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Environmental Testing of Firefighters' SCBA

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Abstract

Self-Contained Breathing Apparatus (SCBA) is used by many groups for many different applications. One group, firefighters, uses SCBA in some of the most severe environments and with the highest frequency. SCBA manufacturers should consider environmental extremes in their test criteria and procedures because various national approval agencies do not. We describe the effects of temperature extremes, of chemical exposure from hazardous material spills, and of rough handling, including both shock and vibration on firefighters' SCBA. The use of solvents, degreasing agents, detergents and disinfecting agents during maintenance is also discussed. We list both breathing machine and man-test data for selected test parameters. A recommended testing program is presented.

Introduction

The testing of self-contained breathing apparatus (SCBA) involves 3 parameters:

(1) *The required function of the apparatus.* In this respect, there are plenty of local and international standards available specifying the most relevant features (European Committees for Standardization, 1976; NIOSH-MSHA Certification tests, 1972). Regarding the requirement for apparatus function, there is no significant difference between apparatus made for firefighters and those made for other users. Most functions are dependent on physiological factors relevant to the user rather than to his or her intended working environment.

(2) *The environmental and usage factors.* In this respect, there are different conditions for every user group. The condition for a worker in a chemical plant, for example, can be very well defined. The environmental factors for a firefighter, on the other hand, are very hard to predict because they can include working in both fires and chemicals often under extreme conditions. The available standards give very little clarification of the firefighters' environment. It is probably true to say the firefighters' environment is the most severe environment of all the user groups and therefore a good firefighter's SCBA is suitable for other users.

(3) *The requirement for equipment to withstand its environment and use.* For certain features, no compromises are accepted, while for others, a malfunction as a result of extreme handling can be accepted.

Table 1 shows features dependent on environmental and use factors listed together with suggested tests. This kind of information can ensure that firefighters' SCBA will function in all possible environments. We will concentrate on those test parameters which have not yet been standardized or perhaps fully considered by approval authorities, manufacturers, and users. All test results presented are based on tests performed only on AGA SCBA; other SCBA may give different results.

Breathing Resistance and Work of Breathing

All standards of SCBA include requirements for breathing resistance. Both from a physiological point of view and a subjective one, it is important for the users' comfort to keep the breathing resistance as low as possible. It is also of value to follow the variation in the breathing resistance during different environmental conditions in order to determine the SCBA's ability to withstand such conditions. It is therefore necessary to have a well-developed procedure for the testing of breathing resistance in order to compare different SCBA and different environmental effects in a realistic way.

REQUIREMENT

1 = FULL FUNCTION DURING AND AFTER TEST

2 = FULL FUNCTION DURING REMAINING TIME OF DURATION

3 = REDUCED FUNCTION ACCEPTED

X = NOT APPLICABLE

(1) ETC, SEE REFERENCE LIST

TESTS	LAB	MAN	REMAINING TIME OF DURATION	CORROSION PROPERTIES	PROTECTION FACTOR (1)	DEAD SPACE (1)	WORK OF BREATHING	BREATHING RESISTANCE (1)	TEMPERATURE, BREATHING AIR	LOW PRESSURE ALARM (1)	STORAGE GAS INDICATOR (1)	FIELD OF VISION (2)	STRENGTH, PRESSURE PARTS (1)	STRENGTH, GAS STORAGE
HEAT, NORMAL	(1)		1	1	1	1	1	1	1	1	1	1	1	1
HEAT, EXTREME	(4)		1	3	2	3	3	3	2	1	3	3	1	1
HEAT + WATER SPRAY			1	1	1	1	1	1	1	1	1	1	1	1
COLD	(1)	(3)	1	1	1	1	1	1	1	1	1	1	1	1
HEAT, COLD, HEAT			1	1	1	1	1	1	1	1	1	1	1	1
FLAME, NORMAL			1	1	1	1	1	1	1	1	1	1	1	1
FLAME, EXTREME	(2)		3	3	2	3	3	3	2	1	3	3	1	1
CHEMICALS, NORMAL			1	1	1	1	1	1	1	1	1	1	1	1
CHEMICALS, EXTREME			3	3	2	3	3	3	2	1	3	3	1	1
CLEANING			1	1	1	1	1	1	x	1	1	1	1	1
DISINFECTION			1	1	1	1	1	1	x	1	1	1	1	1
STORING LONG TIME			1	1	1	1	1	1	x	1	1	1	1	1
STORING + CHEMICALS			1	1	1	1	1	1	x	1	1	1	1	1
DUST, FOAM			1	1	1	1	1	1	x	1	1	1	1	1
EXTERNAL WEAR			1	1	1	1	1	1	x	1	1	1	1	1
IMPACT, NORMAL			1	1	1	1	1	1	x	1	1	1	1	1
IMPACT, EXTREME			3	1	2	3	3	3	x	1	3	1	1	1
IMPACT, FACEPIECE			3	1	1	1	1	1	x	1	1	1	1	x
IMPACT, LENCE	(2)		1	x	1	1	1	1	x	x	x	1	x	x
TENSILE FORCE, HOSES, ETC	(2)		1	x	1	1	1	1	x	1	1	1	1	x
VIBRATIONS			1	1	1	1	1	1	x	1	1	1	1	1
WORK LOAD, NORMAL	(1)	(1)	1	x	1	1	1	1	1	1	1	1	x	x
WORK LOAD, EXTREME		(1)	1	x	1	3	1	1	1	1	1	1	x	x
STORAGE GAS, FULL TO EMPTY			1	x	1	1	1	1	1	1	1	1	x	1

FIRE FIGHTERS SCBA

SUGGESTED TEST PROGRAM

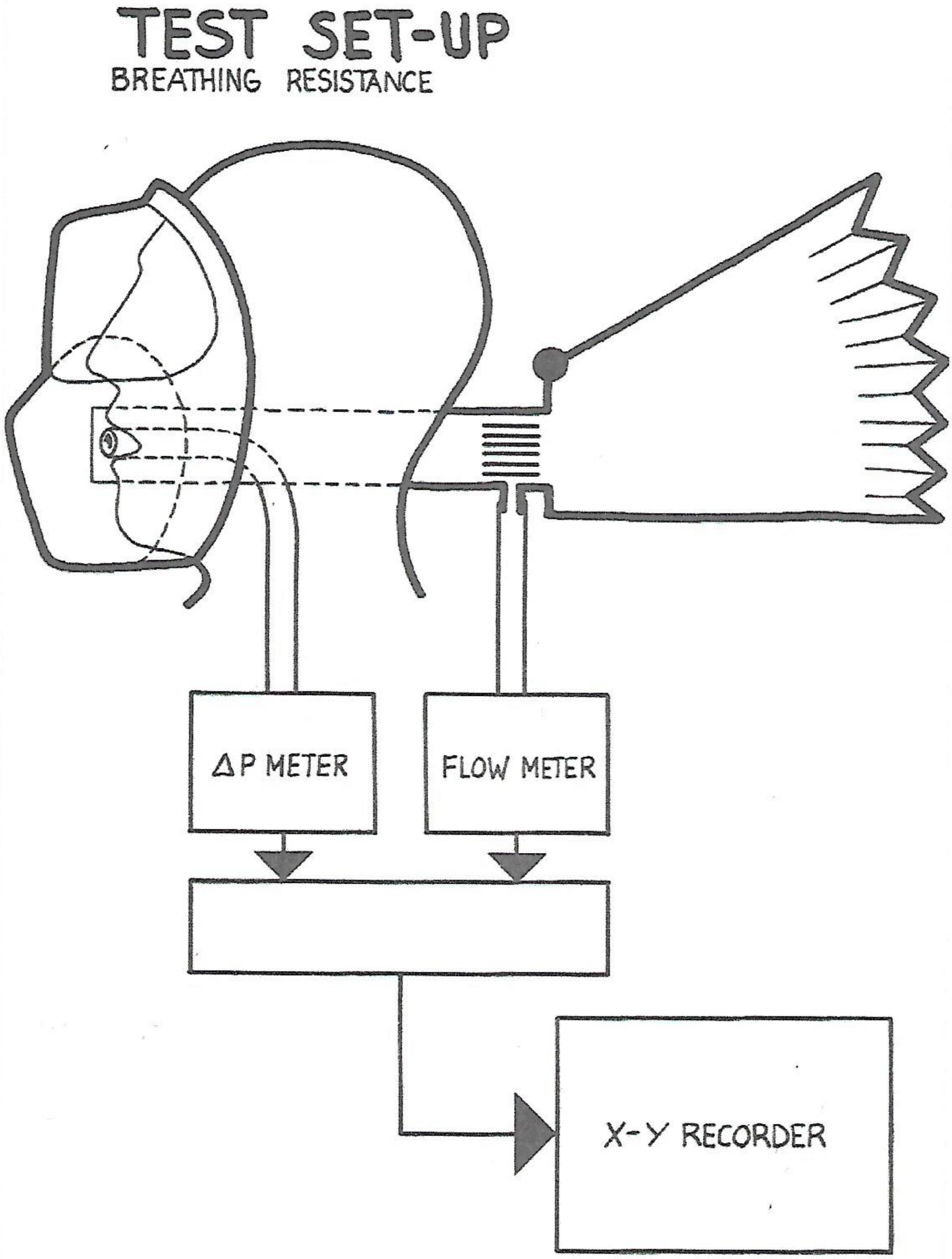


Figure 1. Suggested test program for firefighters' SCBA.

Some standards prescribe a static measurement of breathing resistance at a constant air flow. Although it is a very simple test to conduct and can easily be used for production control, it is not sufficient for physiological purposes. All pneumatic and mechanical systems exhibit hysteresis, which means that the resistance is different if measured at increasing or decreasing air flows. Also, there can be pressure vibrations in the system. Thus, only dynamic measurements can give meaningful results because all the variable factors are taken into account.

We used a machine test where a lung simulator was adjusted to different minute volumes (Figure 1). The ventilating pressure was measured in the inner mask within the full face mask. The result was recorded on X-Y recorder with the breathing resistance on the Y-axis and the air flow on the X-axis. All measurements were made with an AGA Spiromatic SCBA.

Some typical results are shown in Figures 2-4. We suggest that full performance of the apparatus must be at 20-bar cylinder pressure. An extreme work load condition can be simulated at 120 litres/minute volume.

In order to consider the physiological effects of using SCBA and to be able to make a direct comparison between different apparatus, we also used a method to measure the work of breathing. It is known from the diving physiology that if a complete tide of breathing is plotted in a P/V diagram, the area described is proportional to the work needed to take a breath.

This method has not been used extensively so far. In Figures 5 and 6, we show different work-of-breathing rates for different types of AGA SCBA. The test conditions are the same for both measurements. Figure 5 shows the work of breathing for an early model of AGA SCBA. Figure 6 shows the reduced work of breathing for the latest AGA SCBA improved 2.5 times. Total work is represented by the area inside the plot. We suggest that this method should be considered to specify a SCBA's breathing resistance.

Influence by High Work Load and Low Cylinder Pressure on the Protection Factor

Dahlback et al. has described a method of measuring inward leakage (1983). The test setup is presented in Figure 7. During the test, the pressure was measured in the cavity of the mask adjacent to the face seal according to the proposed European standard covering respiratory devices. The result was that no inward leakage could be detected as long as the mask pressure was positive. As soon as the pressure went "negative," inward leakage was detected.

Inward leakage could be detected down to as low as 0.0001%. In other words, Dahlback et al state that the protection factor is higher than 1,000,000 if the pressure in the face mask is positive. The report suggests that a protection factor of this size should be required for a SCBA to safeguard the user.

We followed up this result by measuring the pressure and air flow inside face masks with demand valves at different work loads and different cylinder pressures. Figure 2 shows the conditions at normal work load (40 litres/minute volume) and full air cylinder pressure (300 bar, 4400 psi). The mask pressure was never below 0.1 kPa (1 cm H_2O). The minute volume was increased to 120 litres giving a peak flow of approximately 400 litres/min (Figure 3). Even at that work load, the positive pressure was maintained, which can be seen from Figure 3.

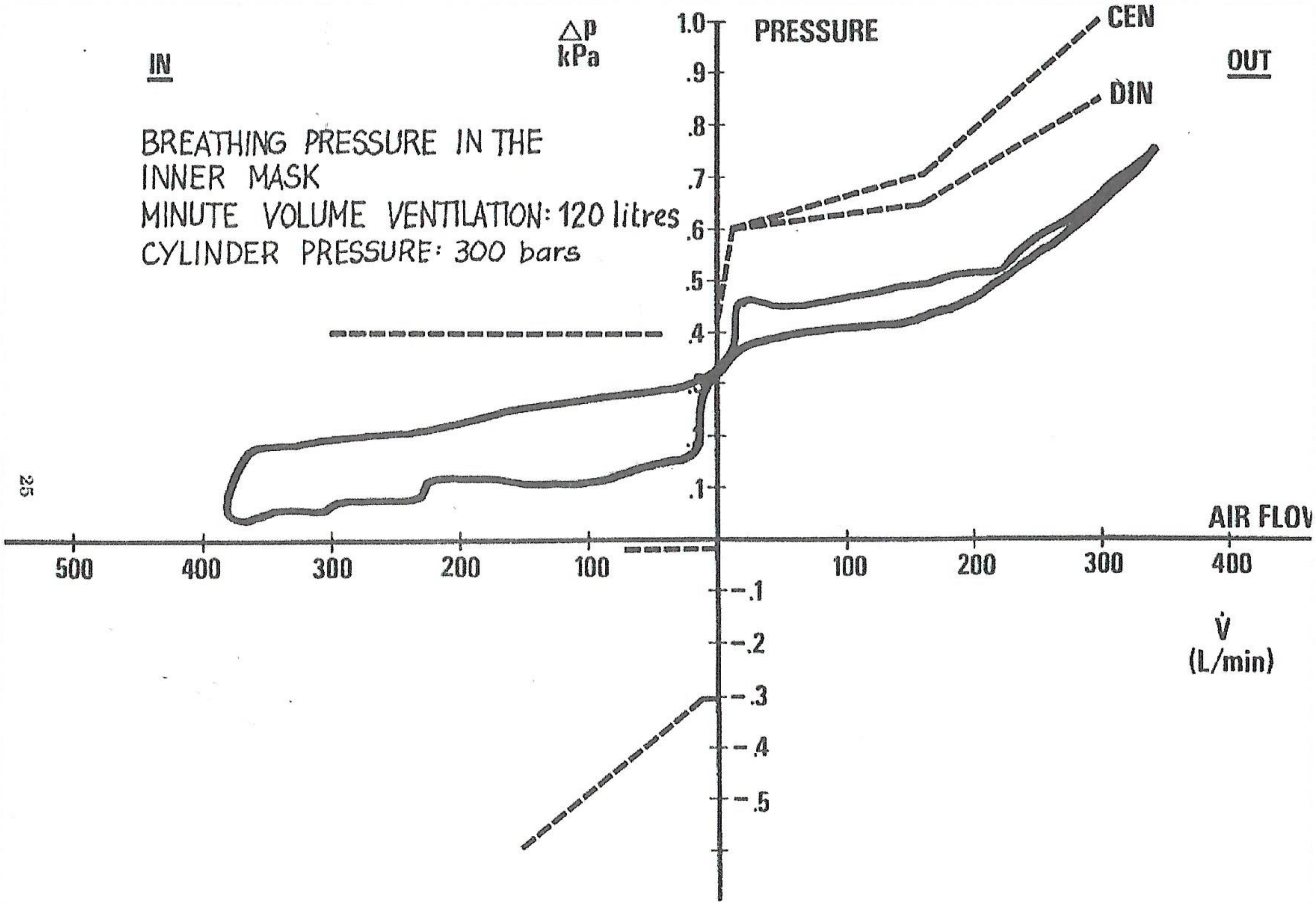
We next lowered the cylinder pressure to 20 bar (290 psi) which is the lowest pressure with full function proposed in the European standard. As seen in Figure 4, the positive pressure is maintained even at this cylinder pressure and the high work load.

It is our understanding from contacts with fire brigades in Europe that results like the ones presented in these diagrams represent a clear requirement for the performance of a firefighter's SCBA in the conditions we have described.

Measuring the SCBA's Dead Space

The effect on a SCBA's dead space under different environmental conditions is probably very limited and has not been studied. The physiological effect of the dead space in SCBA results mainly from reinhalation of exhaled CO_2. The proposed European standard specifies a maximum of 1% CO_2 in the inhaled air using a test method specified in the standard.

We measured the dead space according to this standard with the addition of a Douglas bag for control purposes (Figure 8). There are some SCBA with full face masks used without an inner mask (nose cap), and, therefore, we measured our AGA Spiromatic mask with and without the inner mask.



25

Figure 3. Pressure-volume diagram at high work rate and full gas supply.

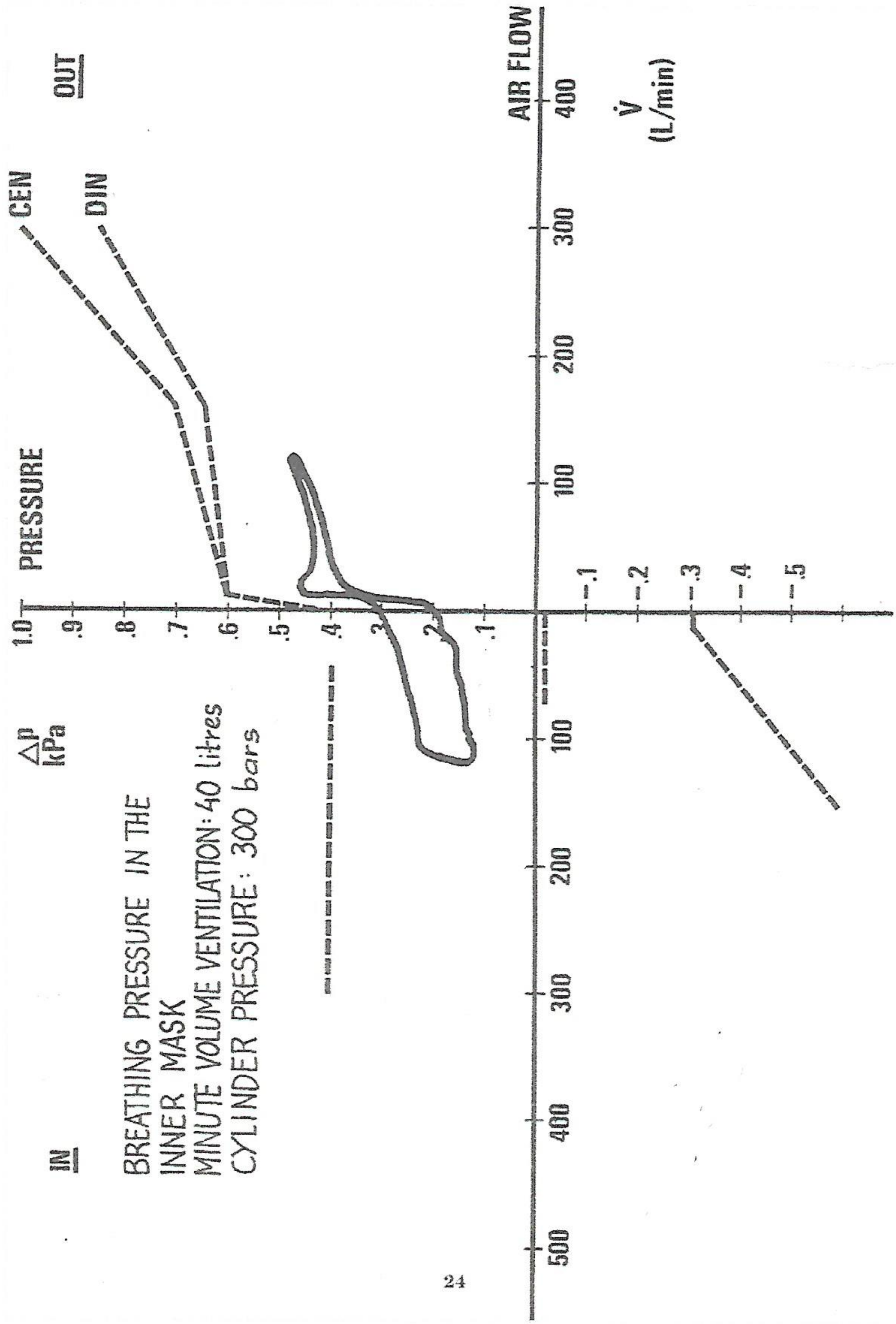


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Figure 2. Pressure-volume diagram for open-circuit SCBA at moderate work rate and full gas supply.

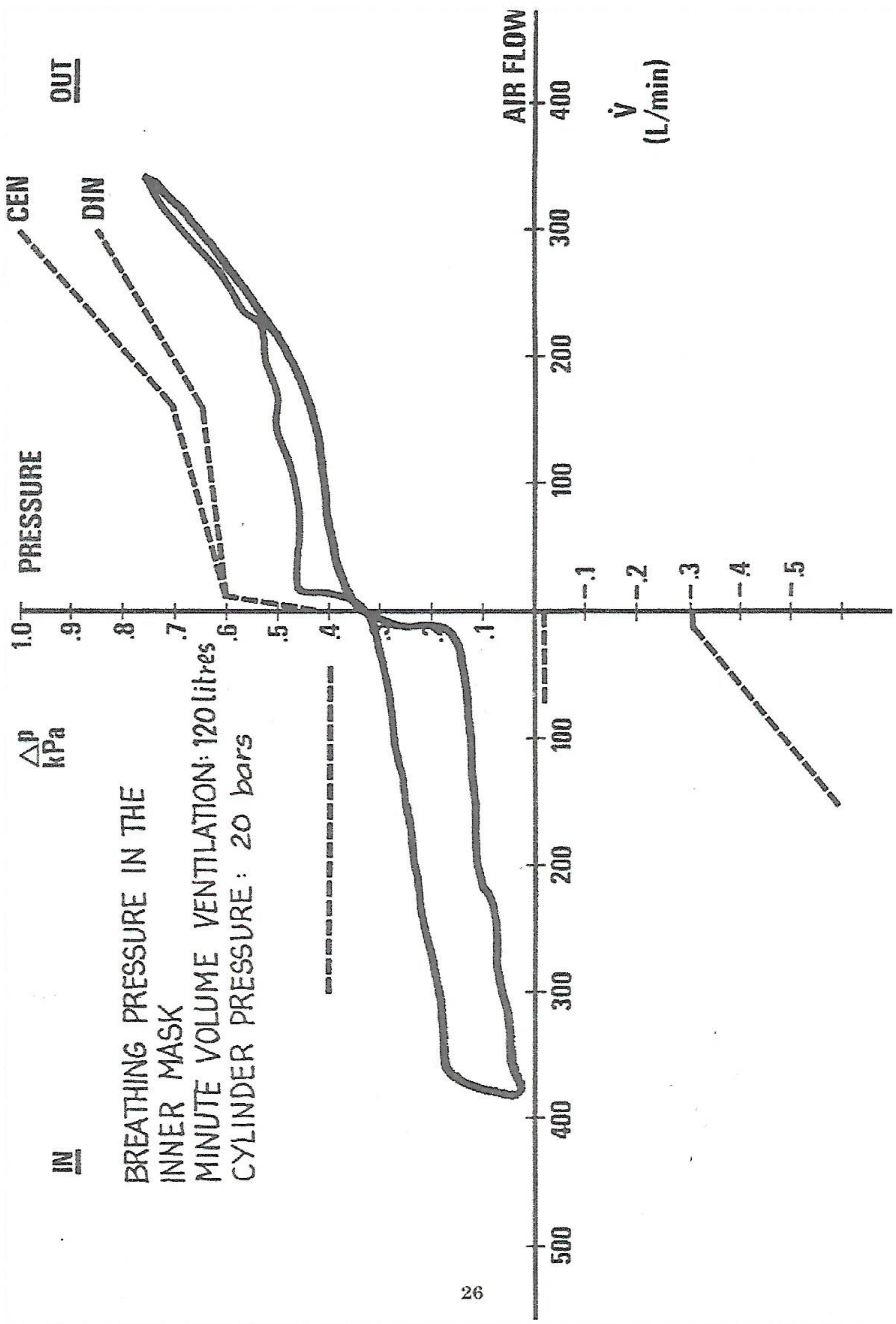

Figure 4. Pressure-volume diagram at high work rate and low gas supply.

26

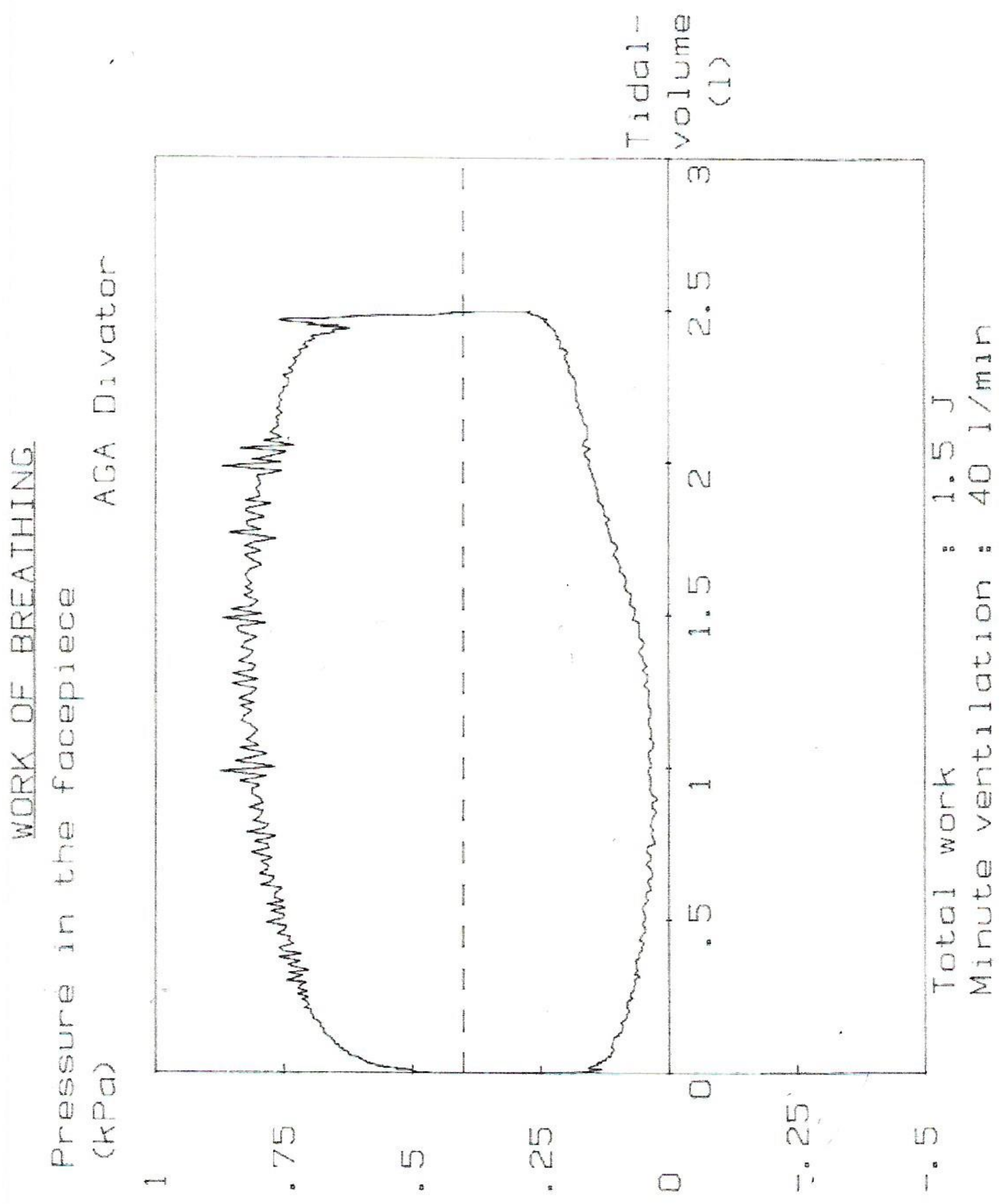

Figure 5. Work-of-breathing rate, normal.

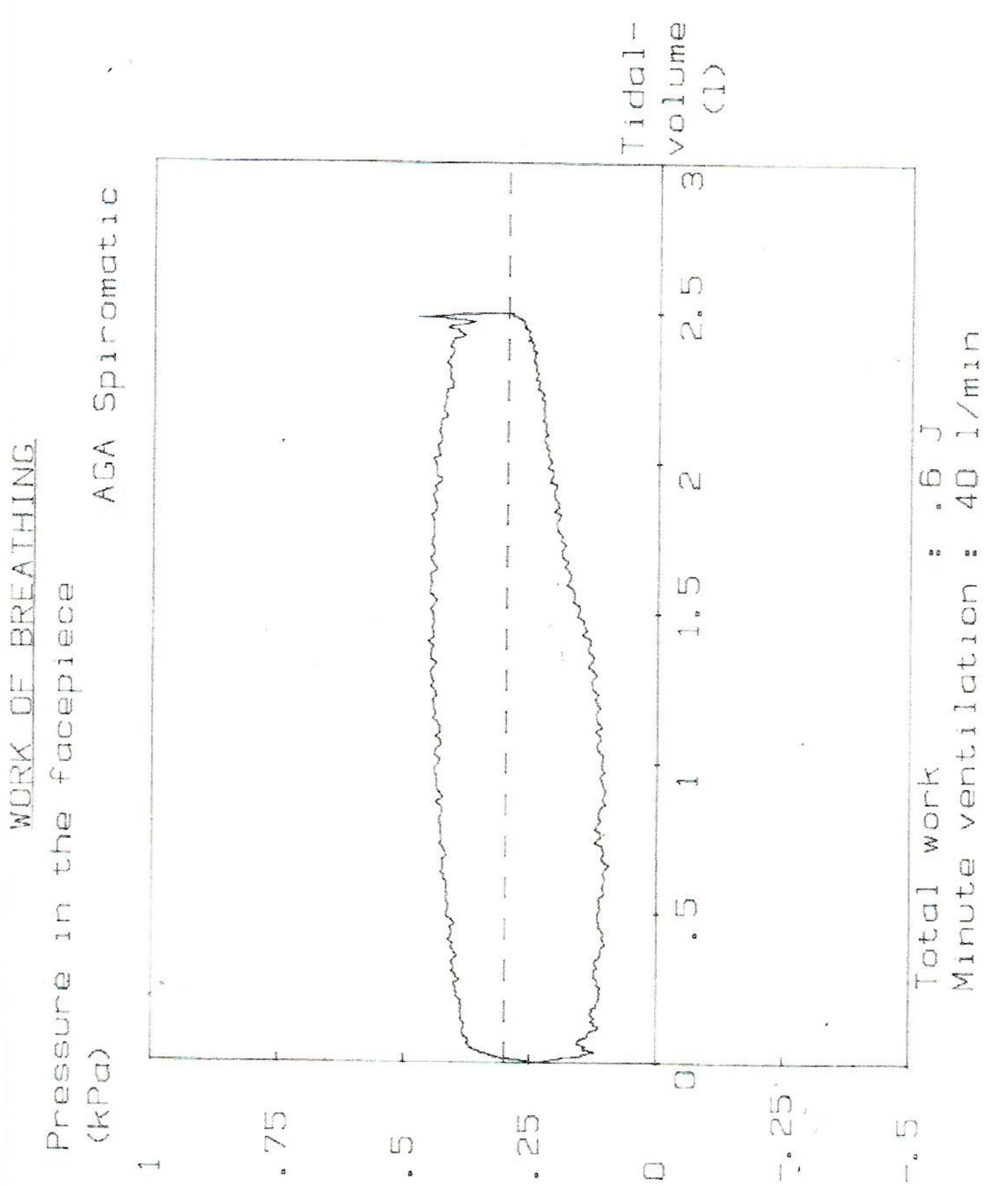

Figure 6. Work-of-breathing rate, reduced.

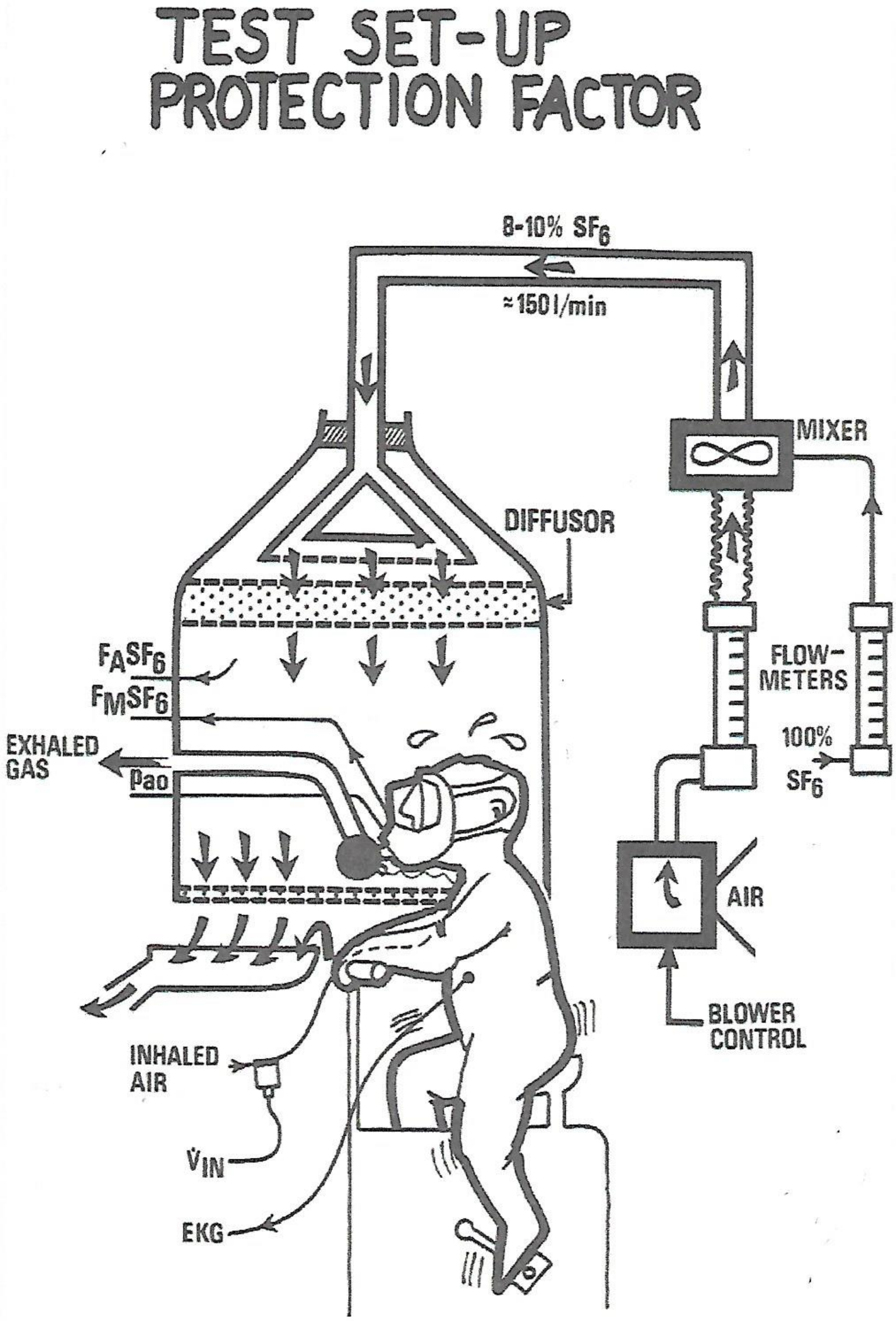

Figure 7. Test setup for measuring SCBA leakage (from Dahlback et al., 1983).

TEST SET-UP DEAD SPACE

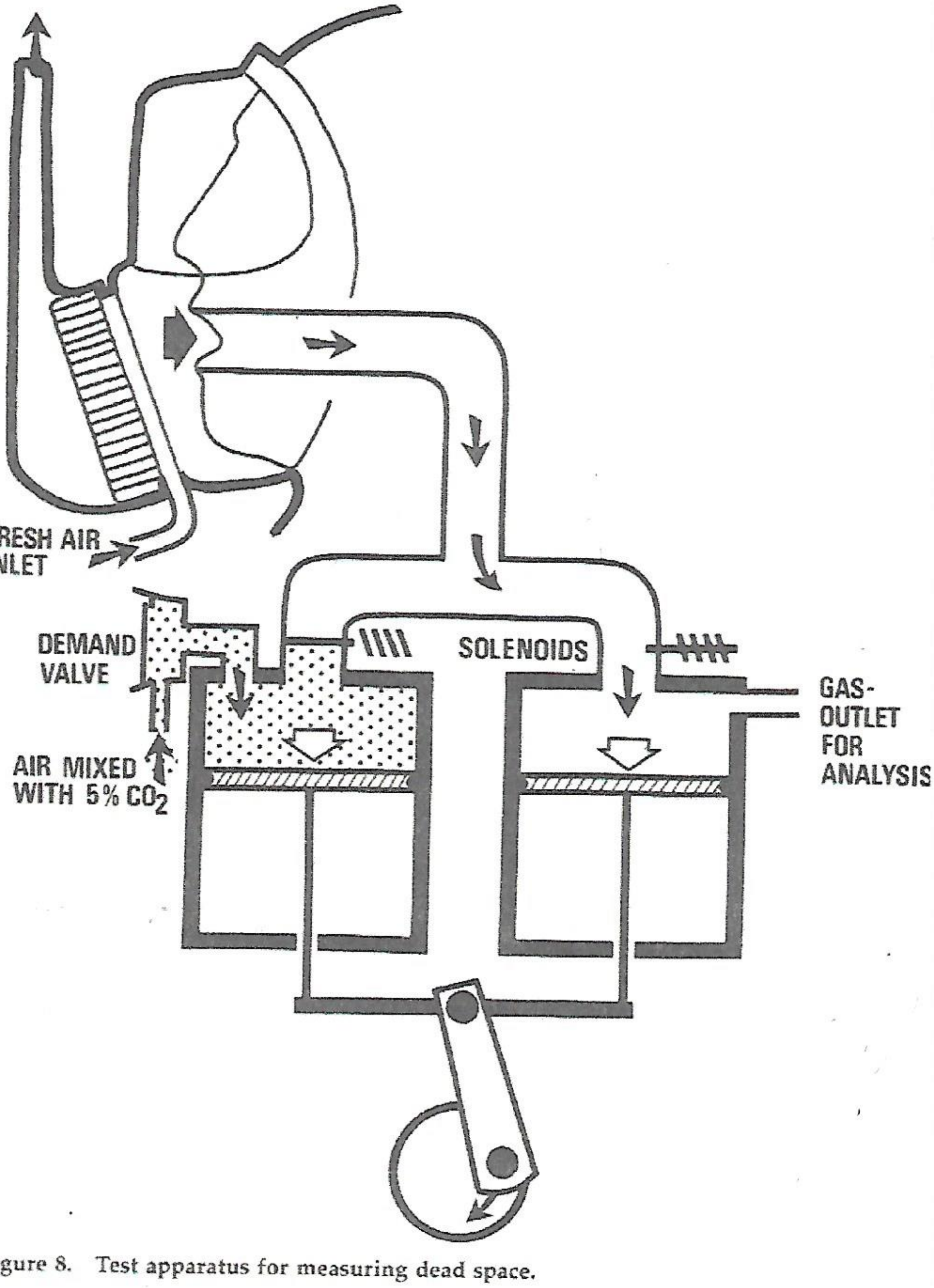

Figure 8. Test apparatus for measuring dead space.

Table 2. AGA Spiromatic test results of dead space with and without inner mask.

Spriomatic SCBA	% CO_2
With inner mask	0.72–0.80
Without inner mask	1.60–1.75

The results indicate that an inner mask should always be used (Table 2). It will also help to eliminate fogging of the lens and—so far as we know—it will have no negative influence on other parameters or on comfort.

Influence of Chemicals on SCBA's Performance

Firefighters are often exposed to unpredictable concentrations of chemicals. By using a pressure-demand system with suitable features, there is no risk of inhaling the chemicals. However, there are two considerations in this context: those chemicals which can influence the body and those chemicals which can influence the SCBA. The first aspect can be dealt with by using ventilated chemical suits. Such suits are available today and give very good protection. The second aspect—chemical influence on the SCBA—includes the influence of chemicals used for cleaning and disinfection and which sometimes can cause a reduction of the service life of a SCBA.

The main consideration when testing SCBA for chemicals is the number of different chemicals encountered in today's environments. We have tried to select a number of chemicals which are likely to be encountered during firefighter rescue operations and which are typically aggressive in one way or another to the SCBA. We are still at the beginning of such a test program, but we will present some discussion on this subject.

Chemicals at Normal Concentrations

The first objective of our test program was to compile a list of commonly used chemicals by concentrations which could easily be found during a rescue operation in a chemical plant or in connection with a train or road accident (Table 3). The test program is very simple (Figure 9). The apparatus is connected to a breathing machine working at 40 litres/minute volume. The apparatus is exposed to each chemical in the concentration mentioned for a period of 5 hours. The best test result would be no effect or influence on the functioning of the apparatus at the conclusion of the test. Such a result could guarantee approval of the apparatus.

Chemicals at Extreme Concentrations

The suggested list of chemicals is presented in Table 3. The test procedure is principally the same as the one presented under "normal" concentrations, however, due to the extra risk to the personnel involved in the test, we normally perform our tests together with chemical company personnel trained to handle the specific chemical to be tested. Therefore, the test method had to be adapted to the equipment available at the company where the tests are carried out. We normally ran the tests for 10 minutes with constant or intermittent spray of the chemical in question. The approved result is that the apparatus maintain its vital functions such as the protection factor during the test and 1 hour after exposure to the chemical. Other functions may be lessened or may be completely reduced resulting in the SCBA being so deteriorated as to require service repairs.

One typical test with liquid chlorine, made in cooperation with Uddeholm AB, Skoghall, Sweden, seriously damaged the face mask after the test, but it maintained its pressure-demand function during the entire time stipulated.

Cleaning and Disinfecting Chemicals

We have put together two lists of chemicals which are examples of the active cleaning substances and disinfectants (Table 4). They are often diluted in water or some alcohol together with

Table 3. Normal and extreme concentrations of commonly used industrial chemicals.

Chemical	% Spray of Liquid/Gas	
	Normal	Extreme
Sulfuric acid (H_2SO_4)	1	40
Chlorhydric acid (HCl)	0.05	15
Ammonia (NH_4OH)	0.5	10
Caustic soda (NaOH)	5	40
Ethanol (C_2H_5OH)		96
Toluole ($C_6H_5CH_3$)	100	
Trichlorethylene ($CHCl=CCl_2$)	100	
N-heptane (C_7H_{16})		100
Vinylchloride ($CHCl=CH_2$)	0.05	100
Formaldehyde (CHOH)	0.4	100
Styrene ($C_6H_5CH=CH_2$)	0.4	100
Chlorine (Cl_2)	0.05	100
Sulphur dioxide (SO_2)	0.02	100

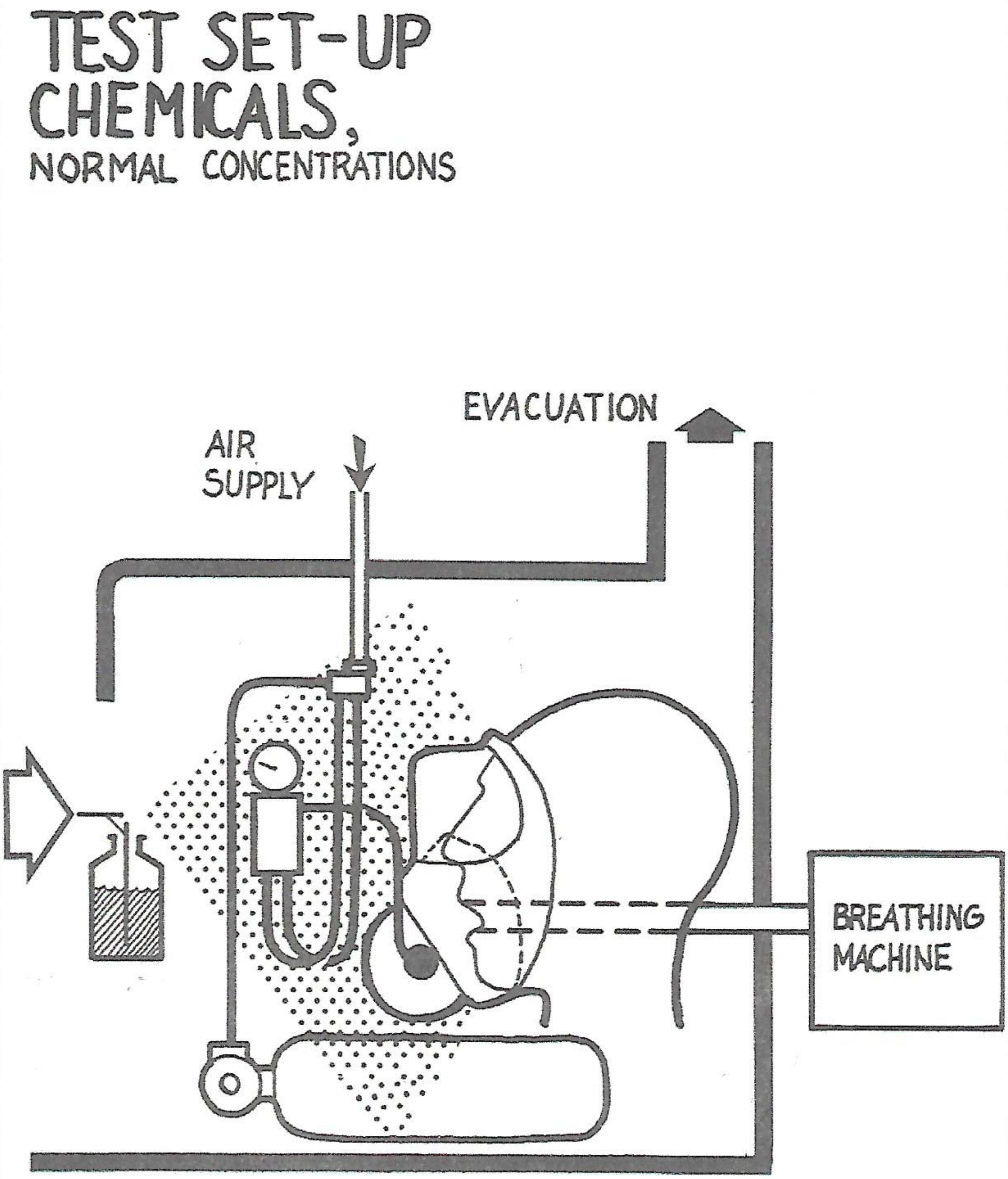

Figure 9. Apparatus for testing chemical exposure to SCBA.

Table 4. Cleaning and disinfecting chemicals tested.

Chemical	Concentration (%)
Cleaning	
Sodium hypochlorite	5
Sodium perborate	5
Sodium laurylsulfat	5
Diethanolamid fatty acid	5
Disinfecting	
Chloramin	5
Chlorhexidin	0.5
Ammoniumchloride complex	0.5
Cetylpyridinchloride	0.5

other components such as tensids, anti-foam, PH-adjusting or complex stabilizer (considered in the list for "normal" chemicals).

The test object, normally parts of the face mask with the demand valve, is dipped into a container with the chemical in question for up to 30 days with inspections after 1, 3, 10, and 30 days. The approved result is that no chemical be absorbed by or affect the test object. This can be checked by weighing and inspecting the object before and after the test.

Influence of Heat and Water Spray on the SCBA's Function

To simulate the common situation where a firefighter's SCBA is first heated up and then exposed to cold water, we examined only the environmental effects on the face mask and demand valve. The mask was placed in a heat chamber and heated to 100°C (Figure 10). The mask was observed from the outside. Of special interest was the condition of the lens. The mask was then repeatedly sprayed with 10 cm^3 of water (0-5°C). No effect was observed. The mask was tested on the breathing machine before and after the test to make sure that there were no subsequent effects on the demand function.

Influence by Cold on SCBA's Function

We suggest that a firefighter's SCBA should be tested at −30°C as a standard requirement. For testing SCBA functions in cold environments, laboratory tests can hardly give a full answer to apparatus performance because of problems simulating moisture in the exhalation air, etc. We support the test procedure described by NIOSH-MSHA using man trials, but we would like to suggest a change in the test setup.

By using a bicycle ergometer in the test, as seen in Figure 11, the following parameters can be measured: breathing resistance, mask pressure (+ or −) inside the face seal to represent the protection factor, and temperature of the inhalation air. We have performed such tests starting from a full air cylinder (300 bar, 4400 psi at room temperature) at a work load giving a minute volume of approximately 40 litres. The results are shown in Figure 12.

The pressure remained positive giving the required protection factor. The air temperature was down to −20°C which seems to have been acceptable. We have also studied the functions of low pressure alarm, field of vision, remaining time of duration (leakage test), and storage gas indicator (pressure gauge), and found no negative influence.

TEST SET-UP HEAT +WATER

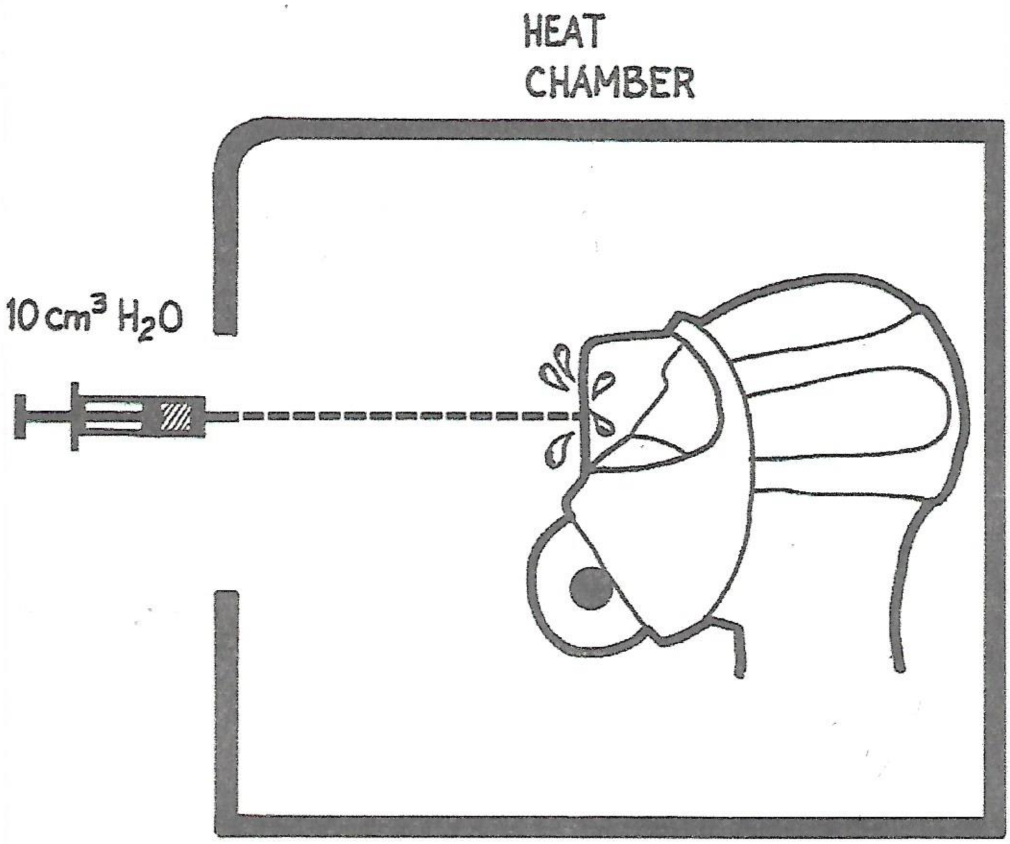

Figure 10. Heat and water test setup.

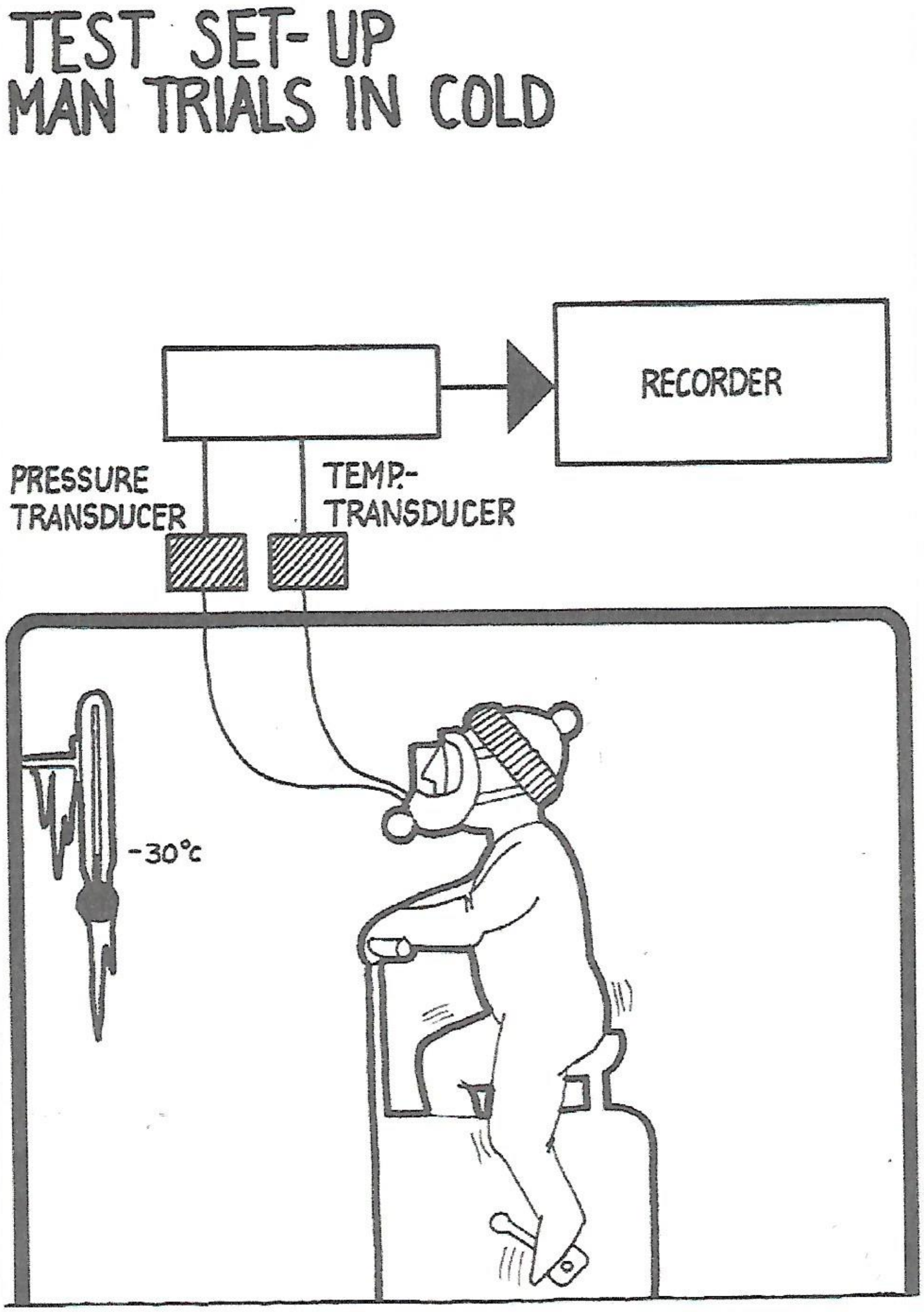

Figure 11. Human subject cold-test apparatus.

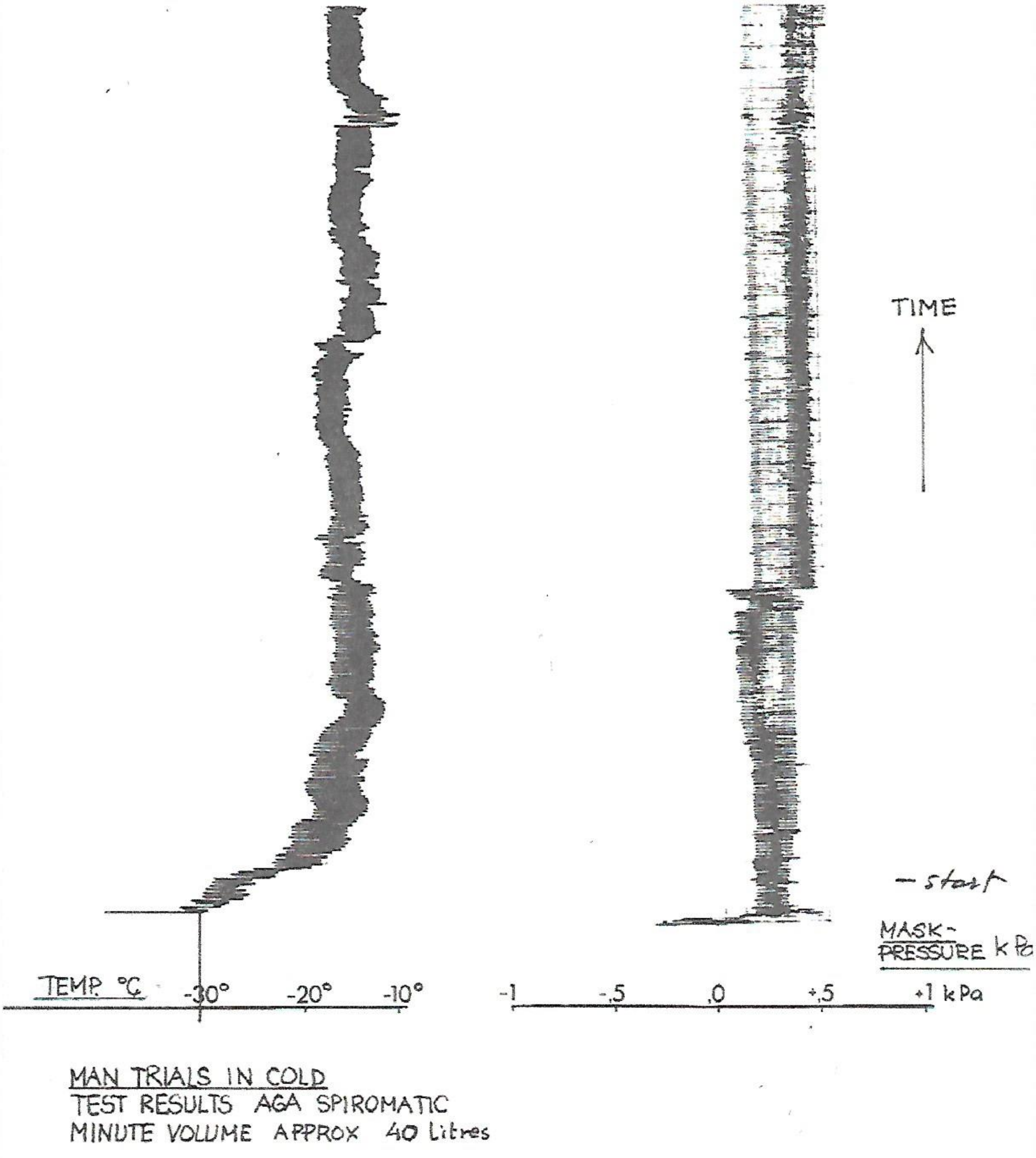

Figure 12. Typical test results for human subject in cold trials (40 litres/minute volume, AGA-Spiromatic).

Conclusion

We stated that the firefighters' environment is probably the most severe of all environments where SCBA are used. We welcome any initiative from the international firefighter organizations to specify what they require from the SCBA. Manufacturers have to test SCBAs by programs like those described in this paper together with many other tests to ensure their products' function. We think it would be of value to both manufacturers and users to have a standardized test program. It will make the manufacturers' presentations of their equipment's performance comparable, and it will make it easier for the user to select the appropriate equipment. In the development of environmental test standards, it is important to note that performance levels represent realistic exposure environments. Users should be involved in such standards so that testing levels are agreed upon.

Bibliography

European Committees for Standardization (1976), *Recommendation for an European Standard Covering Respiratory Protection Devices,* CEN/WG 79/SG 3/25 March.

European Committees for Standardization (1976), *Proposal for an European Standard Covering Respiratory Protective Devices-Self-Contained, Open-Circuit Compressed Air Breathing Apparatus,* CEN/WG 79/SG 6/18 June.

National Institute of Occupational Safety and Health (1972), *Respiratory Protective Devices,* Title 30 CFR Part 11, Subpart H, NIOSH-MSHA Certification Tests. [U.S.A.].

Held, Bruce J. and Charles A. Harder (1980), "Effectiveness of SCBA in a Fire Environment," Paper presented at the *International Environment and Safety Conference,* September 1-4, London, ENGLAND.

Dahlback, Gunnar O. and Lubos Novak (1983), "Do Pressure-Demand Breathing Systems Safeguard Against Inward Leakage?" *Am. Ind. Hyg. Assoc.,* vol 44, No. 5 (May), pp. 336-340.