Breathing Protection," *Int. Fire Chief*, pp. 25-28 (1980).
- Hounam R F, Morgan D J, O'Connor D T, and Sherwood R, "The Evaluation of Protection Provided by Respirators," *Ann. Occ. Hyg.* (7), pp. 353-363 (1964).
- HSE, *Respiratory Protective Equipment, A Practical Guide for Users*, HMSO, HS (G) 53 (1990).
- Hyatt E C, "Air-Purifying Respirators for Protection Against Airborne Radioactive Contaminants," *Health Phys.* (9), pp. 425-432 (1963).
- Hyatt E C, Pritchard J A, Richards C P, and Geoffrion L A, "Effect of Facial Hair on Respirator Performance," *Amer. Ind. Hyg. Assoc. J.* (34), pp. 135-142 (1973).
- Jonsson P G, "Effects of Beards, Stubble and Age Wrinkles on Respiratory Mask Fit," *Forsvarets Forskningsanstalt*, UMEA Sweden, FOA report A40034-C2 (A2, B2), 31 pp. (1980).
- Luria S M, and Dougherty J H, *Leakage into the Navy Oxygen Breathing Apparatus When Worn over Spectacles*, Naval Submarine Medical Research Lab Report No NSMRL-1029, 13 pp. (1984).
- McGee M K, and Oestenstad R K, "The Effects of the Growth of Facial Hair on Protection Factors for One Model of Closed-Circuit, Pressure-Demand, Self Contained Breathing Apparatus," *Amer. Ind. Hyg. Assoc. J.* (44), pp. 480-484 (1983).
- Naber D G, *Effects of Facial Hair in Oxygen Masks*, Naval Air Development Center, Warminster, Rept No NADC-72211-CS, 35 pp. (1972).
- Reed K A, and Moore T O, *Use of MAG-Spectacles with Positive and Negative-Pressure Respirators*, Los Alamos National Laboratory Rept LA-10229-MS, Los Alamos, NM, 38 pp. (1985).
- Skretvedt O T, and Loschiavo J G, "Effect of Facial Hair on the Face Seal of Negative-Pressure Respirators," *Amer. Ind. Hyg. Assoc. J.* (45), pp. 63-66 (1984).
- Stamperius P C, and Husmann R E W, "Effect of Facial Hair on the Leakage in Compressed-Air Breathing Masks," *De Veiligheid* (50), pp. 499-502 (1974).
- Stamperius P C, "Leakage of the Facepiece in Compressed Air Breathing Apparatus with Positive Pressure Facility," *De Veiligheid* (52), pp. 11-13 (1976).
- Stobbe T J, da Roza R A, and Watkins M A, "Facial Hair and Respirator Fit: A Review of the Literature," *Am. Ind. Hyg. Assoc. J.* (49), pp. 199-204 (1988).
- Warncke C, and Schipke W, "Investigations into the Sealing Effect of Facemasks," *Drdger Rev.* 38 (1976).