846-474

MSA

Mine Safety Appliances Company • P.O. Box 426 • Pittsburgh, PA 15230

Telephone: (412) 967-3000

Writers Direct Dial No.

412-967-3142

August 15, 1996

Docket Office Manager
Robert A. Taft Laboratories (C-34)
4676 Columbia Parkway
Cincinnati, OH 45226

Reference: DOCKET ON NIOSH 42 CFR 84 MODULES

Enclosed are MSA's comments based on NIOSH's request for public comment on future revisions to 42 CFR 84.

Should there be any questions on MSA's comments, please call me at the above number. MSA welcomes the opportunity to work with NIOSH in improving the respirator certification regulations.

Sincerely,

John F. Quinn
Product Line Manager,
Air Purifying Respirators

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AUG 16 1996
NIOSH DOCKET OFFICE

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LOCATION: RIDC Industrial Park • 121 Gamma Drive • Pittsburgh, PA 15238

MSA's Written Comments To NIOSH Regarding:

Privatization of Respirator Testing; Changes in Respirator Certification Administration and Quality Control; and the Establishment of Priorities for Future Rulemaking on Respirator Certification

August 16, 1996

MSA fully supports NIOSH's modular approach to revision of 42 CFR 84. MSA also greatly appreciates the sincere efforts NIOSH has made in improving its administrative procedures, especially in light of the recent surge in submittals that was thrust upon NIOSH with the first Part 84 module. NIOSH's openness to improvement has been demonstrated by your willingness to meet with stakeholders regarding easing the approval process' paperwork burden. For this we commend you.

ORDER OF MODULE ASSESSMENT

MSA suggests that NIOSH concurrently address both the Administrative/Quality Assurance module and some of the technical modules. There are different groups within NIOSH who could work on each of these modules separately, yet simultaneously. The Air Purifying Respirator section could work on the PAPR module, while the Supplied Air section was working on Self Contained Self Rescuers. Likewise, while these technical modules were being worked on, other NIOSH employees could be making the recommended improvements for the Administrative and Quality Assurance Module. By working concurrently, NIOSH could move the modules through to final rulemaking quicker. Once these four modules were completed, NIOSH could move to other less important modules; MSA would recommend that NIOSH reevaluate their respirator certification priorities once work on these four modules is completed.

Administrative/Quality Assurance Module

MSA can affirm that private sector laboratories are indeed capable of conducting the respirator testing currently performed by NIOSH. This has been proven by the positive experience MSA has had with the Safety Equipment Institute's NFPA 1981 SCBA certification program. To obtain SEI certification, an SCBA manufacturer must submit its SCBA to a third-party laboratory, and pass a battery of tests to prove that the unit meets all of the requirements of the latest edition of NFPA 1981. MSA feels that a similar process could be implemented for the standard NIOSH approval testing. The SEI testing turn around time is extremely fast--we typically receive approval around two to four weeks after submittal.

We believe that on-going NIOSH audit program of the private laboratories would be necessary to ensure that quality service is being provided by the private laboratories. Certainly, NIOSH's testing procedures must be thoroughly developed to ensure consistency of testing between laboratories. MSA believes that this is a task that NIOSH is well equipped to complete.

MSA supports the use of manufacturers' ISO 9001 accreditation as a means of reducing the depth and frequency of NIOSH's facility audits. The ISO 9001 standard is a model for use by organizations to certify their quality system from initial design and development of a desired product through production, installation, and servicing. Unlike ISO 9002, ISO 9001 includes the requirement of documenting the design and development process. Companies with ISO 9001 registration cover all aspects of product development, production, and servicing under their quality system; other ISO 9000 standards do not cover all phases of the product's life span.

MSA feels that NIOSH should maintain the authority to release a product for testing. However, we also feel that the manufacturer should be allowed to choose, from among approved laboratories, the laboratory to which the manufacturer wants to submit . This will allow the scheduling burden for tests to be assumed by the manufacturer, not NIOSH. NIOSH could then approve a technical package pending a successful test report from the lab. The two efforts, package assessment and testing, are completely independent. Allowing testing to be done outside of NIOSH would free about half of NIOSH's manpower to work on other pressing needs.

MSA believes that ISO 9001 audits can be used instead of NIOSH audits. MSA also thinks that if products are tested after NIOSH approval, for example, to meet the more stringent NFPA requirements, then these tests should be able to be used to replace annual NIOSH post production audits. NIOSH would save valuable resources, in this example, by having the test results sent to them to show compliance, rather than repeating these same tests themselves.

PAPR Module

The most important *technical* module that NIOSH needs to address is the PAPR module. Current regulations require heavy, burdensome products in order to comply with the standard's minimum service life requirements. When the Part 11 PAPR regulations were written, the applications for PAPRs were predominantly for heavy industrial applications where long life filters and long service life batteries made sense. . .and for many of those applications today, these qualities still make sense. However, many other applications for PAPRs have emerged since the initial regulations were penned (after all, 25 years ago, who thought multi-drug resistant strains of Tb would be such a big problem?) And some applications, as in the case of Tb, often require much less filter surface area and battery life than is currently required to gain a NIOSH PAPR approval.

NIOSH needs to consider the positive impact having lighter weight, lower profile PAPRs would have on the user. Respirator acceptance would certainly increase if battery weight and filter size were reduced on PAPRs. The current NIOSH regulations are design restrictive in that they require a minimum service life of four hours, and a minimum flow rate of 4 CFM on tight-fitting facepiece designs. The technology exists today to make breath-responsive PAPRs, which would meet the intent of the PAPR requirement in that they would maintain a slight positive pressure in the facepiece, but which would be unapprovable because they don't deliver a continuous minimum flow to the facepiece--a requirement that is not really relevant to user protection.

Attached is information on, and pictures of PAPRs that meet various users' needs internationally. The Cobra™ PAPR Helmet meets the needs for a lightweight, "all-in-one" PAPR where no breathing tubes or battery cords interfere with the wearer's activity. User acceptance of such a device is high. Likewise, the Cresta™ PAPR meets the need for a longer duration device by more efficiently using the battery life. This PAPR uses a "breath responsive" electronic flow control system to extend the life of conventional particulate and/or gas cartridges (as compared to conventional PAPRs which flow continuously). Neither of these PAPRs, which are popular internationally, can be used or sold in the U.S. currently due to design restrictive NIOSH standards.

Current NIOSH PAPR tests measure PAPR flow rates at the outlet of the blower, not on a head form. Because of the inherent back-pressure sensitivity of PAPRs, it is possible to pass NIOSH flow rate tests but still be negative pressure when in use. Da Roza et. al showed this in their Powered Air Purifying Study published in the Summer of 1990 ISRP (Copy attached). This study clearly showed that PAPRs flowing 6 CFM significantly outperformed PAPRs which only met the NIOSH minimum of 4 CFM. This information suggests that different NIOSH classes and perhaps later, different APFs, should be established for higher flowing PAPRs.

If NIOSH addresses the PAPR module now, we can expect an increase in worker protection due to the use of lightweight positive pressure PAPRs in lieu of negative pressure full face and half mask respirators, as workers seek the comfort of positive pressure airflow without the sacrifice of carrying bulky, heavy PAPRs. Additionally, if classes of PAPRs are established with higher flow requirements, those applications requiring even greater protection could be afforded a better performing respirator.

Other quirks of the current NIOSH system that have occurred due to the inconsistency of having negative pressure air purifying respirators certified to Part 84 while PAPRs are still being *labeled* as if they were Part 11 approvals, would also be cleaned up by addressing the PAPR module. For instance, there are some applications for PAPR devices that require "powered off" operation. This can result in the need for both positive and negative pressure approvals on the same device. The applicable approval depends on whether the switch is on or off.

Because no module exists for PAPR filters, a PAPR filter must have two model numbers if it is used in such an application; one part number for PAPR criteria as established in the past, and a different part number for the criteria as established under Part 84 for negative pressure filters. Moreover, the filter must also be tested to *both* requirements. A new PAPR standard in concert with the existing N, R, and P classes will remove this redundant testing effort and reduce user confusion.

Self-Contained Self Rescuer Module

Another technical module that MSA would like to see addressed by NIOSH is for the Closed Circuit Breathing Apparatus requirements for Self-Contained Self Rescuers (SCSRs). This portion of the standard needs revision because of the reliance of the underground mining industry on SCSRs. The current duration assessment tests for these devices are "human subject tests." While necessary to evaluate the suitability of the device, the human subject tests are very subjective in nature in terms of duration measurement. The test subjects vary from test to test, introducing variables into the evaluation that impact the duration from one day to the next. Such results are statistically invalid.

A metabolic simulator protocol needs to be established to remove the subjectivity of the approval process. Optimization of device designs cannot be achieved without a common duration assessment process. The current duration assessment regulations promote "over-design" of SCSRs at a time when the mining industry is looking for a lightweight, compact design so that the SCSRs can become person-wearable escape devices.

Self-Contained Breathing Apparatus Module

Also in NIOSH's supplied air section, MSA recommends incorporation of the NFPA 1981-1992 edition standard's requirements into the NIOSH standards for SCBA which will be used for firefighting. Some NFPA requirements, higher air flow rates, lens abrasion resistance, etc., make sense for all wearers, not just firefighters.

Additionally, MSA recommends incorporation of the NFPA 1500-1992 edition's requirements for compressed gaseous air in SCBA cylinders. Paragraph 5-3.7 of this standard states "Compressed gaseous air in the SCBA cylinder shall meet the requirements of ANSI/CGA G7.1, *Commodity Specification for Air*, with a minimum air quality of Grade D, as well as meeting a dew point level of -65°F (-54°C) or dryer (24 ppm v/v or less), and a maximum particulate level of 5 mg/m^3 air." Incorporation of this language as a NIOSH requirement, would help prevent SCBA regulator freeze-ups in cold weather environments.

CERTIFICATION FEE SCHEDULE

NIOSH has asked for comments related to its certification fee schedule. MSA strives to bring quality respiratory protection products to market in a timely fashion. We would be willing to pay extra if we could gain speed in getting NIOSH approval, and we feel that implementation of our recommended changes would help to achieve faster NIOSH approvals.

As far as the means of paying for the certification, MSA suggests that the manner in which these fees are collected could be greatly simplified by establishing "accounts" from which approval fees could be drawn. The electronic application can be used to track these accounts.

We appreciate NIOSH's efforts to improve as well as this opportunity to voice our comments. NIOSH can be assured that MSA will continue our aggressive support.

Powered-Air Purifying Respirator Study

R. A. da Roza, C. A. Cadena-Fix, and J. E. Kramer
Hazards Control Department, L-386, Lawrence Livermore National Laboratory, Livermore CA 94550

Abstract

Three brands of powered air-purifying respirators were subjected to a simulated-work-place study. They were worn by six human subjects while working at 80% of their cardiac reserve on a treadmill. The air flow into the respirator was controlled to match that of a respirator with a newly charged battery and with various stages of battery discharge and filter plugging. The simulation took place in a large quantitative fit test chamber containing PEG 400 aerosol. The penetration of aerosol into the breathing zone of the respirator, the pressure in it, and the air flow were monitored while the subject was warming up as well as during the 80% tests. The exercises recommended in ANSI Z88.2 for helmets were also used after the 80% tests were completed. The subjects were tested clean shaven, with three days' growth of stubble, and with a two-month beard growth. A striking result was that the aerosol penetration into the two-helmet respirators increased dramatically as the subjects work rate increased. On the other hand, penetration into the half mask did not change with work rate. The penetration increased as the air flow was decreased in all cases for the helmets and for beard and stubble cases for the half mask. However, for the tight-fitting half mask on a clean-shaven face, the average penetration stayed below 0.001 for all flows.

Introduction

Powered Air-Purifying Respirators (PAPRs) are used at LLNL and other DOE facilities as well as throughout industry. They are a relatively new form of respiratory protection, and their capabilities are not well understood. The protection that they provide has been questioned by field studies at National Institute for Occupational Safety and Health (NIOSH) and the Du Pont Company. It has also been suggested that workers with beards may get the same protection from these devices as do clean-shaven workers since the devices employ positive pressure and some have loose fitting facepieces.

The name, **Powered Air-Purifying Respirator** accurately describes the device. It consists of a **power** source for moving the air that is to be breathed and is carried by the wearer. It is usually a battery powered blower. The **air** is **purified** by being blown through a filter and then into a **respirator** face covering. The face covering can be tight fitting like a full facepiece and a half mask, or it can be loose fitting like a helmet and hood. The NIOSH certification requires an air flow rate of at least 115 lpm for the tight-fitting facepieces and at least 170 lpm for the loose-fitting face coverings. The respiratory protection that the device can provide is accomplished mainly by the tightness of the seal to the wearer and by the air flow rate. The devices do not maintain a positive pressure inside the face coverings at all times.

The purpose of this study is to determine the effect of facial hair growth on the seal of the inlet covering, and the effect of air flow on the performance of PAPRs equipped with high-efficiency particulate filters.

Note: This report was originally released as *Powered -Air Purifying Respirator Study Final Report*, R.A. da Roza, C.A. Cadena-Fix, and J.E. Kramer, Lawrence Livermore National Laboratory report UCRL-53757, February 1987.

Equipment Used

Half-Mask PAPR

Mine Safety Appliances Company catalog number 463354, PAPR with Medium Comfo Facepiece; complete with two HEPA filters, belt, and battery charger. A small and a large Comfo Facepiece were also available as needed.

Helmet-Type PAPR

3M Company catalog number W-344 Airhat Brand High Efficiency System complete with Airhat Brand High Efficiency Helmet, high-efficiency filter, flow test plate, battery pack, waist belt, and battery charger. The standard rubber face seal part W-2934 and chin strap W-2913 were used.

Racal Airstream, Inc. Breathe-Easy 1 with type P3 high-efficiency filters, helmet assembly, breathing tube, Turbo unit, battery pack, and battery charger. A chin strap and a new Tyvec face seal were used.

Measuring Instruments

Phoenix Precision Instruments forward light scattering photometer, Model JM 7000.

Validyne Engineering Corp. differential pressure transducer, Model P24.

Kurz Instruments Inc. flow meter; probe for Model 505 in specially designed tube.

As a data collection system, **Digital Equipment Corp.** LSI-11/23 computer with the RSX-11M operating system.

Quinton Instrument Co. treadmill, Model Q55 with controller.

Methodology

Work Rate Control

The subject's work rate was controlled by use of the treadmill. Data were taken continuously as the subject warmed up by walking on the treadmill at 3.3 mph as it was stepped to increasingly steeper grades. It took about 10 min for the subject to reach 80% of his maximum work rate, i.e., for his heart rate to reach 80% of his cardiac reserve.

Air Flow Rate Control

The air flow rate to the PAPR was controlled by replacing the battery pack with a dc power supply. During the warmup period, the flow was controlled at the level that could be produced by a slightly used battery. Once at the 80% work rate, the flow was varied from that of a freshly charged battery to below the minimum flow required by NIOSH. Table 1 shows the flows used and their order as well as the associated voltage for each of the units.

ANSI Exercises

The exercises suggested in ANSI Z88.2-1980 section A6.1 for testing a respirator equipped with a helmet, hood, or suit were used after the subject cooled down for from 4 to 6 min from the end of the 80% work rate tests described above. The order of the exercises was:

1. Bending knees and squatting.
2. Running in place.

Table 1. Air flow rates used for each PAPR.

PAPR	Flow (lpm)	Flow (cfm)	Voltage (V)
MSA	170	6	5.2
	198	7	6.2
	142	5	4.2
	114	4	3.5
	86	3	2.7
	170	6	5.2
3M	255	9	4.3
	283	10	4.7
	198	7	3.6
	170	6	3.2
	114	4	2.5
	255	9	4.3
RACAL	202	7.1	4.5
	226	8	5.0
	170	6	3.8
	142	5	3.2
	114[a]	4[a]	4.7[a]
	202	7.1	4.5

[a] Two filters are also closed off to get this flow since the unit does not run well at lower voltages.

3. Bending forward and touching toes.
4. Raising arms above head and looking upward.
5. While holding a rod about 76 cm long, twist torso from side to side and slowly raise the arms till pointing upward 45°.
6. Normal breathing while standing.

This order is different from that in the standard since we wanted to do the most active exercises first while the subject's breathing and heart rates were still elevated.

Facial Hair Conditions

Three conditions of facial hair were tested: clean shaven, 3 days growth of stubble, and a full beard of 2 to 3 months growth. All of the above described flows and exercises were used at each facial hair condition.

Measurements

Measurements of aerosol penetration and pressure inside the face coverings were taken on each test. Inlet air flow rate was measured for the MSA half mask and the Racal helmet. Flows could not be measured on the 3M Airhat during exercise without major modifications. The opening to the sampling tube inside the helmet faceshield was located about 1/2 in. from the subject's upper lip. On the half mask it was located flush with the rubber and just above the metal frame. This puts it near the upper lip of most subjects.

The length of each of the three exercise regimens was different. During the warmup period, the grade was increased every 2 min until the subject's heart rate was approaching 80%. Although the instruments sample continuously, their outputs were only sampled by the computer every 250 ms. The data taken at each grade were stored separately. After the subject was at 80%, the flow rate was changed every 2.5 min. The sampling for each 2.5-min period was divided into 30 s of waiting for the changed flow to have its effect, 1.5 min of sampling output every 250 ms, and 30 s of sampling every 16 ms, which is the fastest possible sampling cycle time for our computer and operating system. The 250-ms cycle time is good for obtaining the average value over the experimental period, and the 16-ms cycle is needed to get good definition of pressure and flow changes. Each ANSI exercise was performed for 2 min with a break of approximately 30 s between exercises. The data sampling rate was 250 ms. The faster rate was not needed since no pressure or flow data were taken during the ANSI exercises.

Results

To analyze the test results we took various averages of the data. First the penetration was calculated for each data point and the average penetration calculated for each exercise interval. The flow was also averaged for the same intervals. These interval averages for each subject were then averaged over all of the subjects that had data in that interval. Since penetration follows a lognormal distribution, the geometric means and geometric standard deviations were calculated. A normal distribution was assumed for the flow data, which did not vary greatly. These results for the average subject are presented in Tables 2, 3 and 4. All further calculations and plots (except for the raw data plots) are derived from these tables.

Effect of Varying the Work Rate

At greater work rates, the subject breathes deeper and faster, creating the possibility that he may overbreathe the PAPR. To show this effect, we plotted the penetration, expressed as a fraction, against the grade of the treadmill. This is shown in Figs. 1, 2, and 3 for the three PAPRs. Subparts (a), (b), and (c) of each figure show the three different facial hair conditions. The geometric standard deviation, SD_g, is shown for each value by a vertical line terminated by hour glass characters. The SD_g varies considerably since the number of subjects included in the average varies from one to six depending on how many actually used that particular grade. Some subjects skipped grades, and not many went to 20%. A guide to the typical physiological response of a subject walking at 3.3 mph and the various grades is given in Table 5. Walking at the 10% grade would be considered "somewhat hard" by most people.

Table 2. MSA half-mask PAPR data summary for average subject.

	Clean shaven					Three days of stubble					Full beard				
	Penetration		Flow (lpm)			Penetration		Flow (lpm)			Penetration		Flow, (lpm)		
	Mean$_g$	SD$_g$	Mean	SD	N	Mean$_g$	SD$_g$	Mean	SD	N	Mean$_g$	SD$_g$	Mean	SD	N
Warmup with increasing slope															
Grade %															
2.5	0.318E-3	4.34	167	11.6	6	0.11E-2	2.27	163	4.1	4	0.590E-4	4.52	158	4.4	5
5	0.126E-3	3.66	170	16.3	3	0.585E-3	1.50	165	1.4	2	0.335E-4	5.64	158	4.4	5
7.5	0.298E-3	4.61	168	12.4	5	0.798E-3	1.91	163	3.5	4	0.575E-4	6.33	158	4.3	5
10	0.277E-3	5.52	162	5.3	3	0.574E-3	1.76	163	3.5	3	0.220E-3	7.13	158	4.3	5
12.5	0.457E-3	3.25	170	12.5	4	0.576E-3	1.90	164	2.4	4	0.234E-3	23.5	158	4.9	5
15	0.109E-2	1.15	162	1.0	2	0.864E-3	1.89	162	1.5	3	0.340E-4	0	155	0	1
17.5	0.322E-3	7.18	174	17.0	2	0.169E-2	1.18	162	1.4	2	0.160E-4	0	156	0	1
20	0.95E-4	0	185	0	1	0.150E-2	0	161	0	1	—	—	—	—	—
At 80% work rate with various flows															
Flow (cfm)															
6	0.318E-3	4.63	166	9.9	5	0.107E-2	2.8	162	1.1	5	0.783E-3	4.89	156	7.6	6
7	0.364E-3	4.34	197	12.4	5	0.101E-2	1.98	193	1.1	5	0.285E-3	7.10	184	13.1	6
5	0.341E-3	4.18	132	4.1	5	0.188E-2	3.92	130	4.5	5	0.469E-2	2.30	126	7.0	6
4	0.375E-3	4.53	109	6.7	5	0.292E-2	5.55	107	3.1	5	0.100E-1	1.91	102	8.1	6
3	0.706E-3	0.37	82	9.6	5	0.466E-2	7.58	79	3.9	5	0.100E-1	2.11	78	7.1	6
6	0.516E-3	5.77	168	12.7	5	0.115E-2	2.21	163	1.5	5	0.139E-2	2.33	158	9.0	6
ANSI exercises															
Exercise No.															
1	0.576E-3	3.84	165	4.5	5	0.108E-2	1.69	166	2.6	5	0.548E-4	7.41	158	7.1	5
2	0.704E-3	5.56	164	3.6	5	0.116E-2	1.62	165	2.4	5	0.620E-4	10.2	157	6.8	5
3	0.438E-3	4.38	166	3.8	5	0.101E-2	1.59	168	2.4	5	0.410E-4	6.81	159	7.0	5
4	0.454E-3	3.76	164	5.5	5	0.101E-2	1.54	166	3.7	5	0.458E-4	6.32	158	7.9	5
5	0.493E-3	3.33	163	6.3	5	0.857E-3	1.83	165	3.0	5	0.486E-4	5.49	157	7.5	5
6	0.492E-3	3.14	164	5.6	5	0.810E-3	2.02	166	3.9	5	0.495E-4	5.96	158	7.3	5

Table 3. Racal helmet PAPR data summary for average subject.

	Clean shaven					Three days of stubble					Full beard				
	Penetration		Flow (lpm)			Penetration		Flow (lpm)			Penetration		Flow (lpm)		
	Mean_g	SD_g	Mean	SD	N	Mean_g	SD_g	Mean	SD	N	Mean_g	SD_g	Mean	SD	N
Warmup with increasing slope															
Grade %															
2.5	0.611E-6	12.4	206	9.4	5	0.349E-4	1.76	200	13.1	5	0.322E-4	8.25	199	14.7	6
5.0	0.857E-6	6.62	206	13.1	3	—	—	—	—	—	0.154E-4	10.0	198	13.1	6
7.5	0.199E-5	8.77	202	5.3	4	0.599E-5	4.73	199	12.9	5	0.259E-5	85.8	200	8.0	5
10.0	0.592E-5	320	206	17.7	2	0.249E-4	185	196	18.8	3	0.278E-4	17.0	207	6.5	4
12.5	0.977E-4	448	208	7.8	4	0.814E-4	181	203	7.8	4	0.567E-3	10.1	203	8.5	6
15.0	0.113E-2	23.9	209	8.9	3	0.155E-2	19.6	198	16.9	4	0.143E-2	50.4	204	12.1	3
17.5	0.109E-2	75.5	206	7.8	4	0.554E-2	2.16	198	17.2	4	0.563E-2	7.9	203	11.6	3
20.0	0.778E-2	19.3	203	1.4	2	0.866E-2	4.4	208	14.9	3	0.171E-1	7.5	198	9.9	2
At 80% work rate with various flows															
Flow (cfm)															
7	0.113E-1	7.5	203	8.9	5	0.196E-1	2.64	185	30.1	5	0.111E-1	4.0	201	10.6	6
8	0.951E-2	8.2	226	10.6	5	0.210E-1	2.91	220	21.1	5	0.719E-2	4.23	224	12.4	6
6	0.528E-1	2.48	168	4.9	5	0.611E-1	1.85	167	13.4	5	0.318E-1	2.59	169	9.8	6
5	0.820E-1	2.12	143	4.6	5	0.111E-0	1.45	141	12.4	5	0.616E-1	1.97	144	11.4	6
4	0.136E-0	1.52	110	12.9	5	0.157E-0	1.32	107	13.0	5	0.120E-0	1.60	107	9.5	6
7	0.412E-1	2.16	204	10.5	5	0.422E-1	1.96	195	19.0	4	0.212E-1	3.44	196	13.2	6
ANSI exercises															
Exercise No.															
1	0.369E-3	7.09	203	10.0	5	0.389E-3	6.7	200	22.2	5	0.336E-3	17.3	200	12.8	6
2	0.129E-2	31.1	201	7.4	5	0.288E-2	9.28	199	35.6	5	0.437E-2	39.1	194	14.4	6
3	0.218E-3	121	203	7.3	5	0.776E-3	9.71	195	14.3	5	0.284E-3	12.1	199	15.9	6
4	0.498E-4	56.0	201	7.9	5	0.113E-3	13.2	194	13.9	5	0.162E-3	6.26	196	16.1	6
5	0.921E-5	32.6	203	9.0	5	0.336E-4	5.65	192	12.0	5	0.388E-4	4.83	196	17.0	6
6	0.223E-5	19.8	206	10.9	5	0.107E-4	9.5	194	13.8	5	0.942E-5	3.70	199	17.9	6

Table 4. 3M helmet PAPR data summary for average subject.

	Clean shaven, penetration			Three days of stubble, penetration			Full beard, penetration		
	Mean$_g$	SD$_g$	N	Mean$_g$	SD$_g$	N	Mean$_g$	SD$_g$	N
Warmup with increasing slope									
Grade %									
2.5	0.907E-4	4.54	6	0.170E-3	2.57	6	0.166E-3	18.4	5
5.0	0.623E-4	13.9	2	0.170E-3	3.51	5	0.105E-3	23.4	4
7.5	0.246E-3	3.70	6	0.427E-3	2.61	4	0.318E-3	3.67	5
10.0	0.659E-3	2.51	4	0.647E-3	1.90	5	0.313E-3	7.27	4
12.5	0.495E-2	1.49	4	0.885E-2	3.56	5	0.135E-2	11.9	4
15.0	0.201E-1	2.27	6	0.140E-1	1.90	6	0.218E-2	13.2	5
17.5	0.300E-1	1.79	4	0.256E-1	1.68	4	0.213E-1	2.0	2
20.0	0.400E-1	2.79	2	0.359E-1	1.06	2	0.600E-1	0	1
At 80% work rate with various flows									
Flow (cfm)									
9	0.502E-1	1.52	6	0.572E-1	1.66	6	0.186E-1	5.62	5
10	0.400E-1	1.58	6	0.485E-1	1.76	6	0.270E-1	2.12	5
7	0.900E-1	1.39	5	0.985E-1	1.40	6	0.496E-1	2.09	6
6	0.120E-0	1.29	6	0.126E-0	1.39	6	0.056E-0	2.54	6
4	0.200E-0	1.25	6	0.187E-0	1.22	6	0.107E-0	2.06	6
9	0.500E-1	1.48	6	0.810E-1	2.38	6	0.206E-1	2.87	5
ANSI Exercises									
Exercise No.									
1	0.126E-2	5.24	6	0.125E-2	4.60	6	0.157E-2	3.90	5
2	0.334E-2	4.84	6	0.234E-2	1.86	6	0.220E-2	7.24	5
3	0.260E-2	3.32	6	0.220E-2	4.6	6	0.117E-2	7.88	5
4	0.435E-3	4.56	6	0.269E-2	30.0	6	0.229E-3	7.98	5
5	0.978E-4	4.39	6	0.106E-3	1.73	6	0.432E-4	8.61	5
6	0.382E-4	5.22	6	0.570E-4	7.40	6	0.223E-4	9.98	5

Table 5. Physiological response at various grades.

Grade %	Heart rate per min	Breathing rate per min	Minute volume, l
2.5	116	23	30
5.0	124	23	36
10.0	155	30	53
15.0	165	33	72
20.0	177	41	103

Effect of Air Flow Rate

To study the importance of the amount of filtered air supplied to the PAPR, we varied the air flow rate from below the NIOSH standard to as great as the PAPR could produce with a freshly charged battery and new filters. The results are shown in Figs. 4(a), (b), and (c); 5(a), (b), and (c); and 6(a), (b), and (c). After a short time of use, about 15 min, the battery voltage would drop so that about 1 cfm less air was moved, and then air flow would remain constant for many hours. Our flows varied some from test to test due mainly to variations in the voltage supplied to the PAPR. The standard deviation for the flow is shown as a horizontal line terminated by hour glass characters. The SD$_g$ for the penetration is shown as before. Since the flow into the 3M PAPR was not measured during the exercises, it was assumed to be the same as in the initial bench test.

Effect of Facial Hair

The effect of facial hair on the penetration when the subject is working at 80% is summarized in Figs. 7, 8, and 9. Here, each facial hair condition is plotted with a different symbol on the graph of penetration vs flow for each make of PAPR. For clarity, no standard deviations are shown on these plots.

The ANSI Exercises

The penetrations observed during the ANSI exercises are summarized in clustered bar graphs, Figs. 10, 11, and 12. The fractional penetration has been multiplied by 1000 for better plotting. The data for all three facial hair conditions have been grouped for each of the six exercises, with one plot for each PAPR.

Pressure and Flow in the Facepiece

The pressure in the facepiece changes as the subject breathes in and out. When the subject is working at 80% of his maximum, his peak inhalation flow rate can be greater than that supplied by the PAPR, causing a negative pressure inside the facepiece. The next series of plots show the pressure in the facepiece and the air flow into it vs time. These are shown for each subject both clean shaven and with a 2-month beard at the NIOSH-required flow rate of 4 cfm (114 lpm) for the half mask (Fig. 13), and both clean-shaven and with a 3-day stubble at 6 cfm (170 lpm) for the Racal helmet (Fig. 14). For one subject wearing the half mask, we also show these plots for each of the flow rates used at 80% work rate (Fig. 15). The mask pressure for this subject was about the average for all the subjects. For the Racal helmet, we show the plots at each flow rate used for two subjects. One set shows a typical light breather (Fig. 16), and the other shows a typical heavy breathing subject (Fig. 17). Only one plot is shown for the 3M helmet since the flow was not measured and the pressure trace looked the same for all of the tests (Fig. 18).

Discussion

The Importance of the Work Rate

As the subject's work rate increases and his breathing gets deeper, the penetration into the half mask PAPR remains constant at about 0.0002 (ratio of aerosol particles in the facepiece to those in the test chamber) [protection factor (PF) = 5000] for the average clean-shaven subject, Fig. 1(a). However, the penetration into the Racal helmet increases dramatically from 10^{-6} to 0.01 (PF = 100), Fig. 2(a). Similarly the penetration into the 3M helmet increases from 10^{-4} to 0.1 (PF = 10), Fig. 3(a). The trends with facial stubble or a beard were the same. The flow rates used for these plots were those obtained from a charged battery. The air flow to the helmets was not sufficient for work rates produced by a grade greater than about 10%.

The Importance of the Air Flow Rate

Changing the flow to the half mask did not have any measurable effect on the penetration for a clean shaven subject, Fig. 4(a). It remained about 4×10^{-4} (PF = 2500) for all flows from 3 to 7 cfm. For three days of stubble, we notice that the penetration increased at the lower flow rates, Fig. 4(b), and for a full beard, the penetration increased greatly at lower flows, Fig. 4(c). The PF drops to 67 at a flow of 3 cfm.

The penetration into the Racal helmet increases as the flow is decreased for all facial conditions, Figs. 5(a), (b), and (c). It increases from about 0.01 at a flow of 7 cfm to 0.1 at 4 cfm. The same is true for the 3M helmet, where the penetration increases from about 0.04 at 10 cfm to 0.15 at 4 cfm, Figs. 6(a), (b), and (c).

The Role of Facial Hair

Stubble or a full beard has little effect on the penetration into the half mask as long as the flow rate is high enough, 6 or 7 cfm. However, with a full beard at lower yet approved flows, the penetration is 20 times greater than at 7 cfm. This lowers the PF at 4 cfm from 2667 to 132, Fig. 7. No effect of facial hair was seen on the penetration into the helmet-type PAPRs, Figs. 8 and 9. This is probably because the face to facepiece seal is so poor that the effect of the addition of a beard cannot be detected.

ANSI Exercises

The ANSI exercises performed while wearing the half mask all produced about the same results, Fig. 10. The data with the full beard is puzzling. There is a factor of 20 less penetration with a full beard for the average subject. A look at the individual subject's data reveals that two of the five subjects used for the average had very low penetrations when doing the ANSI exercises with full beards. The other three subjects had about the same penetration as when clean shaven. This skewed the average and caused the large SD_g shown in Table 2.

The helmet data show a general trend downward in penetration as the subjects progress through the exercises. This is partly due to the subject cooling off more and his breathing becoming normal. The Racal helmet data showed an increase in penetration during the running exercise. Again, this is due to increased breathing.

The Myth of Positive Pressure

While it is advertized that PAPRs are positive-pressure respirators, we found that under our test conditions the helmet PAPRs could not maintain a positive pressure inside the facepiece all of the time or even most of the time. The MSA half mask comes close to being a positive-pressure device. The set of plots for the MSA half mask, Fig. 15, show for a typical subject, BGH, how the facepiece pressure changes during the breathing cycle at an 80% work rate. Notice that as the flow increases from 3 cfm up to 7 cfm, the percent of time that the pressure is positive increases from less than 50% to almost 100%. At the NIOSH required flow of 4 cfm it is only positive 50% of the time. At 4 cfm, subject BGH has a facepiece pressure of about 0.8 in. water gauge (wg) when exhaling, but it drops to about negative 0.6 in. wg during inhalation. The average pressure during inhalation is a positive 0.2 in. wg when the flow is 6 cfm, which is the flow that the battery maintains for most of its charge. The pressure plots are shown for the rest of the subjects at 4 cfm in Fig. 13. The pressure goes negative during inhalation for all subjects when the flow is 4 cfm. It appears that the NIOSH-required flow rate is too low.

The pressure inside the Racal helmet facepiece did not change much with flow. It cycled between +0.2 and −0.2 in. wg depending on the subject, but depended very little on the flow rate. Figures 14, 16, and 17 show how the pressure and flow varied for the Racal helmet.

The pressure inside the 3M helmet facepiece stayed within ±0.05 in. wg of zero and showed no discernible pattern associated with breathing. A typical plot is shown in Fig. 18.

Summary

The difference in the performance between the tight fitting half mask and the loose fitting helmets is so great that they should be in separate categories when assigning respirator protection factors. The helmets should not be considered as positive-pressure devices. The half mask is a positive-pressure device at flows of 6 cfm, which is its normal flow rate. At 4 cfm and an 80% work rate, the half mask does not maintain a positive pressure. Facial stubble or a full beard degrade the fit of the half mask. Facial stubble or a full beard do not affect the protection provided by the helmets since it is so poor even when the subject is clean shaven.

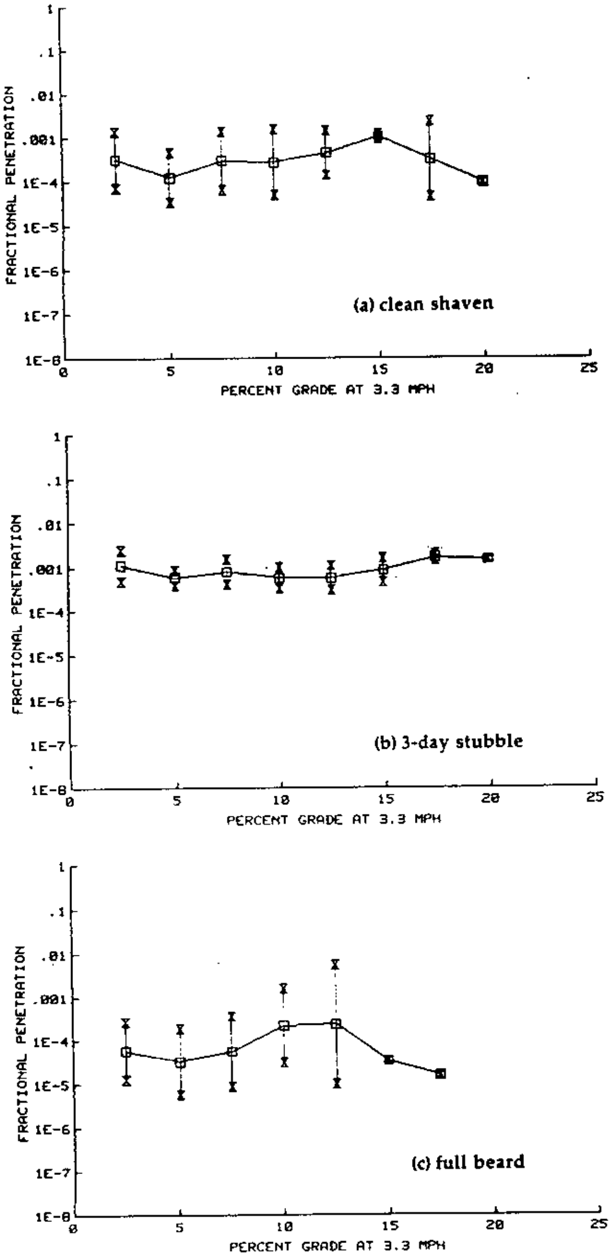

Figure 1. Effect of work rate, average subject, MSA half-mask PAPR.

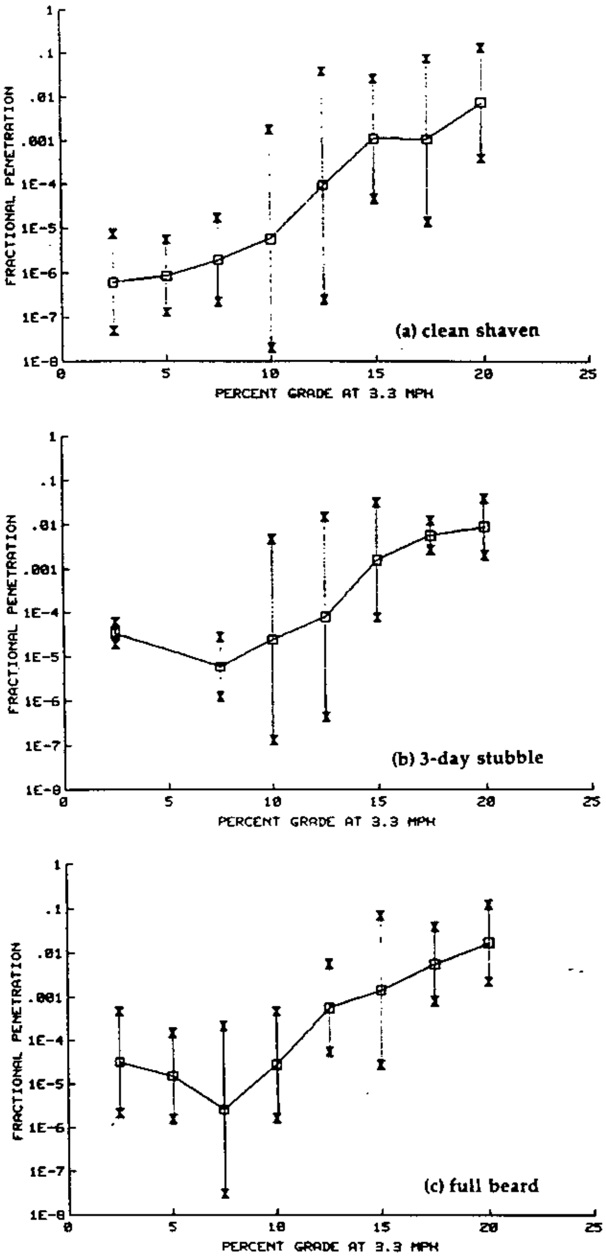

Figure 2. Effect of work rate, average subject, Racal helmet PAPR.

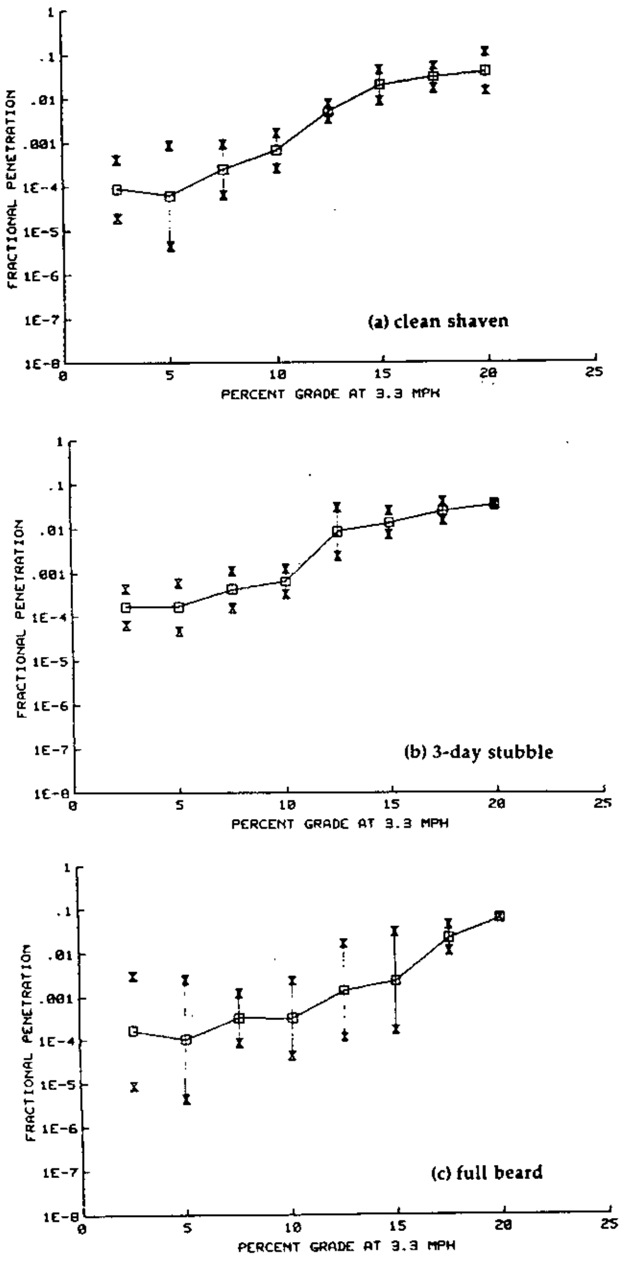

Figure 3. Effect of work rate, average subject, 3M helmet PAPR.

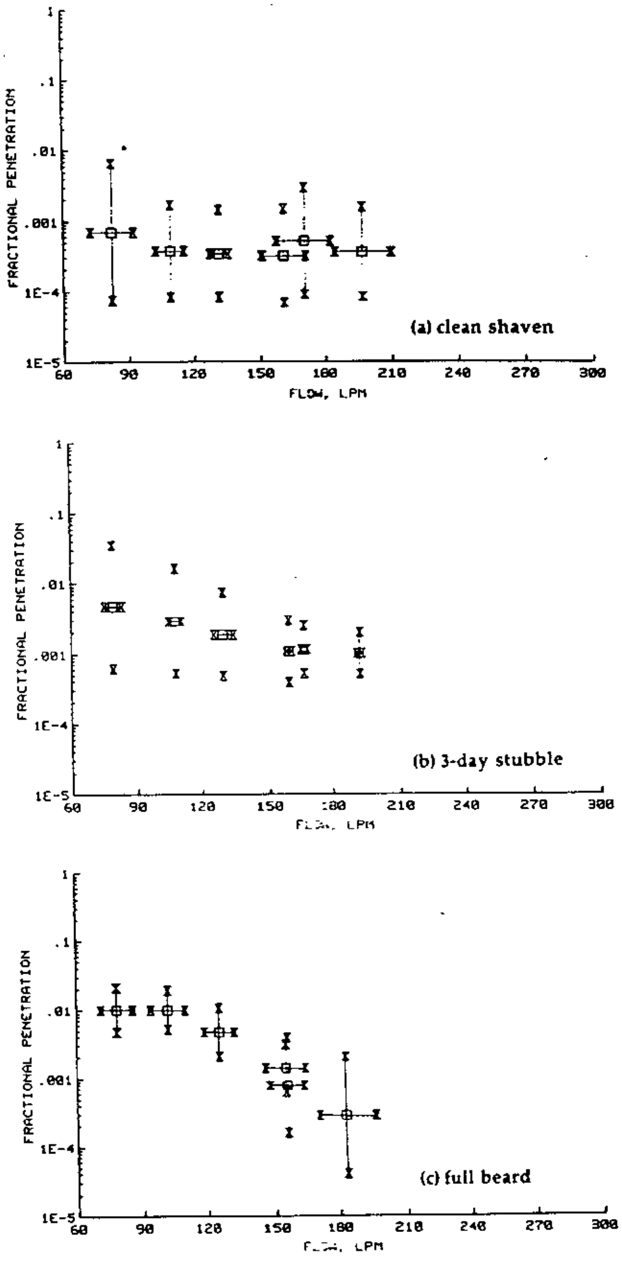

Figure 4. Effect of air flow, average subject, MSA half-mask PAPR.

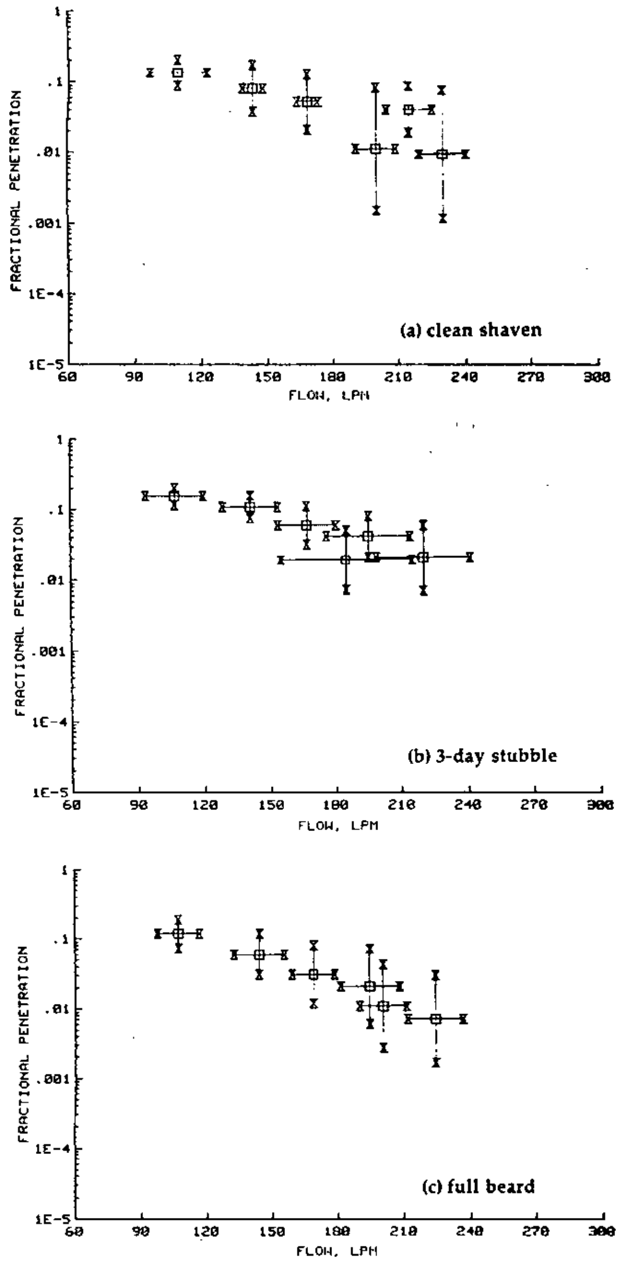

Figure 5. Effect of air flow, average subject, Racal helmet PAPR.

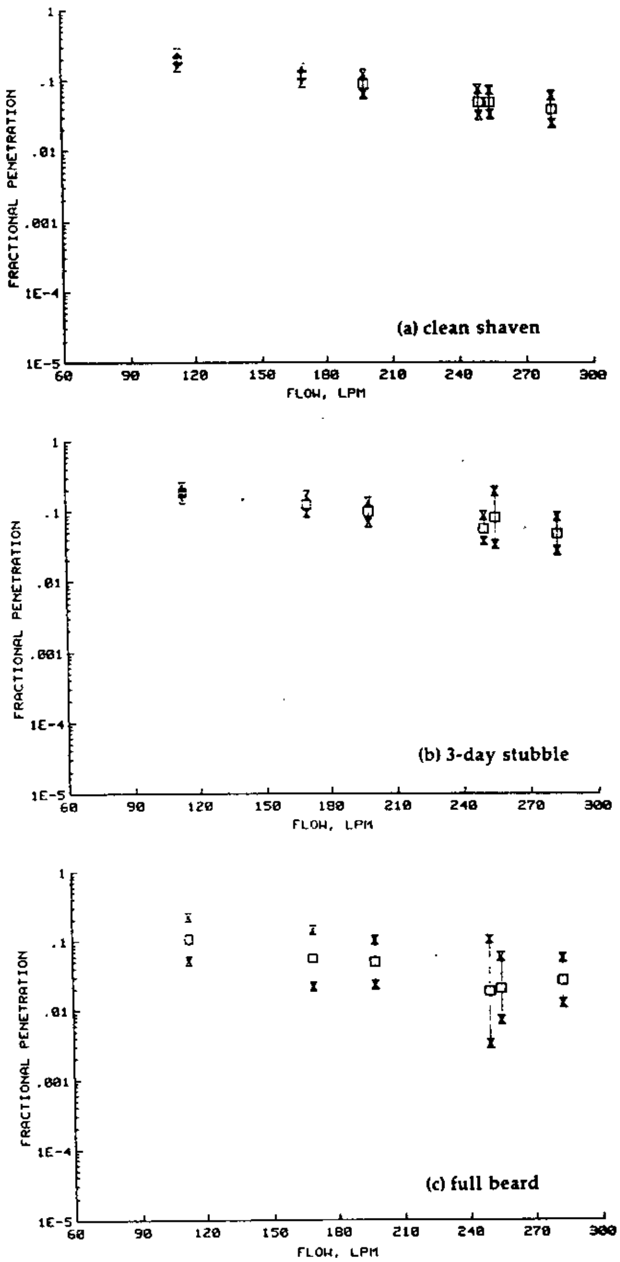

Figure 6. Effect of air flow, average subject, 3M helmet PAPR.

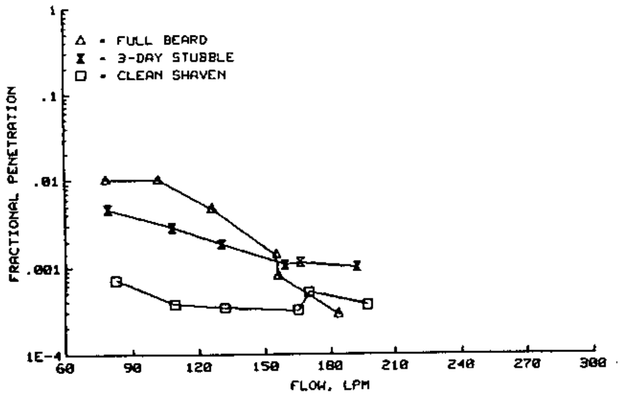

Figure 7. Effect of facial hair at 80% work rate, average subject, MSA half-mask PAPR.

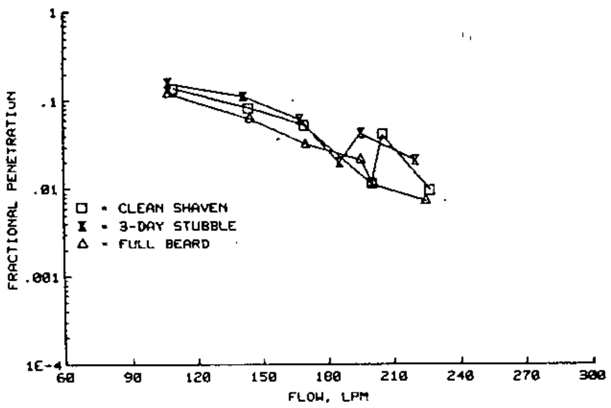

Figure 8. Effect of facial hair at 80% work rate, average subject, Racal helmet PAPR.

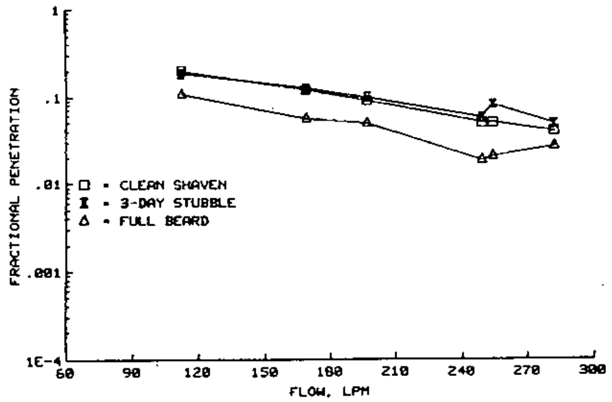

Figure 9. Effect of facial hair at 80% work rate, average subject, 3M helmet PAPR.

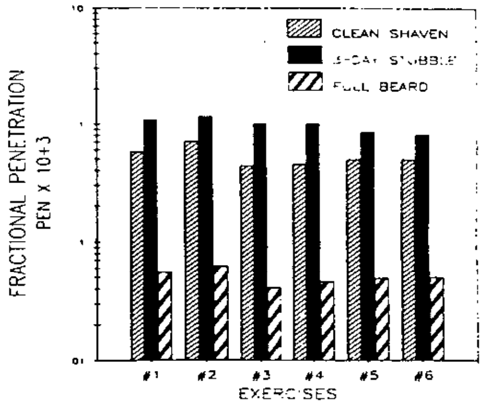

Figure 10. ANSI exercises, average subject, MSA half-mask PAPR.

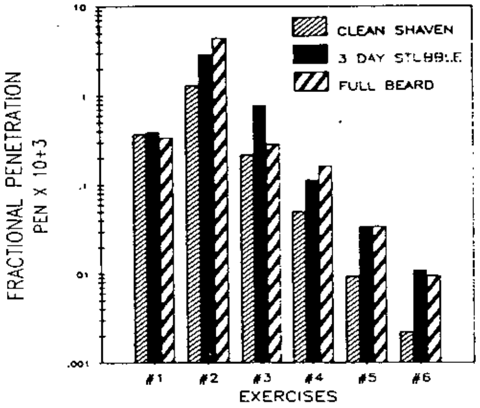

Figure 11. ANSI exercises, average subject, Racal helmet PAPR.

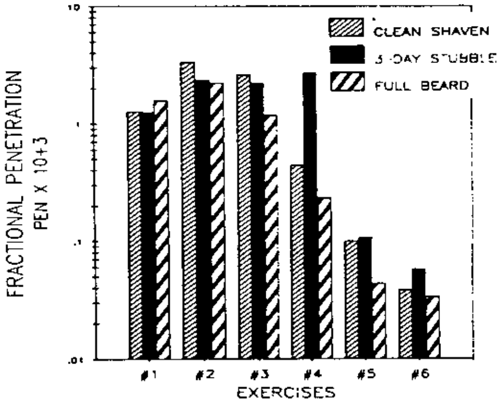

Figure 12. ANSI exercises, average subject, 3M helmet PAPR.

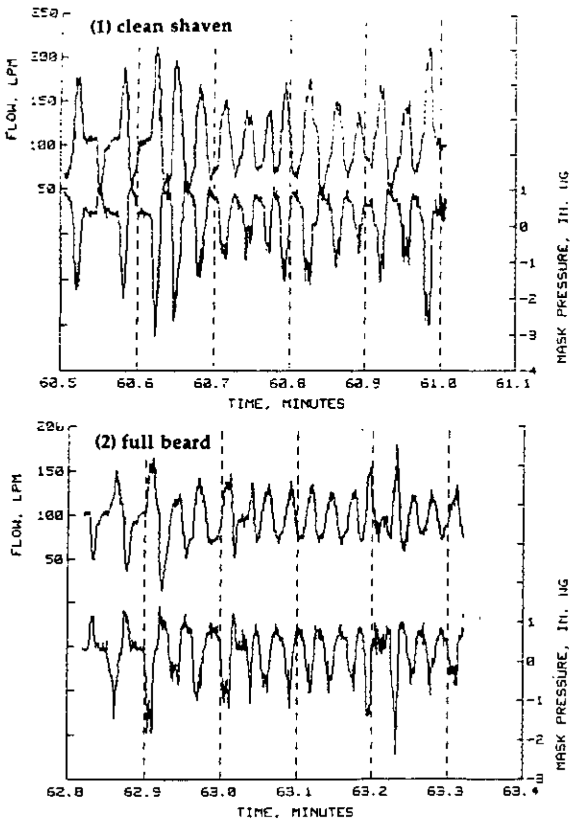

Figure 13(a). Pressure and flow vs time, MSA half-mask PAPR, flow of 4 cfs. Subject DAL.

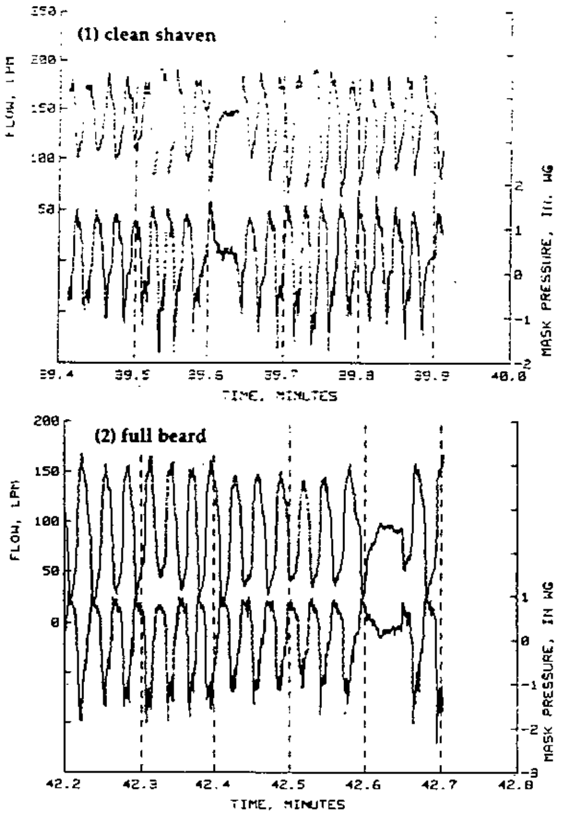

Figure 13(c). Pressure and flow vs time, MSA half-mask PAPR, flow of 4 cfs. Subject SPS.

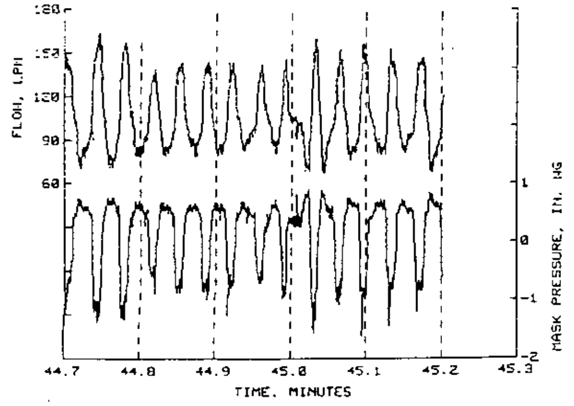

Figure 13(b). Pressure and flow vs time, MSA half-mask PAPR, flow of 4 cfs. Subject JML, full beard.

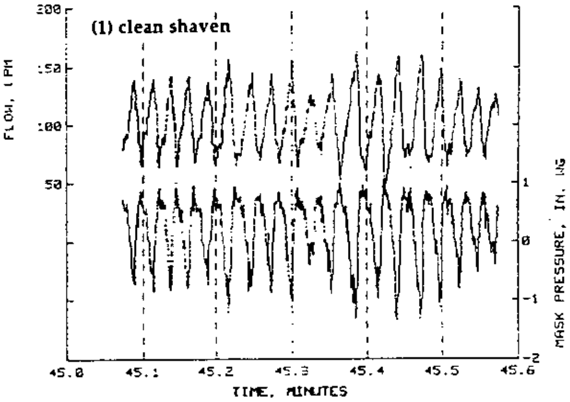

Figure 13(d). Pressure and flow vs time, MSA half-mask PAPR, flow of 4 cfs. Subject WGU.

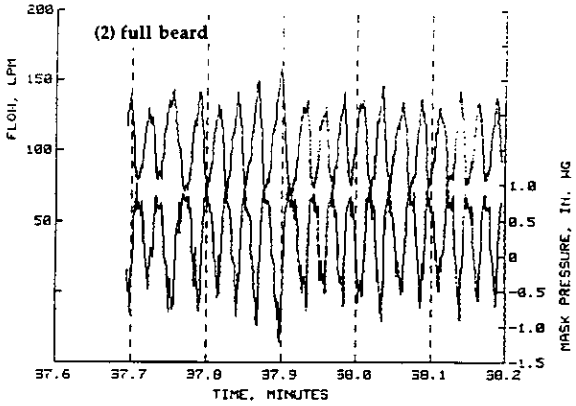

Figure 13(d). (Continued)

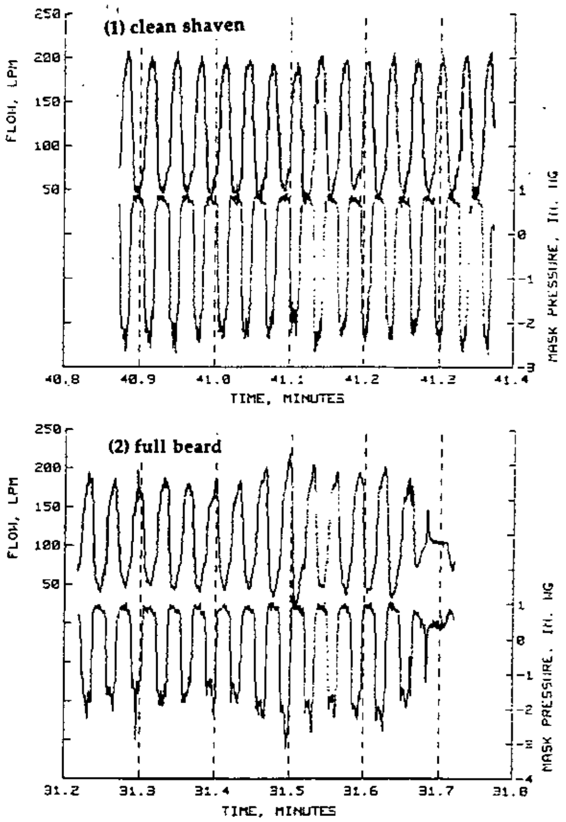

Figure 13(e). Pressure and flow vs time, MSA half-mask PAPR, flow of 4 cfs. Subject KCY.

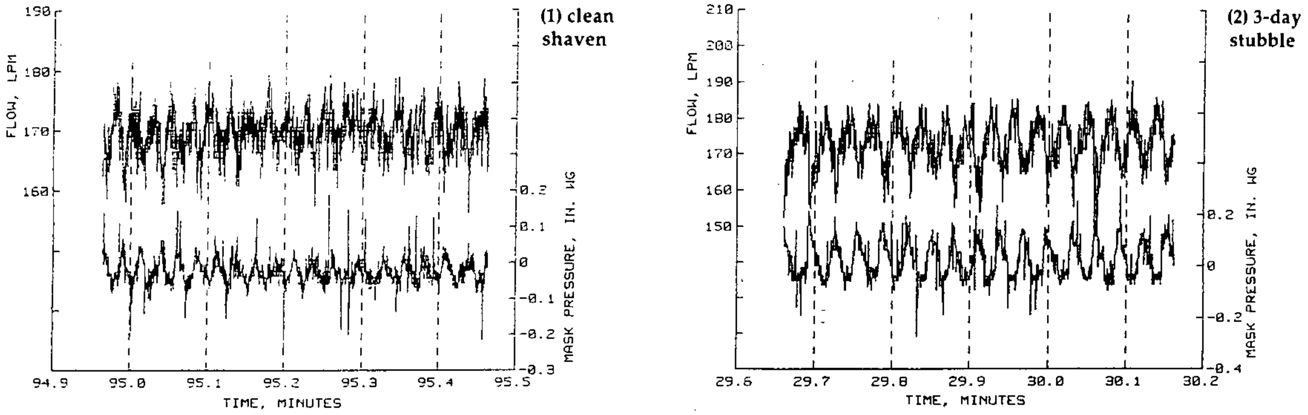

Figure 14(a). Pressure and flow vs time, Racal helmet PAPR, flow of 6 cfm; Subject NCB.

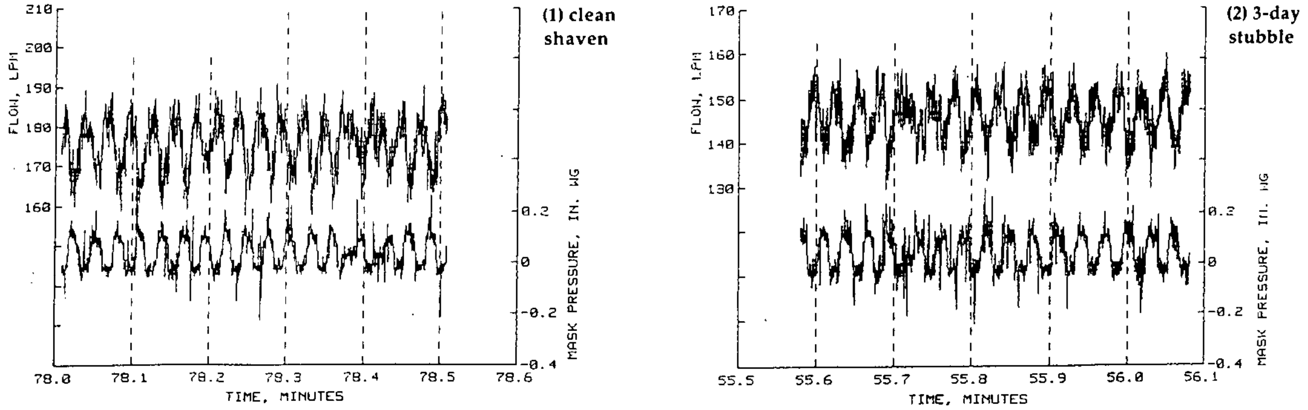

Figure 14(b). Pressure and flow vs time, Racal helmet PAPR, flow of 6 cfm; Subject JWD.

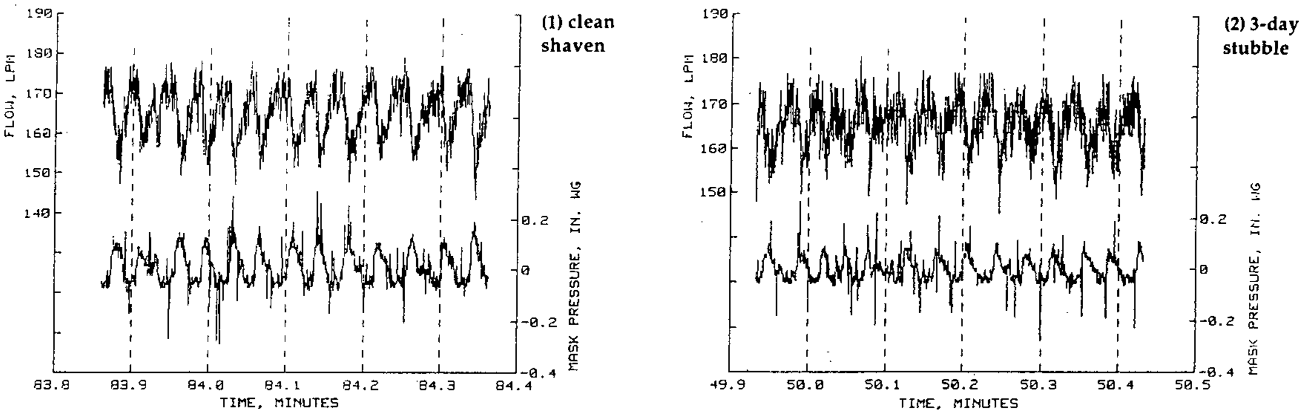

Figure 14(c). Pressure and flow vs time, Racal helmet PAPR, flow of 6 cfm; Subject BGH.

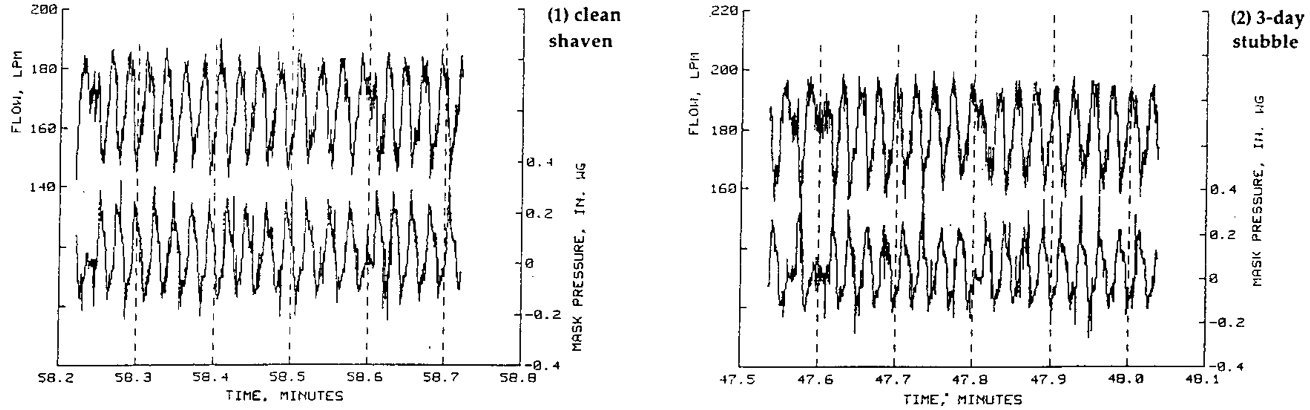

Figure 14(d). Pressure and flow vs time, Racal helmet PAPR, flow of 6 cfm; Subject RAK.

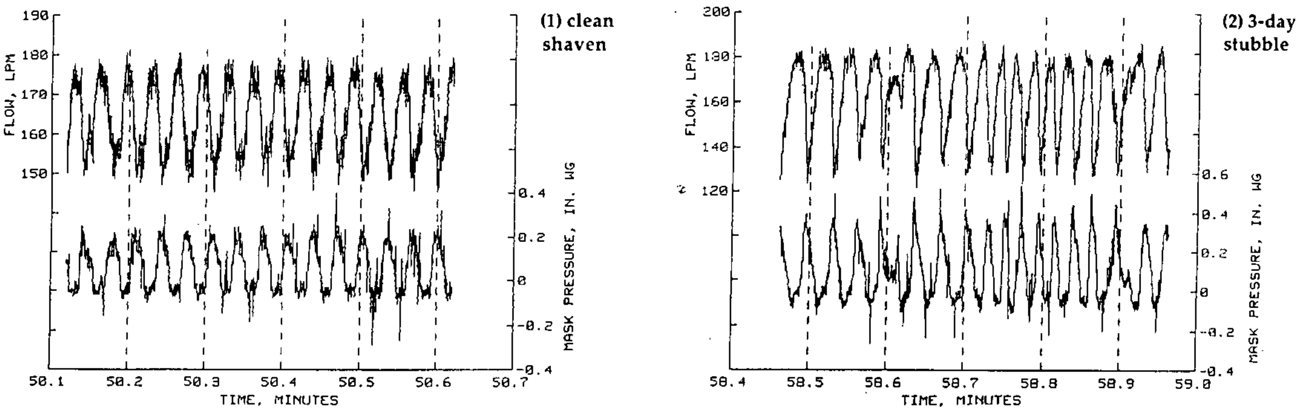

Figure 14(e). Pressure and flow vs time, Racal helmet PAPR, flow of 6 cfm; Subject KCY.

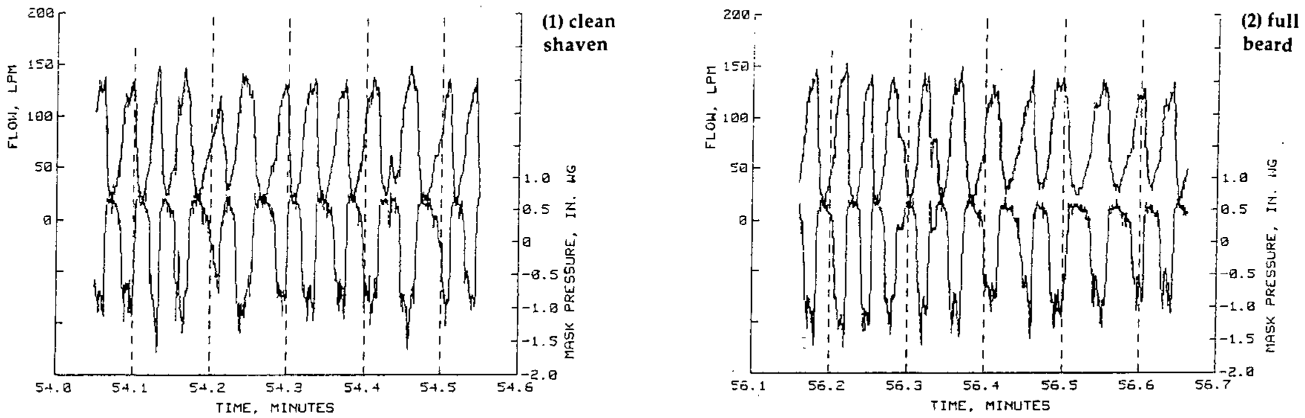

Figure 15(a). Pressure and flow vs time, MSA half-mask PAPR, flow of 3 cfm; Subject BGH.

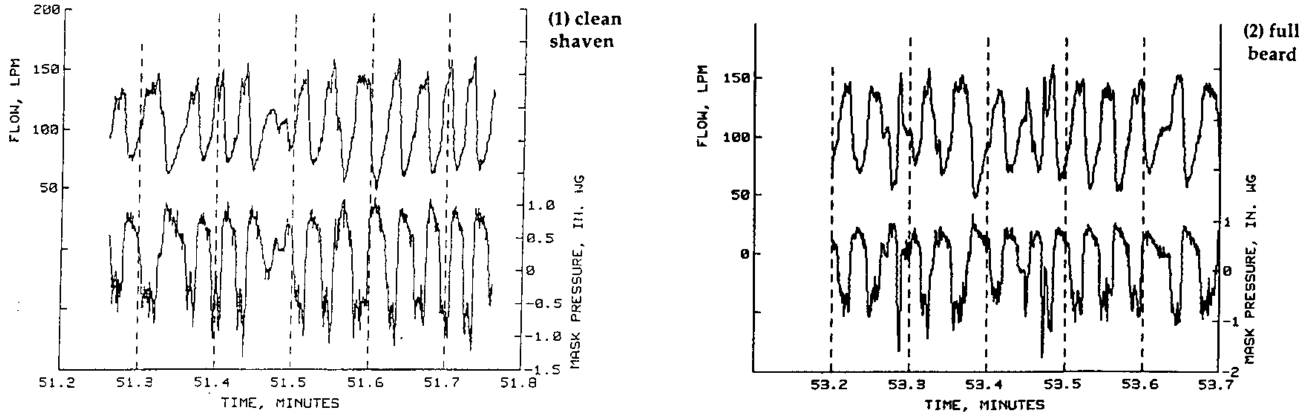

Figure 15(b). Pressure and flow vs time, MSA half-mask PAPR, flow of 4 cfm; Subject BGH.

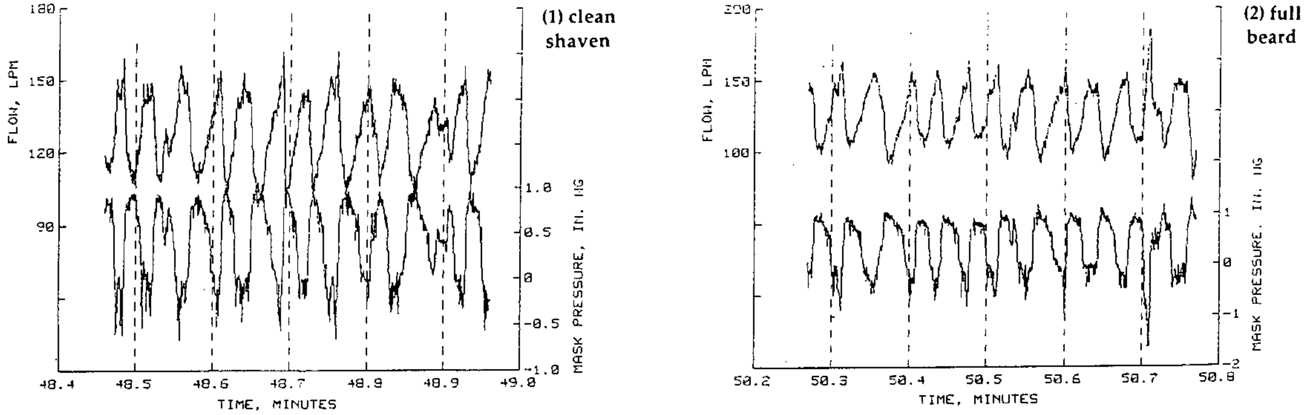

Figure 15(c). Pressure and flow vs time, MSA half-mask PAPR, flow of 5 cfm; Subject BGH.

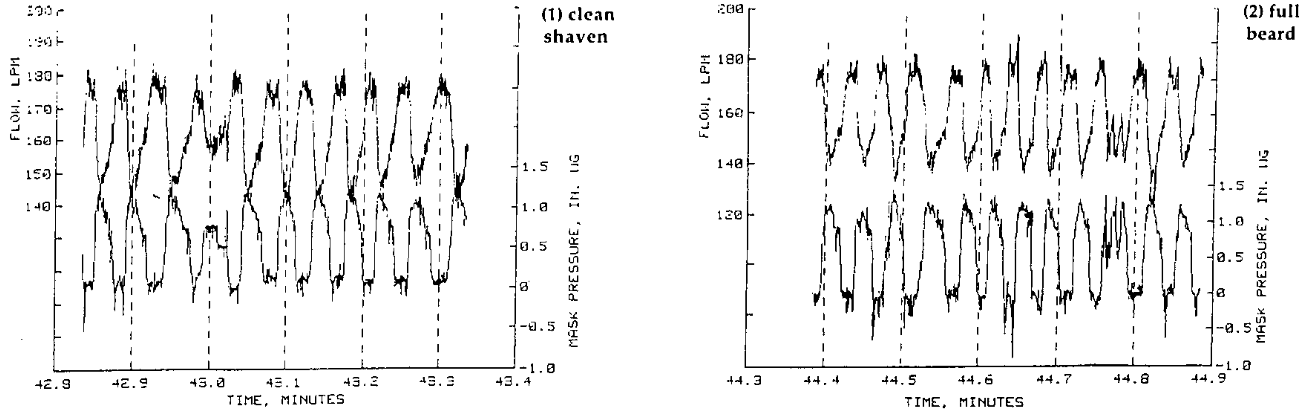

Figure 15(d). Pressure and flow vs time, MSA half-mask PAPR, flow of 6 cfm; Subject BGH.

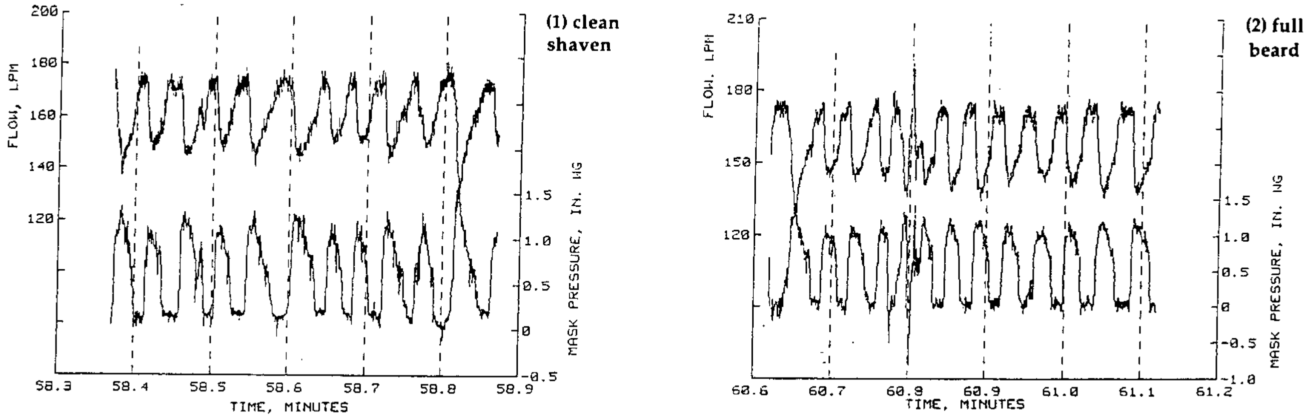

Figure 15(e). Pressure and flow vs time, MSA half-mask PAPR, flow of 6 cfm (repeat); Subject BGH.

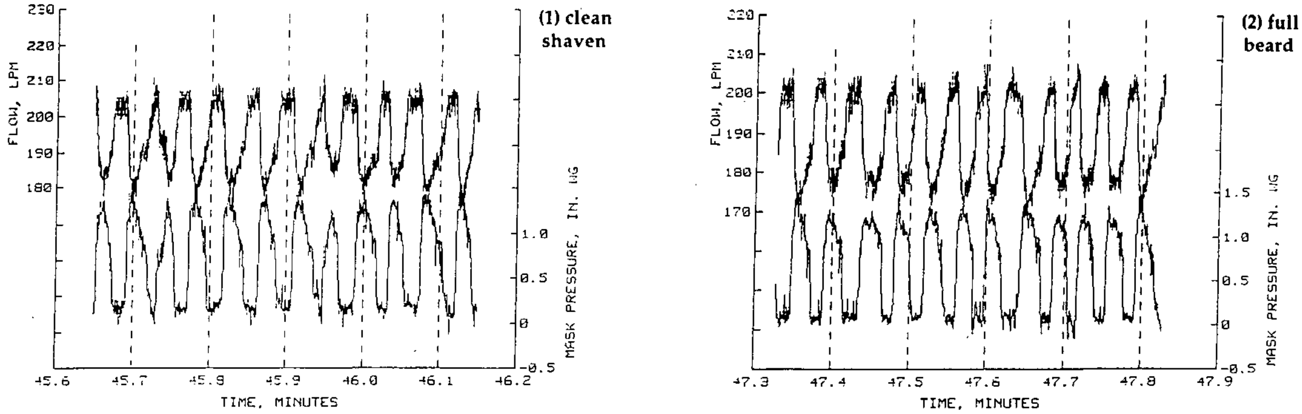

Figure 15(f). Pressure and flow vs time, MSA half-mask PAPR, flow of 7 cfm; Subject BGH.

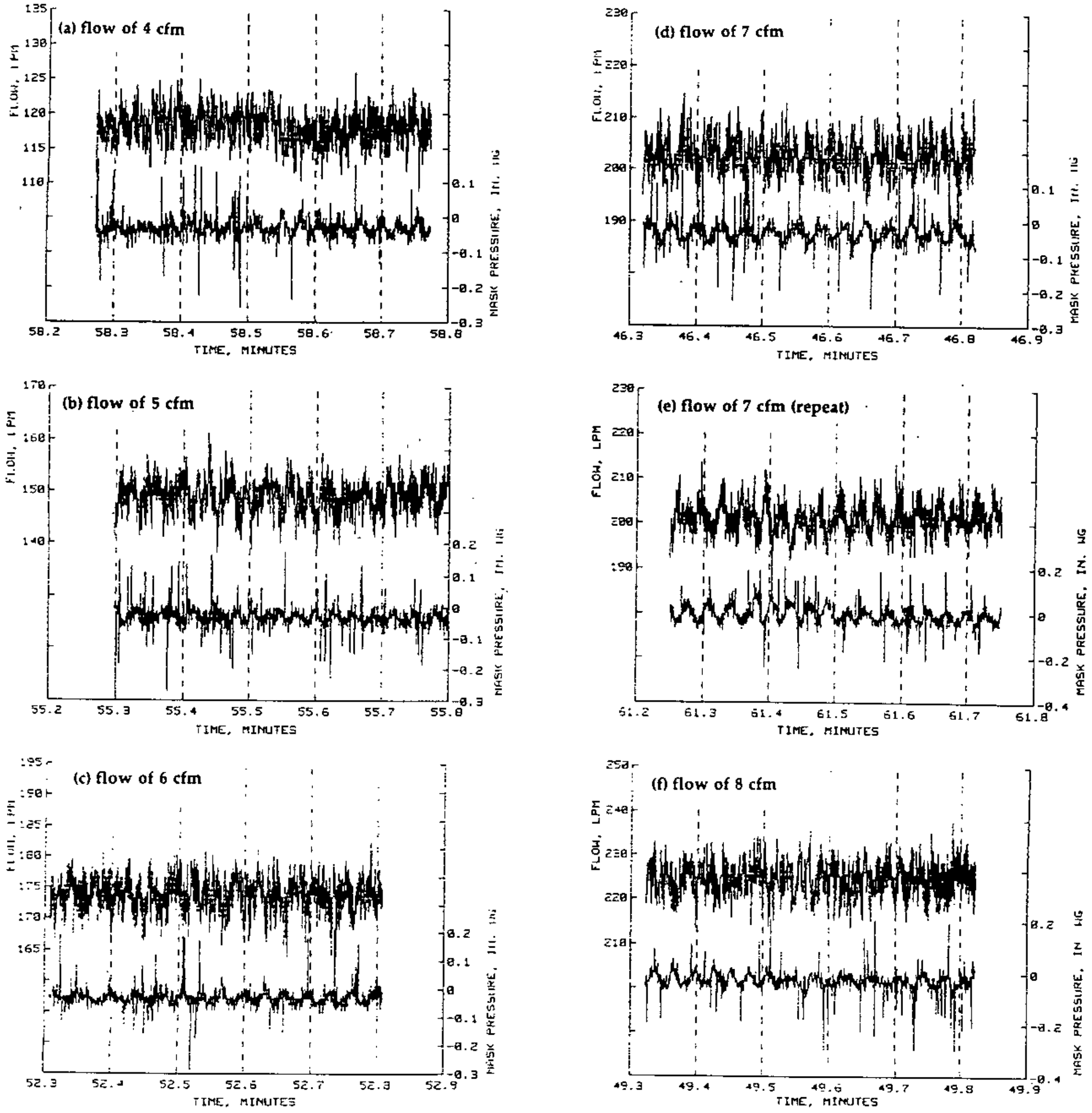

Figure 16. Pressure and flow vs time, Racal helmet PAPR, Subject NCB, full beard.

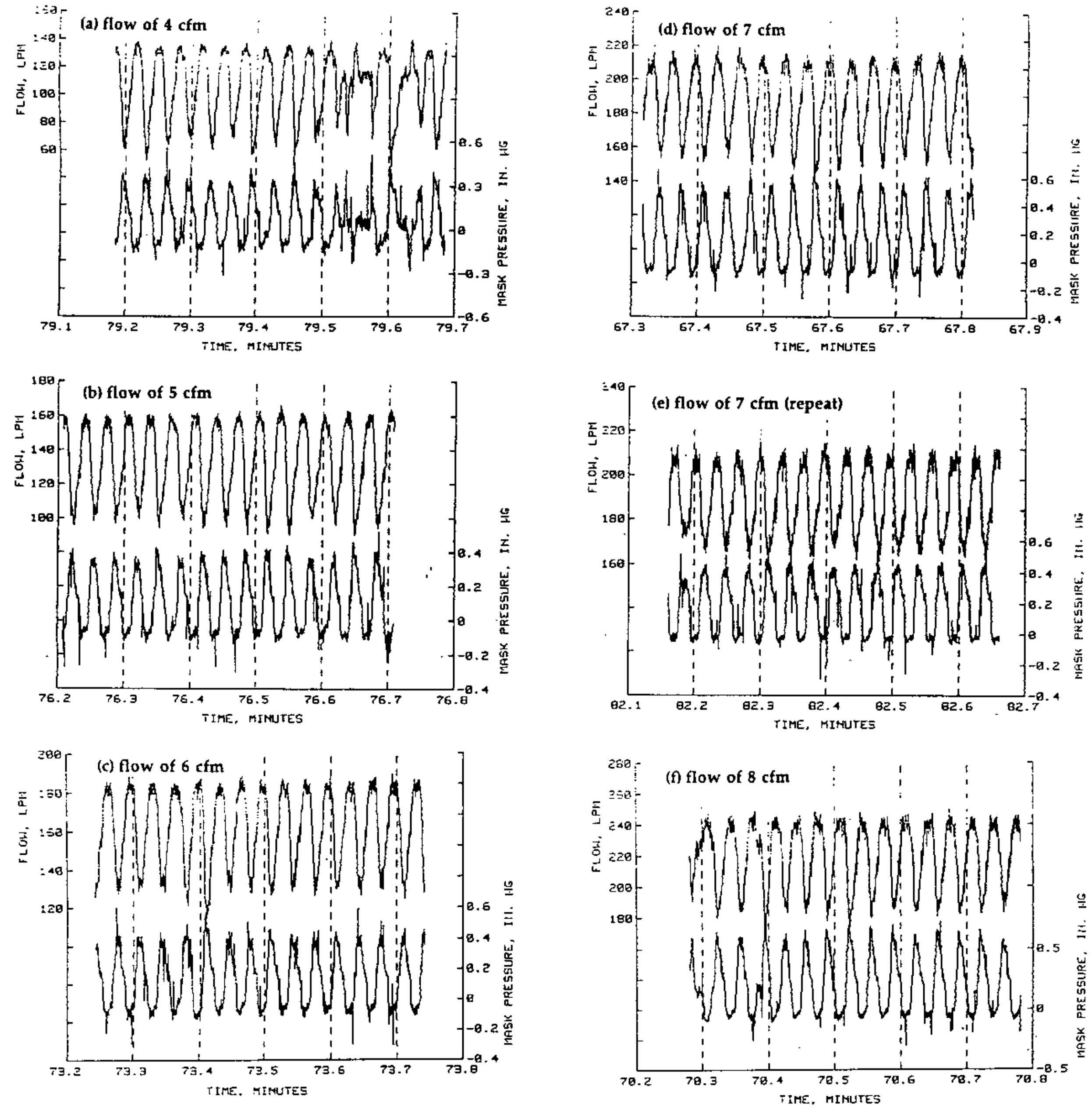

Figure 17. Pressure and flow vs time, Racal helmet PAPR, Subject KCY, full beard.

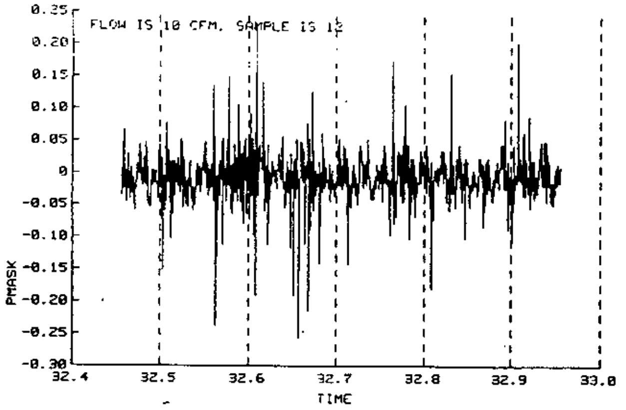

Figure 18. Typical plot of pressure vs time for 3M helmet PAPR.