

The Testing Of Closed-Circuit Breathing Apparatus

- Human Testing And Simulator Testing -

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Introduction

When Hauptstelle für das Grubenrettungswesen, the mine rescue centre, was founded in Essen in 1910, the testing and development of breathing apparatus for mining purposes was assigned to its scope of tasks. After installation of the testing facilities, specimen of breathing apparatus were tested by application of a constant air stream until, in the early 20s, the first breathing machine known as the artificial lung was constructed.

In 1925, Deutscher Ausschub für das Grubenrettungswesen, the German mine rescue committee, issued the first directives for construction and testing of breathing apparatus for mining purposes. Since then, breathing apparatus for mining is tested systematically. Today, not only functional testing by lung simulators is carried out on breathing apparatus but also the suitability of the materials used, viz. resistance against sterilization agents, temperature, humidity, and vibration impacts, is tested. In addition, the wearing properties of the units is found out about in man-tests in the training gallery and in the field. The lung simulator used nowadays by the testing authorities in the Federal

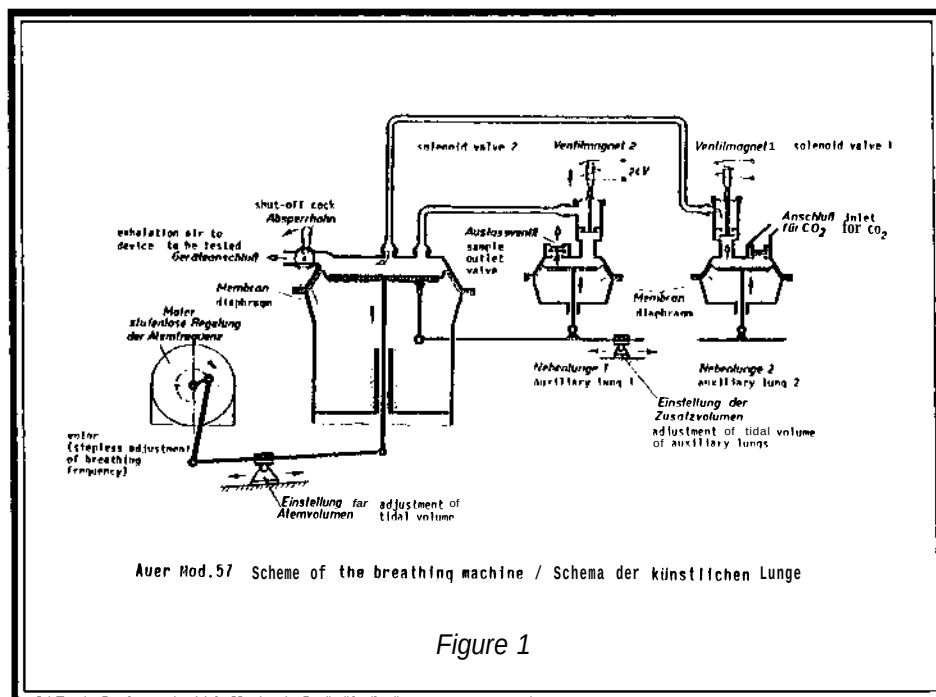


Figure 1

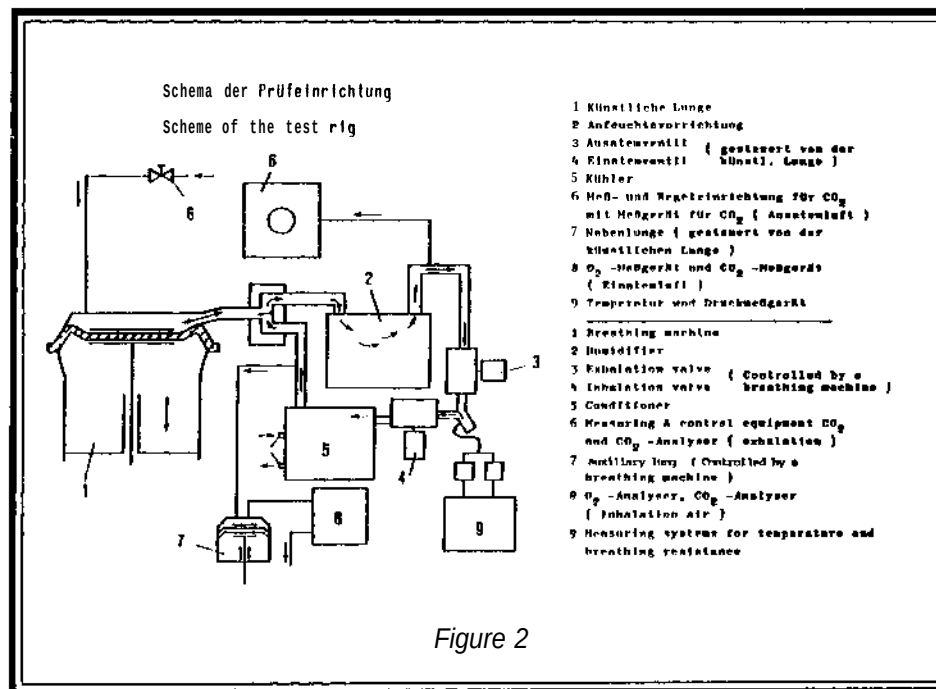


Figure 2

Republic of Germany is the Auer-Membranlunge, Modell 57, with auxiliary lungs (Figure 1).

This simulator allows the breathing frequency to be continuously adjusted between 10 and 45 breathing cycles per minute, and the breathing depth can be adjusted in the range between 300 and 3800 ml. During the inhalation phase, air can be tapped from the respiratory circuit by the auxiliary lung for analysis and, also by the auxiliary lung, CO₂-containing air can be proportioned during the exhalation phase. In some countries, lung simulators with control equipment are used which can be run on breathing curves previously recorded from a man-test.

Human metabolism, i.e. conversion of oxygen to carbon dioxide can be simulated quite exactly by these systems, e.g. by withdrawal of pure oxygen and simultaneous proportioning of carbon dioxide, or by conversion in a suited combustion system. Such a testing set-up which can adapt itself within seconds to any change of breathing frequency and breathing depth as well as to any change of the composition of respiration air in the circuit is necessarily costly and requires a high amount of maintenance. For the determination of the working duration and for checking the physiological requirements of a breathing apparatus such a lung simulator is, in my opinion, not

required. Investigations run at **Hauptstelle für das Grubenrettungswesen** have shown that comparable results are obtained if, during the tests, the changing minute volumes as occurring in the field are replaced by an average minute volume. Prerequisite for comparative testing with the lung simulator is the stipulation of the minute volume, of the CO₂ content, and of temperature and humidity of the exhalation air.

In the Federal Republic of Germany the lung simulator is used for testing breathing apparatus for work and rescue purposes with rated minute volumes of 30, 40, and 50 l/min. The minute volumes were determined by comparative measuring during work and escape exercises with breathing apparatus in the testing gallery as well as at collieries on the surface and underground.

The adjusted CO₂ content of the exhalation air amounts to 4 to 5% by vol., dependent on the minute volume. The exhalation air is heated to a temperature of 37°C and saturated. The above-mentioned physiological data were specified jointly by the European testing authorities, and integrated as performance specifications in the guidelines for construction and testing of chemical oxygen self-rescuers issued by the Standing Committee for operational safety and health of the Commission of the European Communities, and in the draft standard prEN 145 "Self-contained oxygen breathing apparatus" issued by the European Standardization Committee. The facilities and methods for testing breathing apparatus were specified jointly as well and, accordingly,

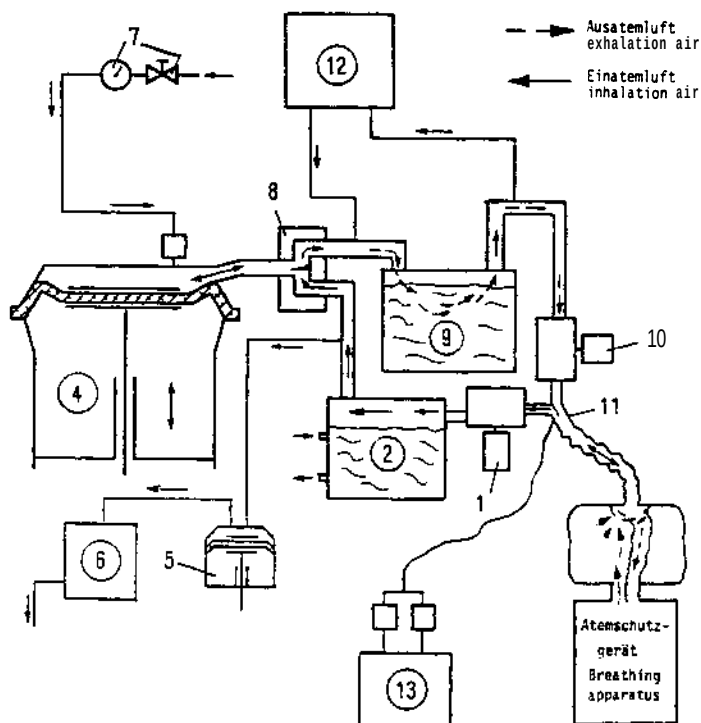


Figure 3

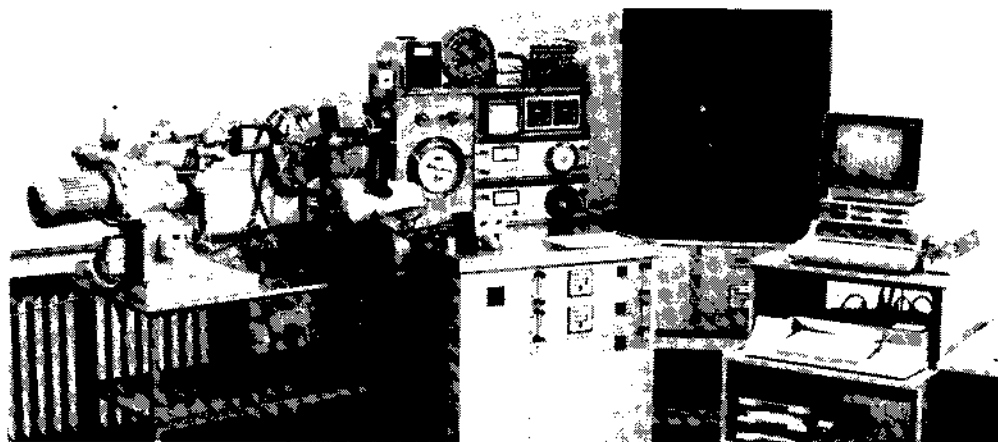


Figure 4: Test-rig with SCSR Mod Auer SSR 120

are identical as far as the key components for testing are concerned, so that in case of comparative testing reproducibility is assured.

Testing Procedures With The Lung Simulator

Figure 2 shows the complete testing set-up for self-contained breathing apparatus, and Figure 3 shows the complete testing set-up with an oxygen self-rescuer connected to it. When testing the unit at a minute volume of 35 l/min, the lung simulator is adjusted to 20 breathing cycles per minute and a volume of 1.75 l per breathing cycle.

During the inhalation phase, 1.75 l/min of the respiration air is taken from the unit via the opened inhalation valve (1) which is controlled electrically by the lung simulator. In the conditioner (2) the inhalation air is cooled down so that,

in the lung simulator, the air temperature is 25°C.

The cooling water flow is controlled by a temperature measuring system in the simulator. From the conditioner, the respiration air is cycled via the pressure-controlled inhalation valve (3) into the lung simulator (4). During inhalation, a respiration air quantity corresponding to human oxygen consumption is tapped from the circuit between conditioner and valve control via the auxiliary lung (5), and the carbon dioxide and the oxygen content are determined (6). At the same time, 78.5 ml corresponding to 4.5% of CO₂ are proportioned via the measuring and control system (7) to the lung simulator. During exhalation, the circuit air is cycled from the simulator via the exhalation valve (8), the humidifier (9), the solenoid valve (10), and the connector (11) to the oxygen self-rescuer. In the humidifier, the exhalation air is saturated and heated so that, at the connector the air temperature amounts to 37°C. By the measuring unit (12) the carbon

dioxide concentration of the exhalation air is measured. In the connector (11) the temperature of inhalation and exhalation air is measured by thermocouples - the breathing resistance is measured as well - and all data are recorded (13). The measured results of the tested unit and the variable data of the test rig, e.g. temperature, CO₂ and O₂ concentration of inhalation and exhalation air, and the tapped volume are displayed and recorded.

Additionally, the most important data are displayed on VDU and printed out. Breathing resistance, temperature of inhalation and exhalation air as well as carbon dioxide break-through are plotted in form of a diagram by a plotting unit. All data pertaining to the unit, the testing procedure, and the measured results, are recorded on magnetic discs.

Lung Simulator Test

The testing procedures in force are described in the following by the example of the test of a KO₂ oxygen self-rescuer. Figure 4 shows the test

Zeit Time (min)	Atemwiderstand (mbar) Breathing-resistance		Temperaturen / Temperature (°C)		CO ₂ conc. (Vol.-%) concentrations		O ₂ -gehalt (Vol.-%) O ₂ conc. (Vol.-%)
	Inspiration -	Expiration +	Einatmung Inspiration	Ausatmung Expiration	Einatmung Inspired	Ausatmung Expired	
Beginn	3,6	4,3	-	37,0	-	4,50	21
5	4,5	3,9	28,1	37,5	0,65	5,15	78
10	4,5	4,2	31,4	37,5	0,70	5,20	92
20	4,6	4,3	34,3	37,2	0,70	5,20	96
30	4,7	4,3	36,4	38,8	0,70	5,20	96
40	4,8	4,6	39,1	37,7	0,70	5,20	96
50	5,0	4,7	41,4	37,6	0,70	5,20	96
60	5,2	4,8	43,2	38,8	0,70	5,20	96
70	5,4	5,0	45,1	39,1	0,70	5,20	96
80	5,6	5,3	47,2	39,3	0,70	5,20	96
90	6,0	5,3	48,6	39,9	0,95	5,45	96
100	6,5	5,3	49,1	40,6	1,20	5,70	95

Einstellung der künstl. Lunge 20 x 1,75 l/min-AMV 33 l/min
Lung simulator test AT 35 L.min⁻¹

SGSR Auer SSR 120 - Test results / Messergebnis einer Prüfung

Figure 5

set-up with a type Auer-SSR 120 (size category K 90) oxygen self-rescuer supplied by Auergesellschaft GmbH, Berlin, an affiliate of MSA. On the left, the lung simulator is shown, in the centre the various measuring and control devices, and on the right the air-conditioned chamber. By special arrangement of the lung simulator, also units placed in the air-conditioned chamber can be tested in the temperature range between -40°C and 100°C and in the climatic range between -20°C and 95°C.

On the table in Figure 5 the results of a test run on the Auer oxygen self-rescuer 120 are shown. The tests were run at a minute volume of 35 l/min. In these tests, the unit recorded operation periods of 100 min. The term "operation periods" in this context stands for the testing time which a unit stands until specified physiological thresholds are exceeded. The threshold values read: For inhalation air an O₂ content of > 21% by vol., a CO₂ concentration of < 1.5% by vol. and a temperature of < 50°C; for inhalation resistance, a pressure variation of +6.5

mbar and -6.5 mbar.

Figure 6 shows a graphic display of the test results.

Since the working duration of KO₂ oxygen self-rescuers depends on the minute volume, additional tests with various minute volumes were run. Figure 7 shows the working duration

of 120 type self-rescuer as a function of the minute volume. This period ranges between 60 minutes at a minute volume of 50 l/min, and 400 min at a minute volume of 10 l/min.

Even though nowadays we are in a position to check breathing resistance, chemical performance, and function of breathing apparatus by simulators, I am convinced that also in the future man-tests will not become superfluous. The opening and putting-on of breathing apparatus, the wearing properties under various operation conditions, the protection devices against contact with excessively hot components, human respiratory ducts becoming dry, irritative cough, bad taste and bad smell, tightness of the face mask or mouth piece, all can only be determined and assessed by man tests.

For this reason, any breathing apparatus undergoes man-testing in the training gallery and in the fuel subsequent to successful laboratory testing.

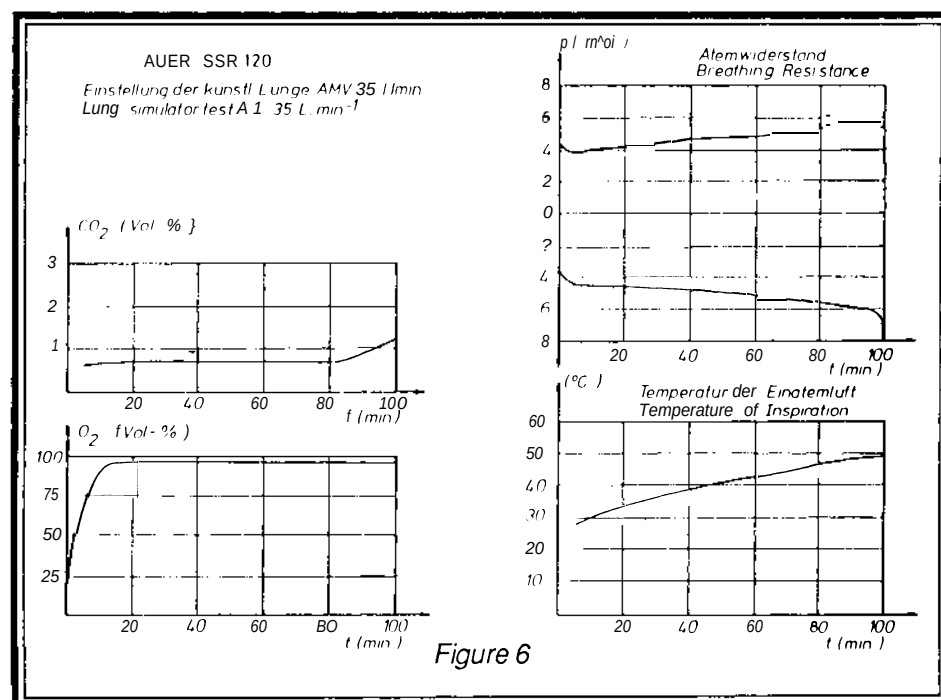
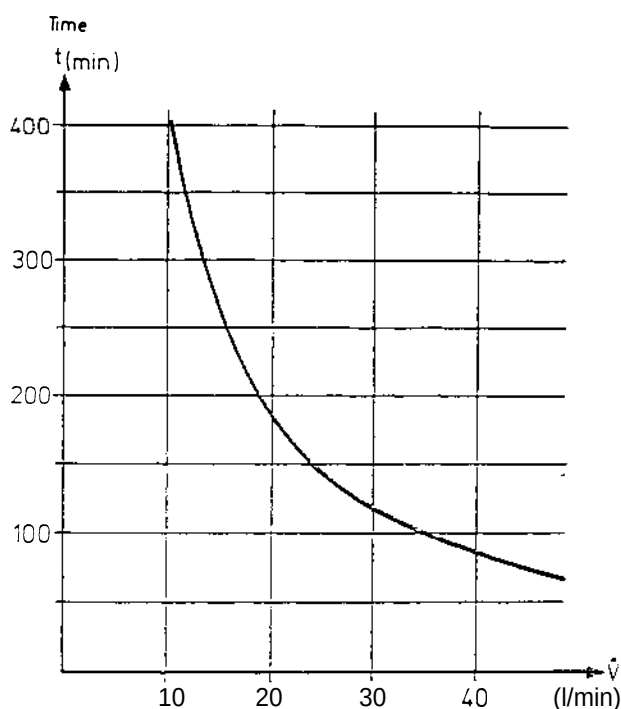


Figure 6



Atemminutenvolumen
Breathing minute volume

Auer Sauerstoffseltretter SSR 120

Haltezeit in Abhängigkeit von Atemminutenvolumen
Working duration depending from breathing minute volume

Figure 7

under test ranged between 19.3 and 48.9 l/min. The average minute volume of all experimental runs underground is of 31.5 l/min. The escape speeds recorded varied according to the features of the escape way:

20 to 60 m/min in roadways,
8 to 25 m/min in coalfaces, and
4 to 8 m/min in shafts.

The self-rescuer man test in the training gallery is designed to simulate the escape conditions prevailing underground. The training gallery of our mine rescue centre used for this purpose leads over 495 m with heights between 0.75 and 2 m on four floors. The training gallery can be darkened completely, filled with smoke, and heated to a temperature of 40°C.

The man test is subdivided into four similar phases of 30 minutes each, one following immediately the other (Figure 8). In each of the phases the test person needs to perform as follows: running over 1 minute, speed: 8 km/h; 4 minutes walk, speed: 3.3 km/h; 23 minutes travel through the training

Escape Exercises In The Training Gallery And In The Field

Sixty-nine escape exercises with 211 test persons, average age 41 years, are the basis for man test arrangements for self-rescuers.

During the escape exercises underground with put-on breathing apparatus, minute volume and escape velocity were determined for various performances on the escape way, e.g. creeping in coalfaces, bent walking in roadways, climbing in staple shafts, walking upwards and downwards gradients, etc. The average minute volumes recorded for the individuals

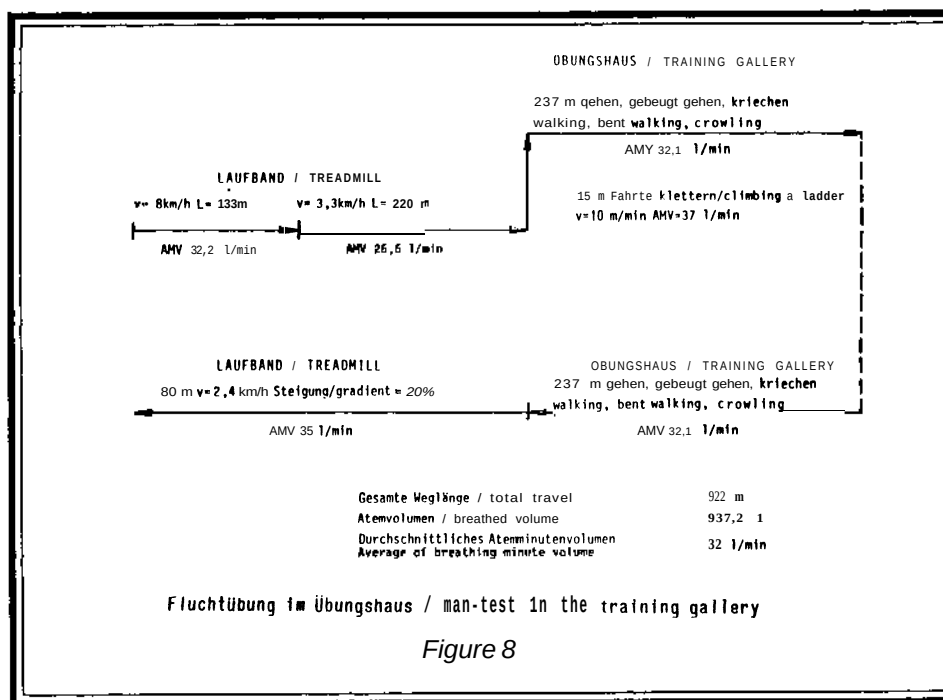


Figure 8

gallery; 2 minutes walk at 2.4 km/h and 20% gradient.

The average minute volumes recorded in these tests for the individual persons ranged between 32 and 37 l/min.

During the exercises, the test persons' rectal temperature, the breathing frequency, the pulse frequency (by electrocardiogram, if necessary), and the oxygen concentration of the inhalation air can be monitored and recorded by telemetric systems.

Temperature and carbon dioxide of the inhalation air are measured prior to and after each special performance. After each testing phase and at the end of the exercise the test persons are to give a personal assessment covering:

- temperature of the inhalation air,
- breathing air,
- irritation-conditioned cough,
- breathing frequency,
- weight,
- wearing properties.

The assessment marks range from "excellent" (+2) to "very uncomfortable" (-2) (Fig 9). Furthermore, wearing and putting-on characteristics of the units are tested.

The final assessment of any breathing apparatus is based on the results of the lung simulator tests, those of the other equipment tests, and of the man tests as well as on experience made when taking the self-rescuers out of the containers and putting them on, and eventually on the statements of the wearers.

Summary

In comparative assessment of a large number of lung simulator tests and man tests run in the training gallery and underground it was found that the measured values coincided well. Thus, e.g. the working duration of the Auer

SSR 120 ranged between 100 and 110 minutes on the simulator and between 108 and 120 minutes in the man tests. All physiological thresholds, e.g. breathing resistance, temperature of the inhalation air, CO₂ binding, and O₂ development can exactly be measured in simulator tests. These tests are reproducible. Objective comparative assessment can be administered to makes of various manufacturers.

The man tests are a necessary complement of the simulator tests. In man tests, the persons can give subjective assessment of the units' features in terms of properties when put into operation, wearing properties, and breathing properties.

For this reason, the testing authorities in the Federal Republic of Germany run lab tests on lung simulators and complementary man tests.

test subject Versuchsperson: _____	test Übung: _____
remarks of test subject / Bemerkung der Versuchsperson	
1. INHALATION AIR TEMPERATURE EINATEMLUFTTEMPERATUR excellent sehr angenehm (2) fairly good angenehm (1) acceptable neutral (0) uncomfortable unangenehm (-1) very uncomfortable sehr unangenehm (-2)	4. BREATHING RESISTANCE ATEMWIDERSTAND excellent sehr angenehm (2) fairly good angenehm (1) acceptable neutral (0) uncomfortable unangenehm (-1) very uncomfortable sehr unangenehm (-2)
2. INHALATION AIR ATEMLUFT very humid sehr feucht (2) humid feucht (1) acceptable neutral (0) dry trocken (-1) very dry sehr trocken (-2)	5. WEIGHT GEWICHT very light sehr angenehm (2) light angenehm (1) acceptable neutral (0) heavy unangenehm (-1) exceedingly heavy sehr unangenehm (-2)
3. COUGHING HUSTENREIZ none nein slight leicht strong stark	6. WEARING TRAGEEIGENSCHAFTEN very light sehr angenehm (2) light angenehm (1) acceptable neutral (0) heavy unangenehm (-1) exceedingly heavy sehr unangenehm (-2)
7. remarks _____ Bemerkungen _____	

Figure 9