

COMPARISON TESTING OF OXYGEN SELF-RESCUERS

by Nicholas Kyriazi¹

*** ABSTRACT

A performance study of oxygen self-rescuers of varying durations from the United States and other countries was undertaken as an assessment of present worldwide technology. The apparatus were tested on a Breathing and Metabolic Simulator in the Life Support laboratories of the Bureau's Pittsburgh Research Center. Parameters monitored during the testing were inhaled levels of CO₂, O₂, inhaled gas temperature, and breathing resistance. The metabolic demand placed on the apparatus represented the 50th percentile miner performing Man-test 4, as described in 30 CFR 11H, for 60 min. Results presented include apparatus duration and subjective comments as well as averages and peaks of monitored parameters.

*** INTRODUCTION

On June 21, 1981, coal mine operators in the United States were required to make available to each underground coal miner a Self-Contained Self-Rescuer (SCSR). The regulations (30 CFR 75.1714) require that each person in an underground coal mine wear, carry, or have immediate access to a self-rescuer that provides an oxygen source. The oxygen self-rescuer will replace the filter self-rescuer (FSR) as primary escape equipment. FSR's protect only against low levels of CO.

In an effort to compare performance of the six SCSRs approved by the National Institute for Occupational Safety & Health (NIOSH), a Breathing and Metabolic Simulator (BMS) was used to test the apparatus at a work rate equal to the

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average rate of a 50th percentile miner performing Man-test 4 for 1 hour as described in 30 CFR 11H. In addition to the six U.S. apparatus, six other oxygen self-rescuers from different countries, and four prototypes developed for the Bureau over the past decade and stored since then were tested. All of the apparatus tested are listed in Table 1, with their intended durations, country of origin, oxygen source, and weight.

It was not attempted in this study to do an in-depth analysis of the design of each apparatus but merely to scrutinize performance behavior.

*** DESCRIPTION OF APPARATUS

All of the apparatus tested are of two types: chemical oxygen or compressed oxygen. Most of the chemical oxygen apparatus tested use potassium superoxide (KO_2) for both the oxygen source and the CO_2 absorbent. One of the chemical oxygen apparatus uses a sodium chlorate candle for an oxygen source and a separate chemical bed for CO_2 absorption.

The compressed oxygen apparatus use bottled oxygen under high pressure for the oxygen source with a separate chemical bed for CO_2 absorption.

The two types of apparatus share many common parts, such as the mouthbit, breathing hoses, CO_2 absorbent bed, breathing bag and relief valve. The compressed oxygen self-rescuers have need of some extra parts not necessary with chemical oxygen self-rescuers. These include a high-pressure storage bottle, a regulator to step down the high pressure, a constant-flow valve, and in most cases, a demand valve.

There are many variations possible in the size, shape and placement of the various components which are necessary in any breathing apparatus as will be seen in the separate descriptions of the apparatus tested which follow.

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TABLE 1. - Oxygen self-rescuers tested

Apparatus	Duration, min	Country	O ₂ source	Weight, kg	
				In case	In use
NIOSH-Approved					
CSE AU-9A1.....	60	U.S.A...	Cylinder	4.95	4.30
Draeger OXY-SR 60B	60	Germany. (FRG)	KO ₂	3.80	3.40
MSA 60-min SCSR...	60	U.S.A...	KO ₂	4.04	3.00
Ocenco EBA 6.5....	60	U.S.A...	Cylinder	3.51	3.10
PASS 700.....	60	U.S.A...	Cylinder	8.60	6.60
U.S.D. SCEBA-60...	60	U.S.A...	Cylinder	3.40	3.24
Foreign - Not NIOSH-Approved					
Auer SSR-90.....	90	Germany. (FRG)	KO ₂	4.69	3.08
AZG-40.....	40	China...	KO ₂	2.03	1.68
Draeger OXY-SR 30.	30	Germany. (FRG)	Cylinder	2.39	2.39
Draeger OXY-SR 45.	45	Germany. (FRG)	Cylinder	2.39	2.39
Fenzy Spiral II...	45	France..	KO ₂	3.49	3.05
WC-7.....	45	U.S.S.R.	KO ₂	2.94	2.55
Bureau Prototypes					
Lockheed PBA ^{1/} ...	60	U.S.A...	KO ₂	2.11	2.00
MSA 10-min PBA ^{1/} ...	10	U.S.A...	KO ₂	1.24	.82
MSA 10/60 ^{1/}	70	U.S.A...	KO ₂	2.18	4.73
Westinghouse PBA..	60	U.S.A...	Sodium chlorate candle	3.85	3.44

^{1/}NIOSH-approved prototype

NIOSH-APPROVED

CSE AU-9A1

The AU-9A1 is a compressed-oxygen self-rescuer with a throwaway steel bottle but otherwise reusable parts. It is field serviceable by trained personnel only. It has a bidirectional flow path, a constant O₂ flow of at least 1.5 L/min and a pressure-activated demand valve and relief valve. The cylinder contains 130 L of oxygen, and the CO₂ absorbent is LiOH. Figures 1 and 2 show the apparatus in the case and deployed, and schematically diagrammed.

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Draeger OXY-SR 60B

The OXY-SR 60B is a chemical-oxygen self-rescuer which can be returned to the distributor, National Mine Service, for refurbishing. It has a unidirectional flow path through the KO_2 (potassium superoxide) bed and a pressure-activated relief valve. A chlorate candle is provided for an initial spurt of oxygen until the KO_2 bed is sufficiently activated by the user's breath. The KO_2 is pelletized. Figures 3 and 4 show the apparatus in the case and deployed, and schematically diagrammed.

MSA 60-Min SCSR

The MSA SCSR is a chemical-oxygen self-rescuer which is entirely throwaway. It has a unidirectional flow path through the KO_2 bed and a volume-activated relief valve. A chlorate candle is utilized for initial oxygen flow. The KO_2 is in granular form. Figures 5 and 6 show the apparatus in the case and deployed, and schematically diagrammed.

Ocenco EBA 6.5

This device is a compressed-oxygen self-rescuer with a fiber-glass-wrapped aluminum bottle which is reusable. The apparatus is refurbishable only by the manufacturer. It has a unidirectional flow path with directional check valves in the mouth bit assembly, a constant flow of at least 1.5 L/min and pressure-activated demand and relief valves. The cylinder contains 157 L of oxygen, and the CO_2 absorbent is $LiOH$. Figures 7 and 8 show the apparatus in the case and deployed, and schematically diagrammed.

PASS 700

The PASS (Portable Air Supply Systems) self-rescuer is a compressed-oxygen system with an aluminum bottle which is reusable after refurbishing by the manufacturer. It has a unidirectional flow path through the CCl_2 scrubber, an enclosed breathing bag, no demand valve, a constant flow of oxygen of at least 3 L/min and a pressure-activated relief valve. The cylinder contains 240 L

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of oxygen, and the CO_2 absorbent is soda lime. Figures 9 and 10 show the apparatus in the case and deployed, and schematically diagrammed.

U.S.D. SCEBA-60

This self-rescuer is a compressed-oxygen system which has some reusable parts but is not presently being commercially produced because it became available only after mine operators were required to have placed orders for their oxygen self-rescuers. It has a bidirectional flow path, a constant flow rate of oxygen of at least 1.5 L/min, and volume-activated demand and relief valves. The relief valve is triggered by bag volume but dumps from the breathing hose air that has not yet been scrubbed of CO_2 or enriched with oxygen. It is available with a standard steel, throwaway bottle or a lightweight, fiber-glass-wrapped aluminum, reusable bottle containing 130 L of oxygen. The CO_2 absorbent is LiOH. Figures 11 and 12 show the apparatus in the case and deployed, and schematically diagrammed.

FOREIGN

Auer SSR-90

The SSR-90, manufactured in Germany by Auer, a subsidiary of MSA, is a chemical-oxygen self-rescuer which can be user-refurbished. It has a unidirectional flow path through the KO_2 bed, a volume-activated relief valve, and a 'quickstarter' for initial oxygen flow. Figures 13 and 14 show the apparatus in the case and deployed, and schematically diagrammed.

AZG-40

The Chinese self-rescuer uses KO_2 and is not reusable. It has a bidirectional flow path, a volume-activated relief valve which vents from the breathing hose, a heat exchanger, and a quick-starting mechanism for initial oxygen flow. Figures 15 and 16 show the apparatus in the case and deployed, and schematically diagrammed.

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Draeger OXY-SR 30

This device is a compressed-oxygen self-rescuer which is user refurbishable. It has a unidirectional flow path through the soda lime scrubber, a pressure-activated relief valve, a volume-activated demand valve, and a constant flow of oxygen of at least 1.5 L/min. The steel cylinder contains 64.5 L of oxygen. Figures 17 and 18 show the apparatus in the case and deployed, and schematically diagrammed.

Draeger OXY-SR 45

This self-rescuer is nearly identical to the OXY-SR 30 with the following differences: the constant flow rate is only 1.2 L/min and the oxygen flow cannot be turned off once it is activated. Figure 19 shows the apparatus schematically diagrammed.

Fenzy Spiral II

The Spiral II is a chemical-oxygen self-rescuer which is user serviceable. It has a unidirectional flow path through the KO_2 bed and a pressure-activated relief valve. A very small compressed-oxygen bottle is utilized for initial start-up. The bottle is yanked upward by pulling on a plastic ball connected to the bottle which breaks a metal seal rapidly releasing the contents into the system. Figures 20 and 21 show the apparatus in the case and deployed, and schematically diagrammed.

WC-7

The Soviet self-rescuer uses KO_2 as the oxygen source and is throwaway. It is a bidirectional flow path device with a volume-activated relief valve. The starting device utilized delivers 6 L of oxygen within 30 seconds. Figures 22 and 23 show the apparatus in the case and deployed, and schematically diagrammed.

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BUREAU OF MINES-DEVELOPED PROTOTYPES

Lockheed PBA (Personal Breathing Apparatus)

This device is a NIOSH-approved prototype. The apparatus were manufactured in 1974 and stored in warehouses until tested for this study. These chemical-oxygen self-rescuers were intended to be throwaway devices. The flow path is unidirectional with check valves in the mouth bit. It has a pressure-activated relief valve and a chlorate candle for initial oxygen flow. Figures 24 and 25 show the apparatus in the case and deployed, and schematically diagrammed.

MSA 10-Min PBA

These NIOSH-approved prototypes were also manufactured in 1974 and were similarly stored in warehouses until being tested. The 10-min PBA is a one-use, chemical-oxygen self-rescuer with bidirectional flow, a chlorate candle, and two breathing bags, one of which contains a volume-activated relief valve. Figures 26 and 27 show the apparatus in the case and deployed, and schematically diagrammed.

MSA 10/60 Oxygen Self-Rescuer

These NIOSH-approved prototypes were built in 1979 and were stored until being tested. The chemical-oxygen 10/60 was designed so that the 10-min apparatus could be belt-worn with the 60-min canister being stored. In an emergency, the 10-min device is donned and the user proceeds to the storage place of the 60-min canisters, which are then attached without the need to remove the mouth bit. The oxygen source in both portions is KO_2 . Chlorate candles are provided on both portions of the device; the candle on the 60-min portion is automatically activated when the device is attached to the 10-min portion. The entire apparatus is one-use only. The 10-min apparatus has a bidirectional flow path, but when the 60-min canister is attached, the flow path is changed to unidirectional flow. Figure 28 shows the 10-min apparatus

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in the case and deployed, and the 60-min canister. The 60-min canister does not have its own case but is stored in a plastic bag. Figures 29, 30, and 31 are schematics of the 10-min apparatus, the 60-min canister, and the combination flow scheme.

Westinghouse PBA

This is the first Bureau prototype ever developed. The apparatus tested were manufactured in 1971 and were not certified by NIOSH. The flow path is bidirectional with a two-chambered breathing bag, one chamber for exhalation and one for inhalation, with a pressure-activated relief valve on the inhalation side of the bag. The oxygen source is a large, L-shaped, sodium chlorate candle which provides at least 3 L/min of oxygen flow continuously, regardless of usage rate. The CO₂ scrubber uses LiOH. The original directive for this contract included face protection, and the design included a combination hood-lens-noseclip-mouth-bit. Only three of these prototypes remained for testing in this study. Figures 32 and 33 show the apparatus in the case and deployed, and schematically diagrammed.

*** TEST APPARATUS AND EXPERIMENTAL PROCEDURE

A breathing and metabolic simulator (BMS) was used for testing the apparatus in this study (Figure 34). The BMS elicits a constant and repeatable metabolic demand on the breathing apparatus; human subjects cannot be depended upon to do this. Also, human subjects would not have tolerated the high temperatures and breathing resistances encountered during some of the tests.

The BMS was built by Reimers Consultants in Arlington, VA^{3/}. It has a unidirectional flow path, unlike a human being. The air movement is effected by a bellows moved through a mechanical linkage to a motor. A smaller bellows

^{3/}Use of brand name is for identification purposes only and does not imply endorsement by the Bureau of Mines.

withdraws a varying percentage of the volume of the main bellows, depending upon the O_2 concentration, simulating O_2 consumption. Another small bellows injects CO_2 and N_2 into the system, replacing the O_2 consumed and the N_2 removed in the process. The gas inhaled into the BMS is also heated and humidified (in this study, to approximately 37°C and 80 pct RH).

The metabolic parameters used in this study follow (all volumes at STPD):

$$\dot{V}_{O_2} \text{ (oxygen consumption)} = 1.35 \text{ L/min}$$

$$\dot{V}_{CO_2} \text{ (CO}_2 \text{ production)} = 1.30 \text{ L/min}$$

$$\dot{V}_e \text{ (ventilation)} = 31.9 \text{ L/min}$$

$$V_t \text{ (tidal volume)} = 1.21 \text{ L/breath}$$

$$F_r \text{ (respiratory freq)} = 26.5 \text{ breath/min}$$

$$\dot{Q}_{\text{peak}} \text{ (peak flow rate)} = 126 \text{ L/min}$$

The performance parameters measured were inhaled concentrations of O_2 and CO_2 , inhaled gas temperature, and both inhalation and exhalation breathing resistances. The inhaled gas concentrations were measured in a box just inside the inhalation port of the BMS where the inhaled gases are mixed, called the inhalation mixing box. Measurement at this point has the advantage of including effects of dead space volume, such as that of the breathing hoses which have bidirectional flow paths. Breathing resistances and temperature were measured at the mouth bit. Factors determining test termination were CO_2 higher than 4 pct, O_2 lower than 15 pct or low bag volume indicating an expired O_2 source.

Breathing circuit tightness was determined by pulling a negative pressure of 70 mm H_2O at the mouth bit of an apparatus and measuring the time required to rise to -60 mm H_2O . Times longer than 60 s are considered passing. This test was performed on a CSE test stand which is also used for checking relief

valve activation pressure and constant flow rate. The tightness standards are the same as Draeger specifies for the BG-174A rescue breathing apparatus using a functionally identical test stand. This has not yet been related to protection factors.

When testing compressed-oxygen self-rescuers, it was necessary to purge the BMS breathing loop of most of the ambient nitrogen. Otherwise, the small amount of oxygen in the apparatus breathing loop would be so diluted due to the large volume of the BMS breathing loop as to result in such a low concentration of oxygen that the test would be forced to be cancelled. If used on a person, with a much smaller volume in the breathing loop, this would not occur in most cases. This situation would arise only when the constant flow rate of O_2 was less than the O_2 consumption rate ($\dot{V}_{O_2}$), and when there was a substantial amount of N_2 in the breathing loop, if one forcefully exhaled into a breathing apparatus from ambient, for example.

To start the test, 10 inhalations on the BMS were taken from each compressed oxygen self-rescuer with a demand valve, elevating the O_2 concentration to 60 pct or greater. If the apparatus termination mode were low volume in the breathing bag due to an empty bottle, the amount of O_2 used for the 10 breaths was added on in minutes to the end of the test. Ten breaths equals approximately 14 L at ambient, which would work out to about 9 min at our usage rate. This procedure was unnecessary for KO_2 apparatus since they overproduce O_2 and thus continually purge N_2 from the breathing loop.

*** RESULTS AND DISCUSSION

See Tables 2 and 3 for the means of both the average and the peak values of monitored parameters for all the apparatus tested.

We were amazed at the wide range of designs of the apparatus. The performance of the apparatus also ranged over a large spectrum as can be seen from the two results tables.

TABLE 2. - Means of average values of monitored parameters
(Standard deviations in parentheses)

Apparatus	Duration, Min	Cause of Termination	O ₂ , pct	CO ₂ , pct	Exhalation resistance, mm H ₂ O	Inhalation resistance, mm H ₂ O	Temperature, °C
CSE AU-9A1	73 (6)	high CO ₂	70 (13)	2.5 (.1)	50 (8)	50 (4)	42 (1)
Draeger OXY-SR 60B	72 (4)	low bag volume	78 (3)	1.0 (.1)	46 (6)	26 (6)	37 (2)
MSA 60-min SCSR...	83 (6)	low bag volume or high CO ₂	82 (1)	1.0 (.2)	58 (6)	26 (3)	44 (2)
Ocenco EBA 6.5 —	110 (8)	low bag volume	74 (7)	.7 (.2)	51 (5)	38 (3)	41 (1)
PASS 700	86 (7)	low bag volume	81 (3)	1.1 (.1)	51 (4)	24 (3)	39 (1)
U.S.D. SCEBA-60...	79 (10)	low bag volume or high CO ₂	71 (10)	2.2 (.4)	54 (7)	56 (2)	40 (1)
Auer SSR-90	82 (2)	low bag volume	81 (5)	.7 (.1)	57 (5)	35 (3)	40 (2)
AZG-40	38 (3)	high CO ₂	66 (5)	2.5 (.1)	116 (9)	101 (9)	50 (4)
Draeger OXY-SR 30.	47 (4)	low bag volume	80 (3)	1.5 (.2)	45 (3)	19 (2)	41 (0)
Draeger OXY-SR 4b.	55 (7)	low bag volume or high CO ₂	76 (7)	1.6 (.1)	42 (9)	18 (1)	41 (1)
Fenzy Spiral II ...	34 (3)	low bag volume	64 (4)	1.7 (.7)	56 (12)	22 (7)	36 (2)
WC-7	67 (4)	high CO ₂ or low bag volume	77 (4)	1.8 (.1)	63 (5)	59 (5)	56 (4)
Lockheed PBA	34 (9)	high CO ₂ , low bag volume or low O ₂	60 (16)	1.6 (.5)	113 (30)	120 (46)	49 (10)
MSA 10-min PBA —	14 (1)	high CO ₂	44 (4)	1.8 (.2)	63 (8)	119 (5)	47 (3)
MSA 10/60:							
10-min	9 (1)	high CO ₂	37 (10)	1.6 (.1)	74 (10)	79 (12)	38 (2)
60-min	73 (21)	low bag volume	67 (11)	2.2 (.6)	83 (13)	60 (15)	42 (2)
Westinghouse PBA. .	60 (1)	low bag volume	84 (1)	.6 (.1)	121 (35)	31 (6)	40 (2)

TABLE 3. - Means of peak values of monitored parameters
(Standard deviations in parentheses)

Apparatus	O ₂ , pct	CO ₂ , pct	Exhalation resistance, mm H ₂ O	Inhalation resistance, mm H ₂ O	Tempe rature
CSE AU-9A1	76 (10)	4.0 (0)	56 (9)	55 (6)	44
Draeger OXY-SR 60B	93 (2)	1.3 (.1)	83 (18)	45 (19)	44
MSA 60-min SCSR...	91 (2)	3.1 (1.2)	69 (13)	40 (14)	53
Ocenco EBA 6.5....	81 (12)	1.8 (.5)	54 (5)	41 (1)	43
PASS 700	89 (4)	1.5 (.4)	53 (3)	27 (3)	42
U.S.D. SCEBA-60...	79 (6)	2.9 (.8)	59 (7)	65 (7)	42
Auer SSR-90	88 (4)	1.7 (.3)	66 (7)	48 (4)	48
AZG-40	79 (2)	4.0 (0)	160 (10)	153 (9)	60
Draeger OXY-SR 30.	82 (3)	2.0 (.4)	52 (4)	21 (2)	44
Draeger OXY-SR 45.	81 (8)	2.8 (9.0)	48 (7)	21 (3)	44
Fenzy Spiral II ...	89 (1)	2.0 (.7)	80 (29)	42 (19)	43
WC-7	85 (5)	3.8 (.4)	75 (9)	78 (12)	69
Lockheed PBA	75 (13)	3.4 (1.0)	148 (34)	157 (48)	64
MSA 10-min PBA —	57 (5)	4.0 (0)	82 (15)	221 (13)	53
MSA 10/60:					
10-min	44 (10)	4.0 (0)	114 (15)	137 (31)	45
60-min	76 (12)	3.0 (.8)	117 (40)	80 (47)	47
Westinghouse PBA. .	91 (1)	.9 (.2)	136 (35)	61 (13)	44

The two self-rescuers from the U.S.S.R. and China both evidenced a design philosophy of light weight and small size, sacrificing comfort in the areas of breathing resistance and inhaled gas temperature.

The prototype apparatus, which had not seen routine production, had a high variation in performance parameters, reflecting their hand-made construction. This was seen most readily in the U.S.D. SCEBA-60, the Lockheed PBA, and the MSA 10/60.

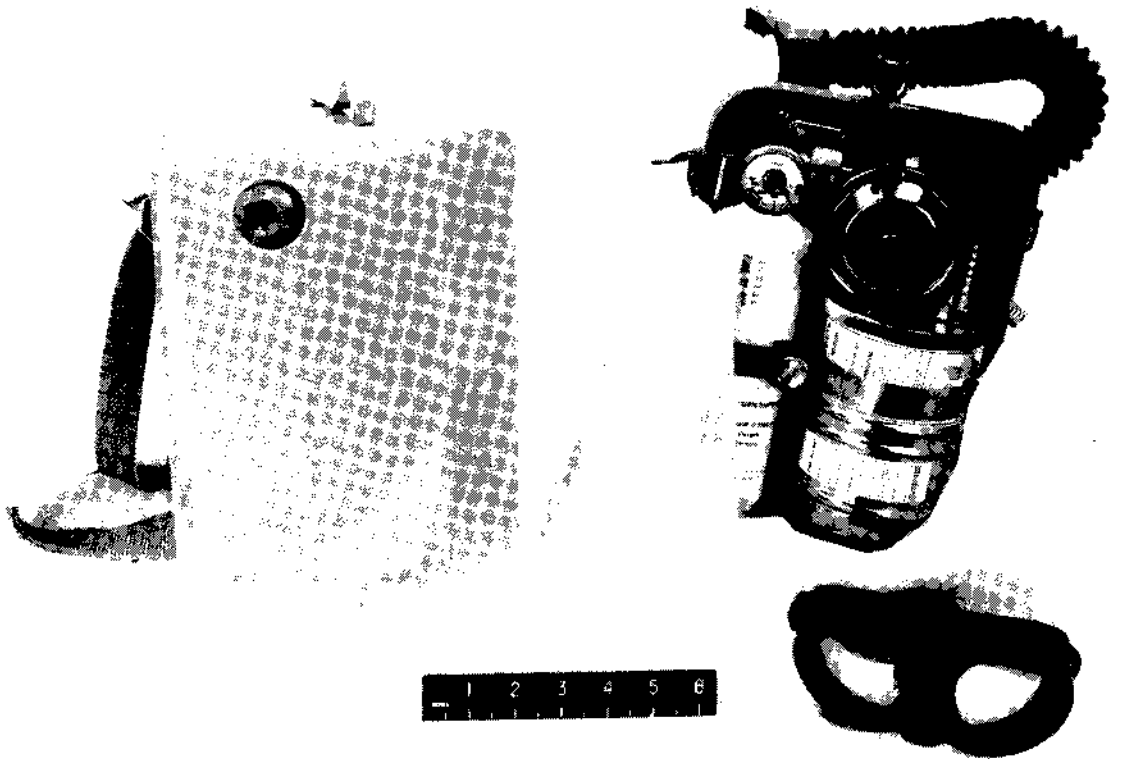
In the apparatus that were stored for some time, we saw that some aged better than others. The prototype Lockheed and Westinghouse apparatus had problems with badly deteriorated rubber parts which required extensive repair before they could be tested. However, some of the WC-7 apparatus were built 10 years ago and performed perfectly.

The Ocenco EBA 6.5 required a great amount of negative pressure (approximately 195mm H₂O) to open the demand valve - on the order of four to five times more pressure than the CSE or the U.S.D. apparatus. Also, the breathing loop was not a tight one, and all failed the CSE negative pressure tests as did all PASS 700's. Of the foreign apparatus, the Auer was also leaky. Of the prototype units, we got inconsistent results with some passing and some failing.

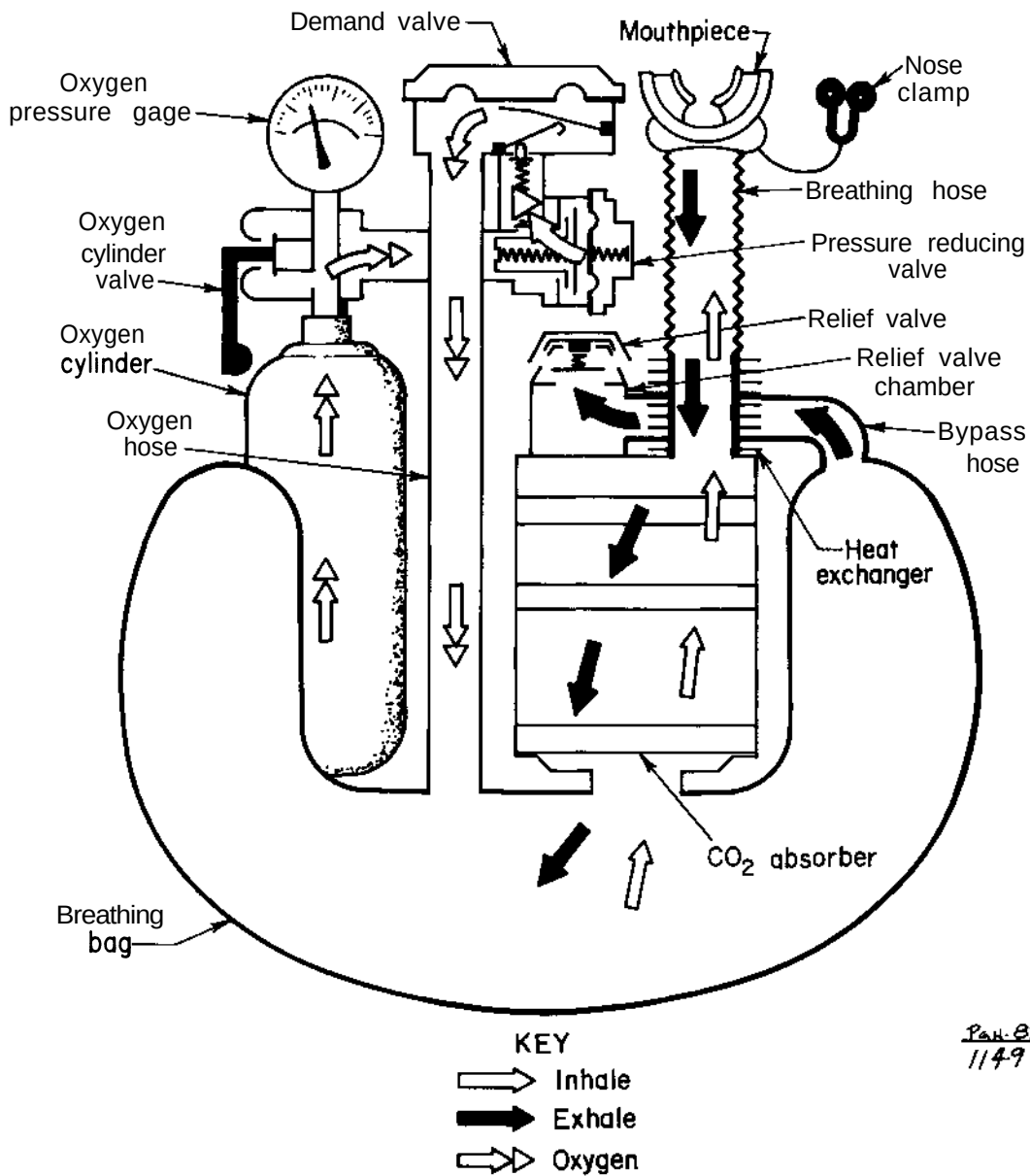
Suspicious of the low durations, we dissected a Fenzy Spiral II and found that the KO₂ beds were only half used, which indicates a poor bed design.

***CONCLUSIONS

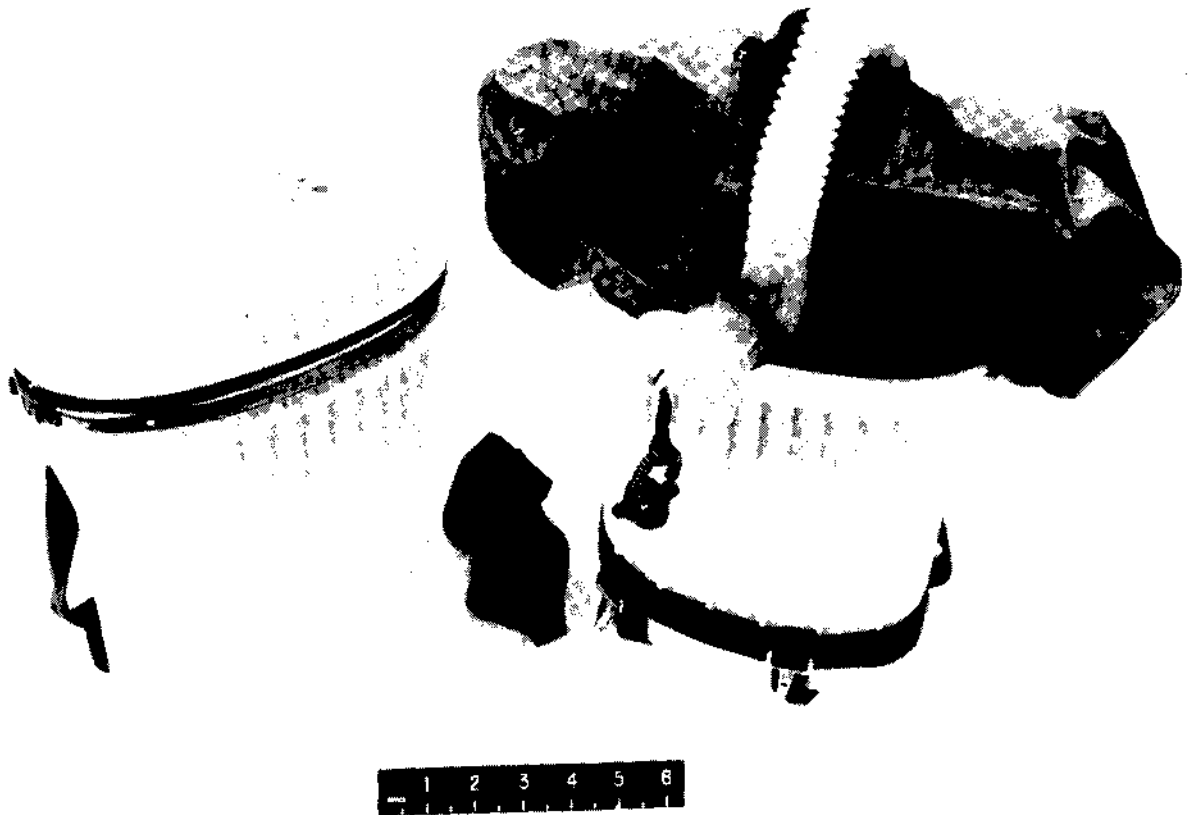
There are many design philosophies utilized in the apparatus tested. Ideal performance would include an obvious termination mode, such as an empty bag. Other parameters, such as CO₂, temperature, and breathing resistance, would be low so as not to interfere with normal respiratory and metabolic functions. An ideal device would give such performance and also be small and lightweight. Trade-offs are, of course, necessary. In this paper, we have tried to show how different manufacturers have made different trade-offs and the results of their philosophies.



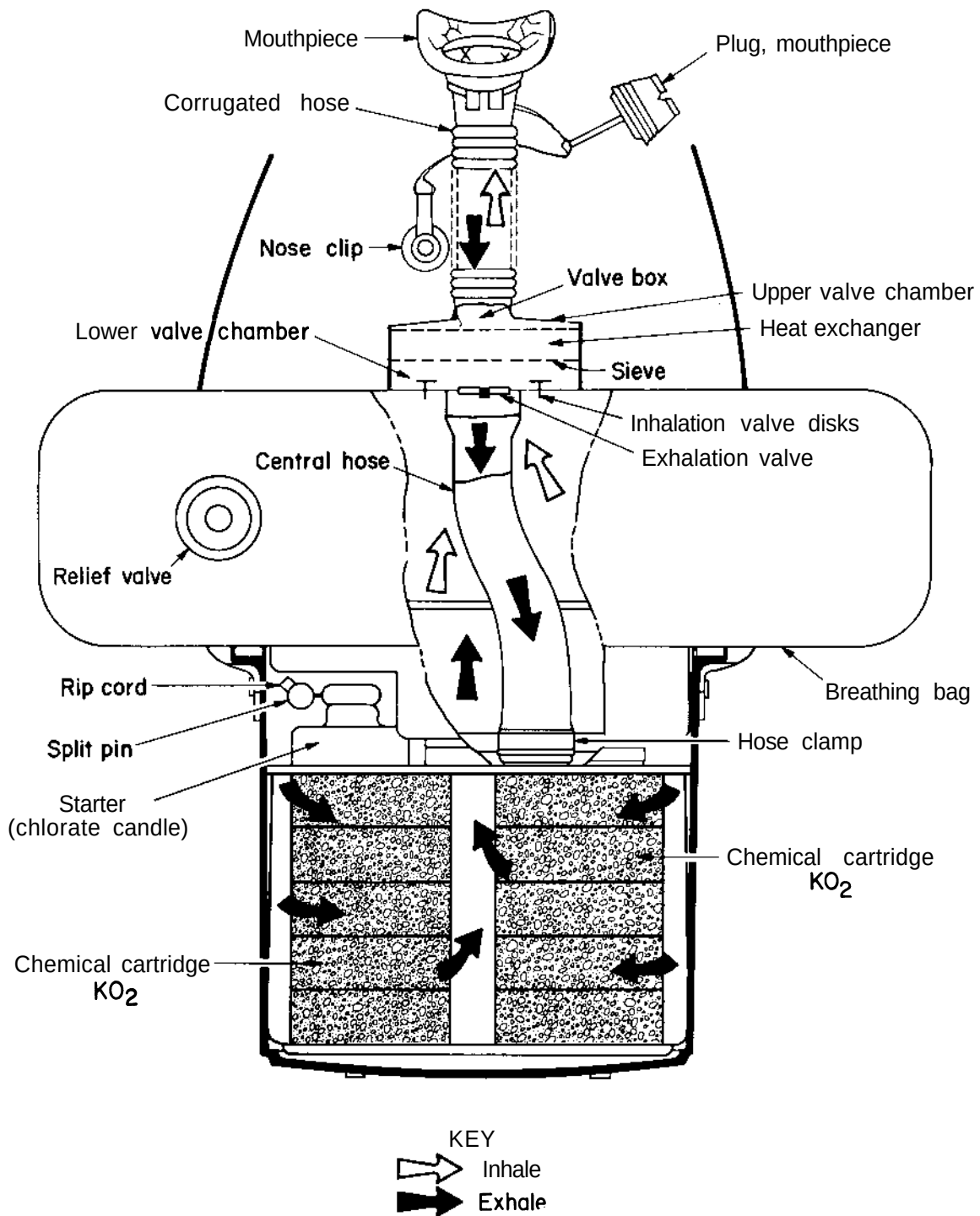
1. CSE AU-9A1.....



2. CSE AU-9A1 schematic.....

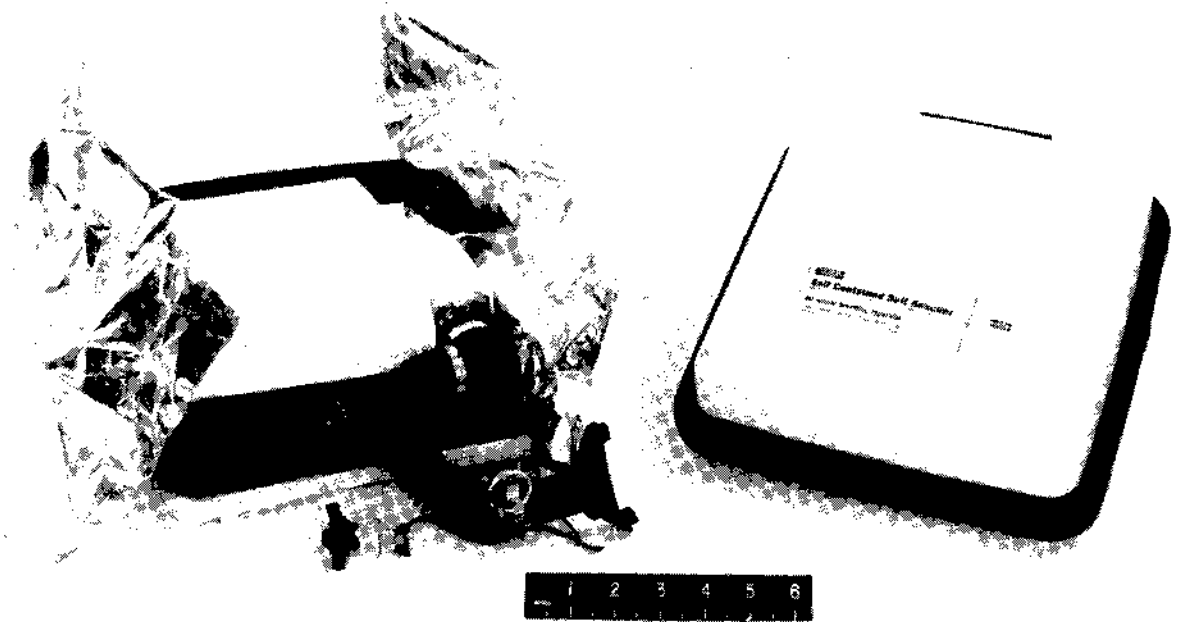


3. Draeger OXY-SR 60B.....

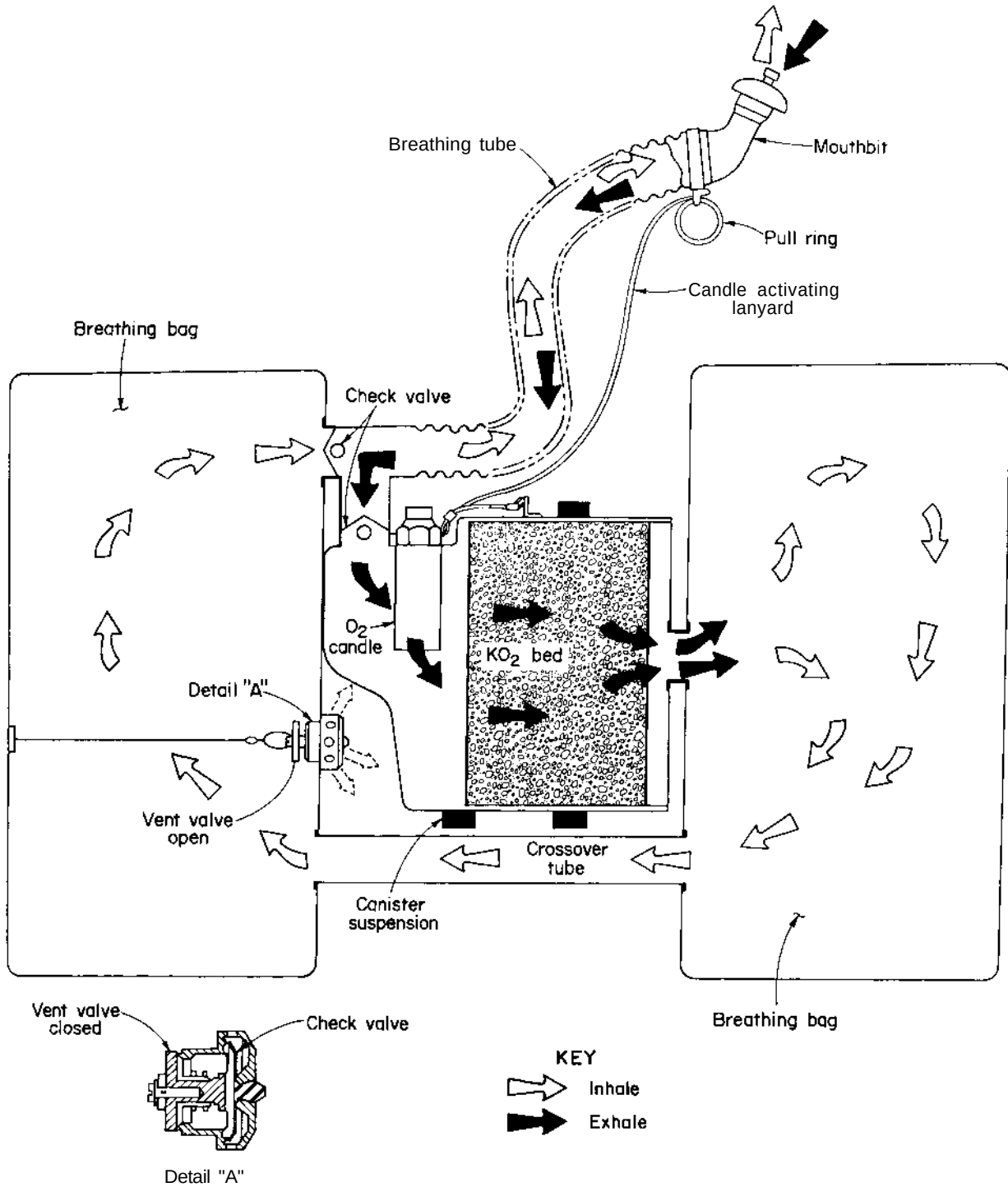


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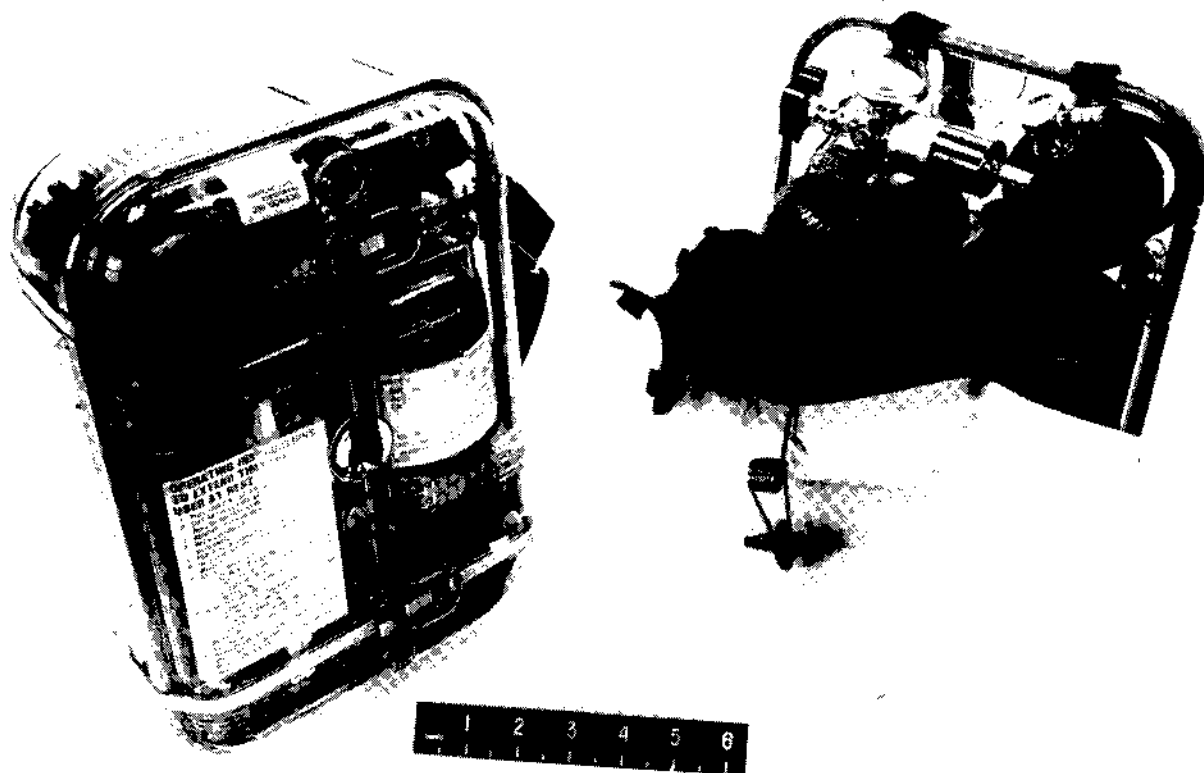
4. Draeger OXY-SR 60B schematic.....

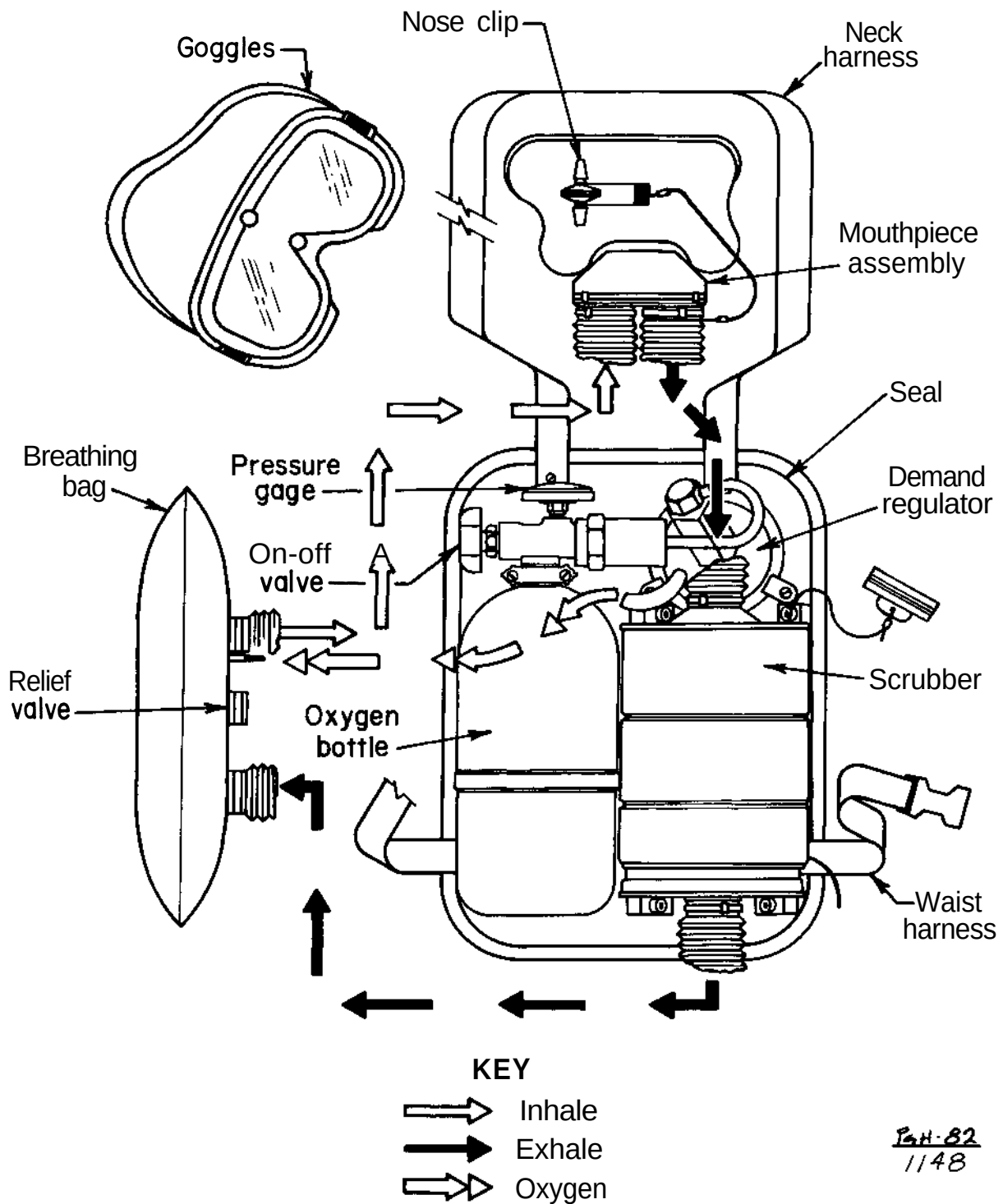


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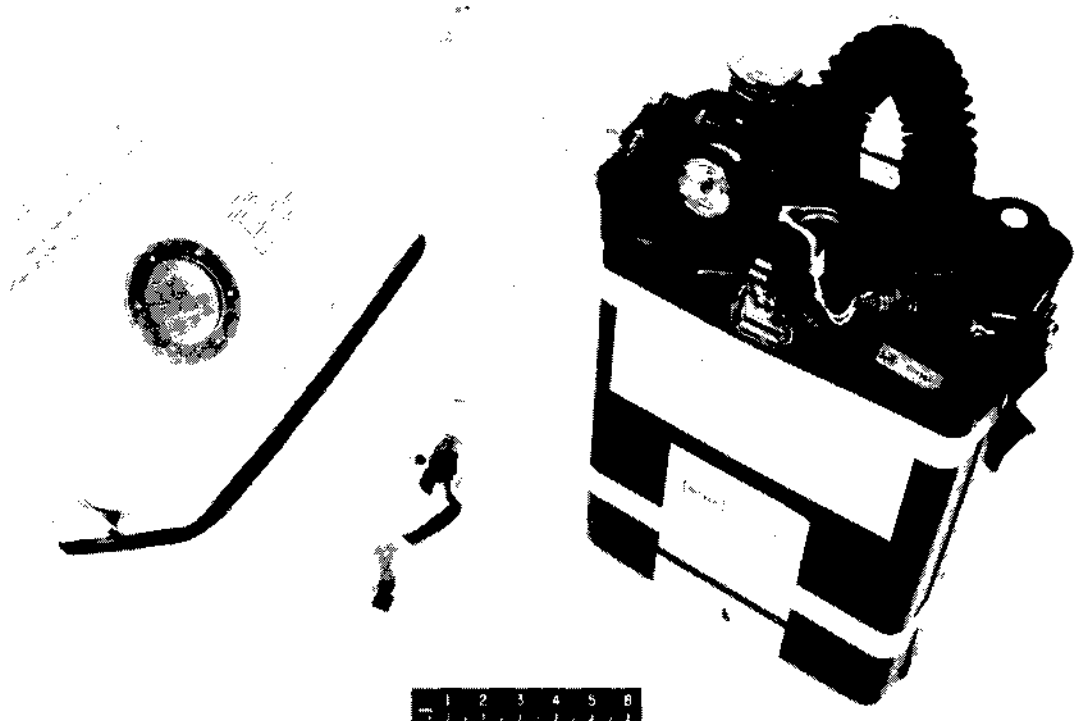


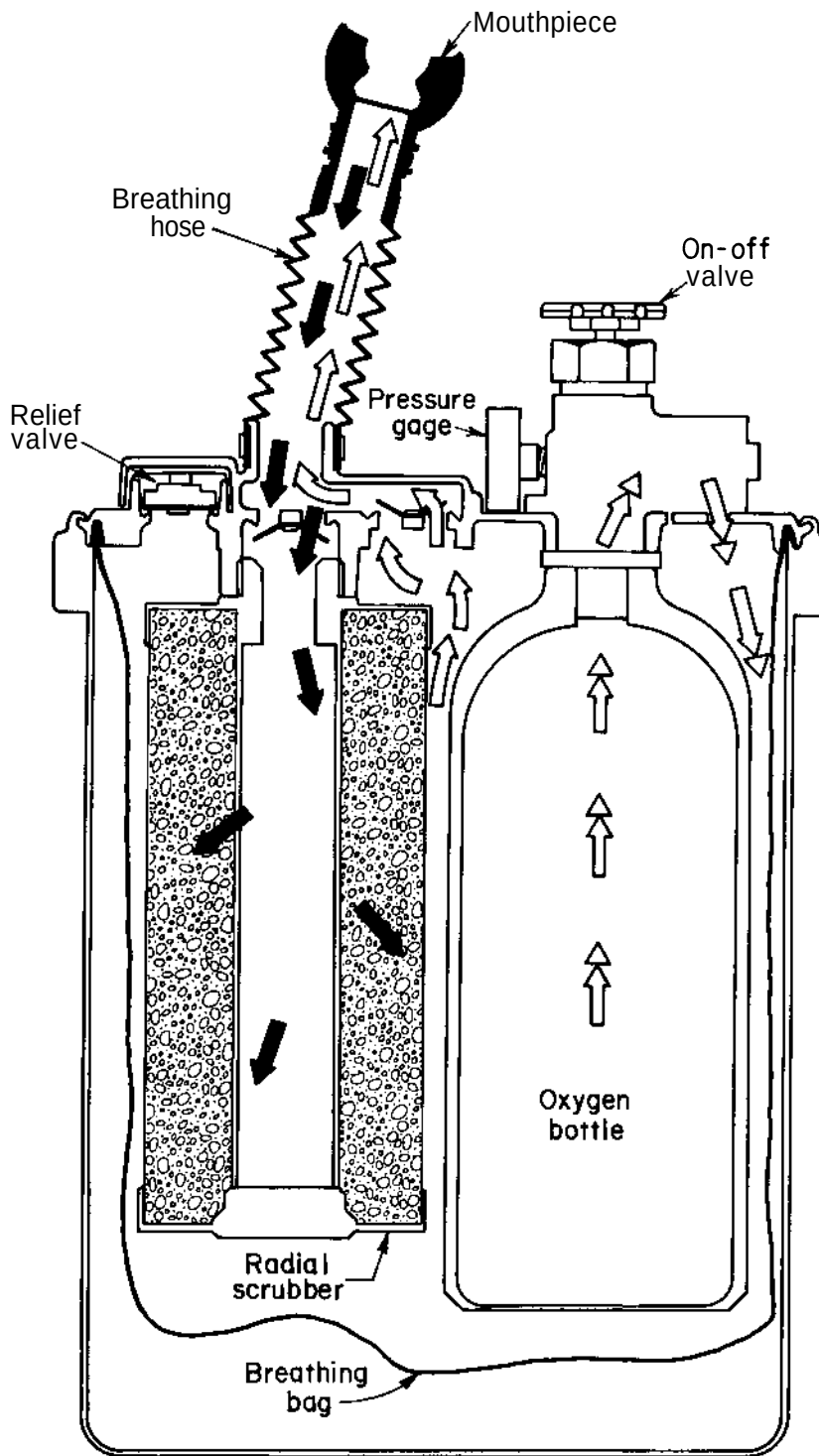
6. MSA 60-min SCSR schematic.....





8. Ocenco EBA 6.5 schematic,.....





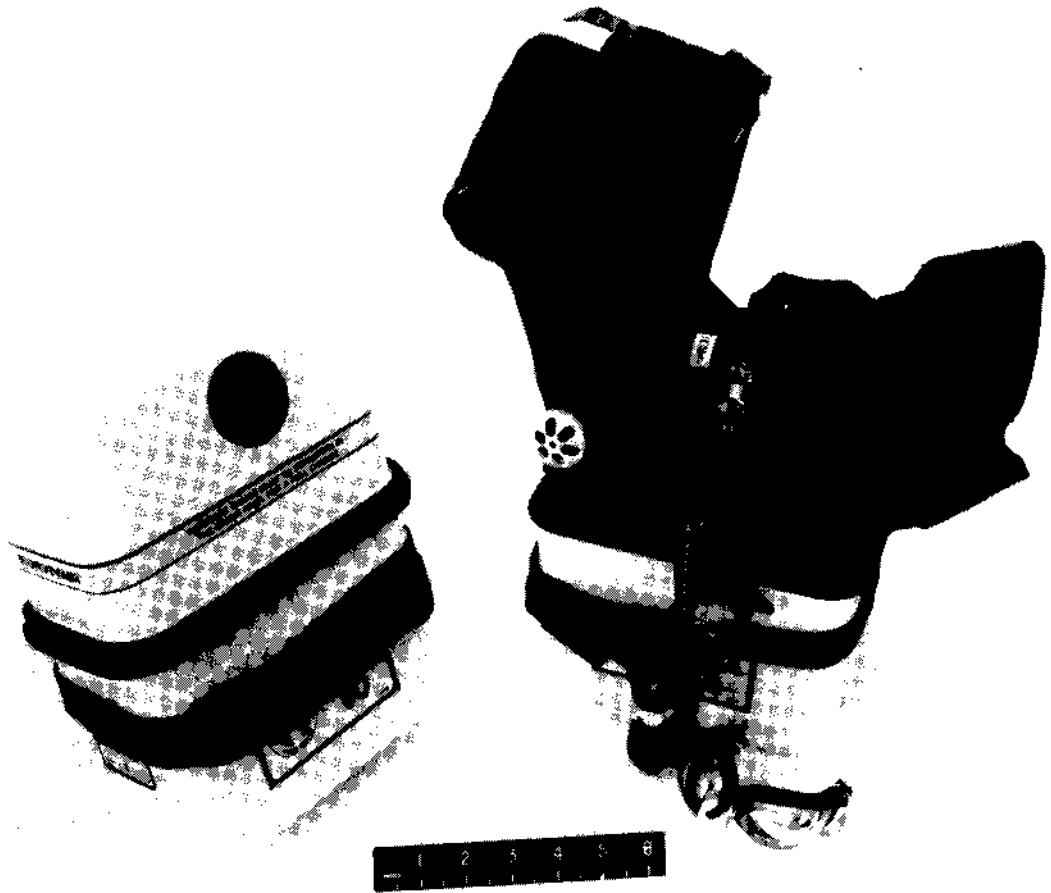
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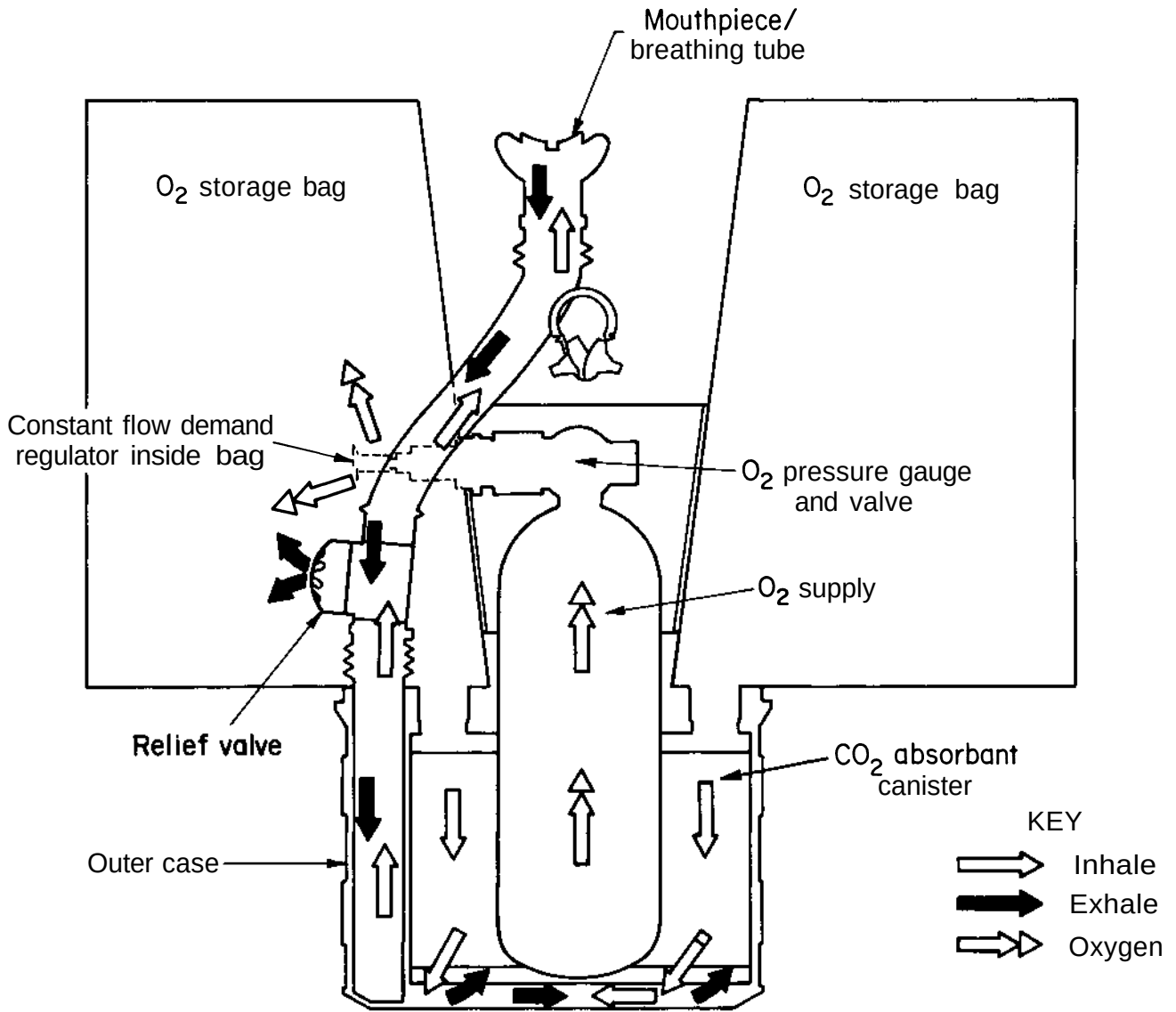
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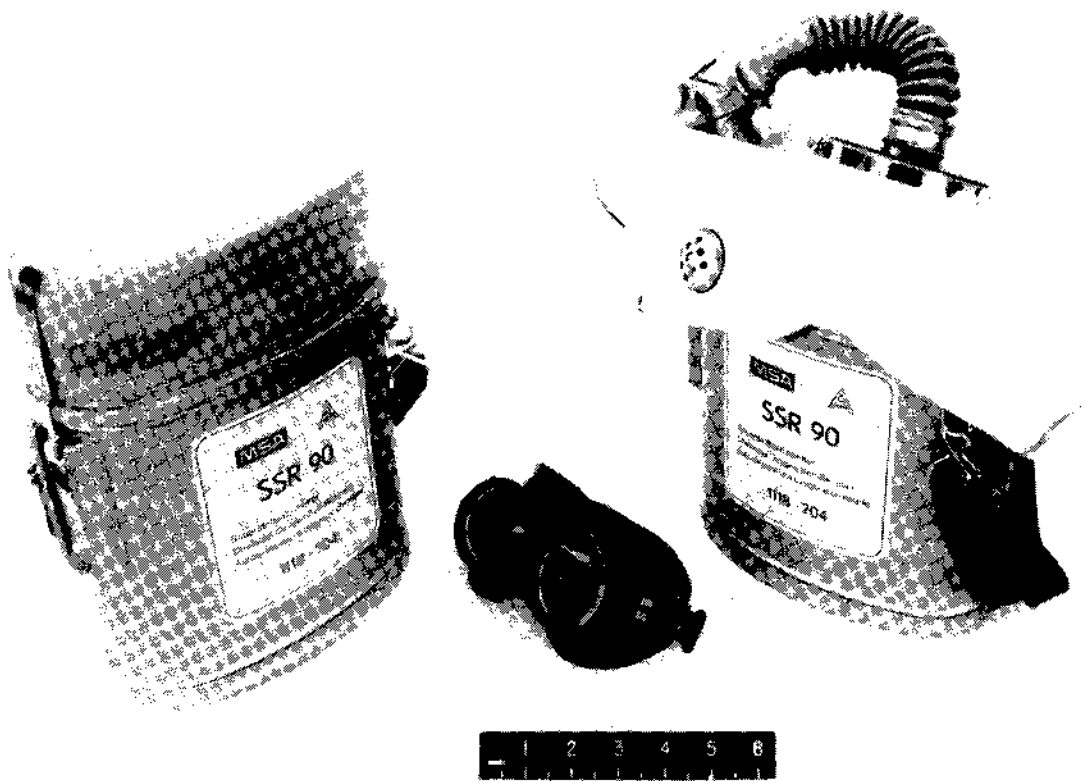
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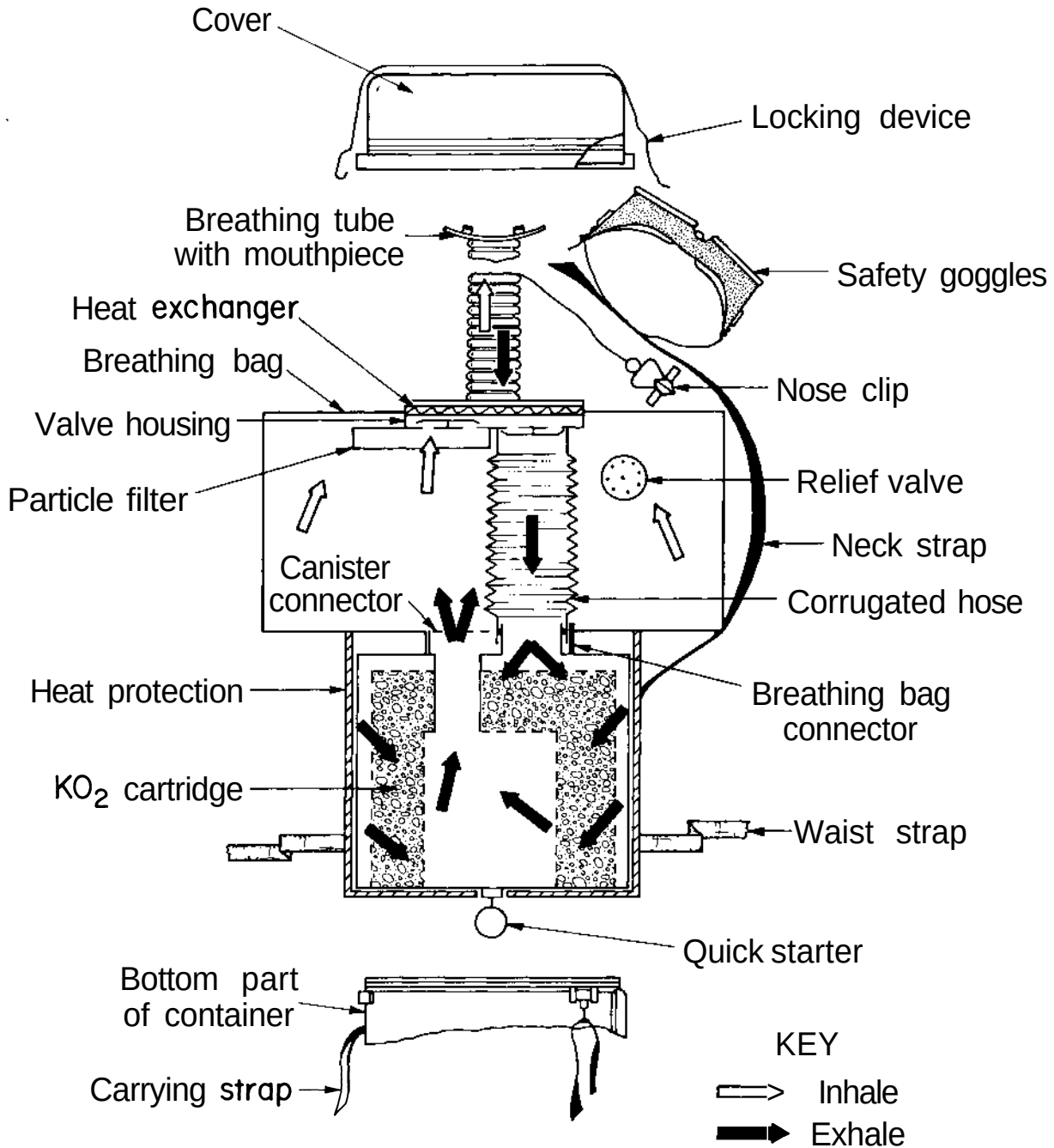




P6H-82
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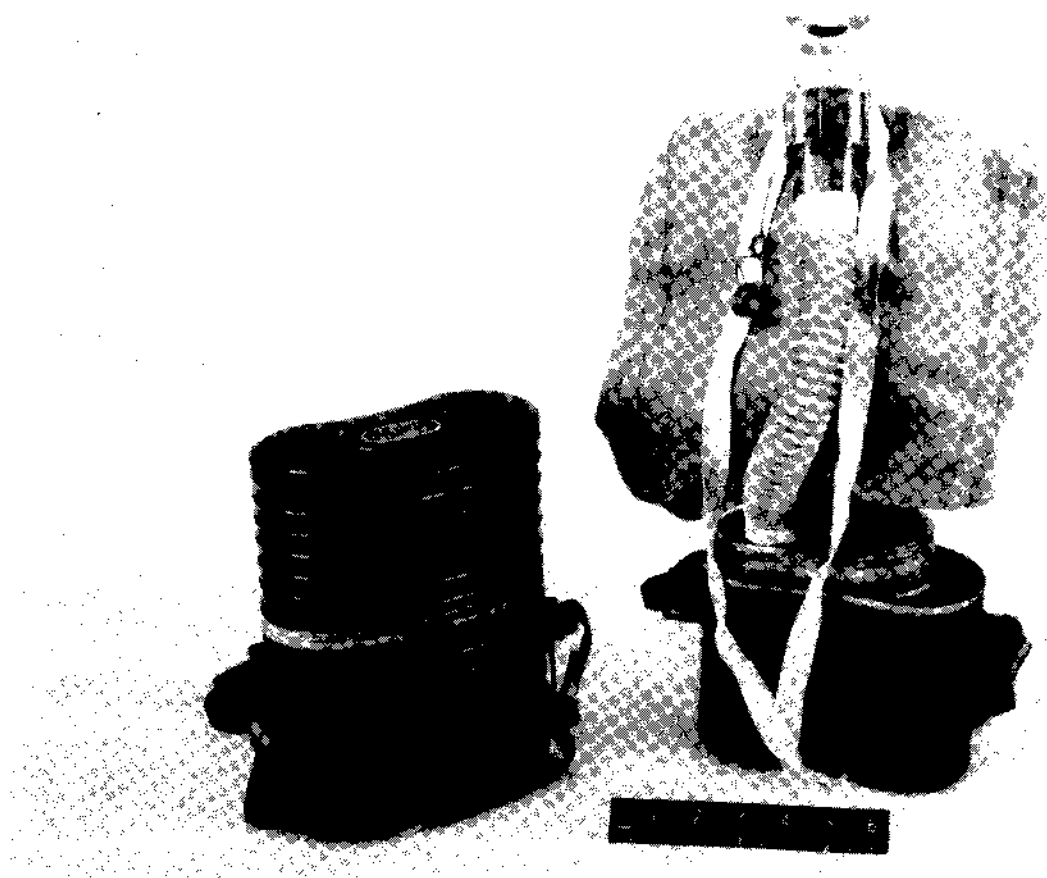


13. Auer SSR-90,.....

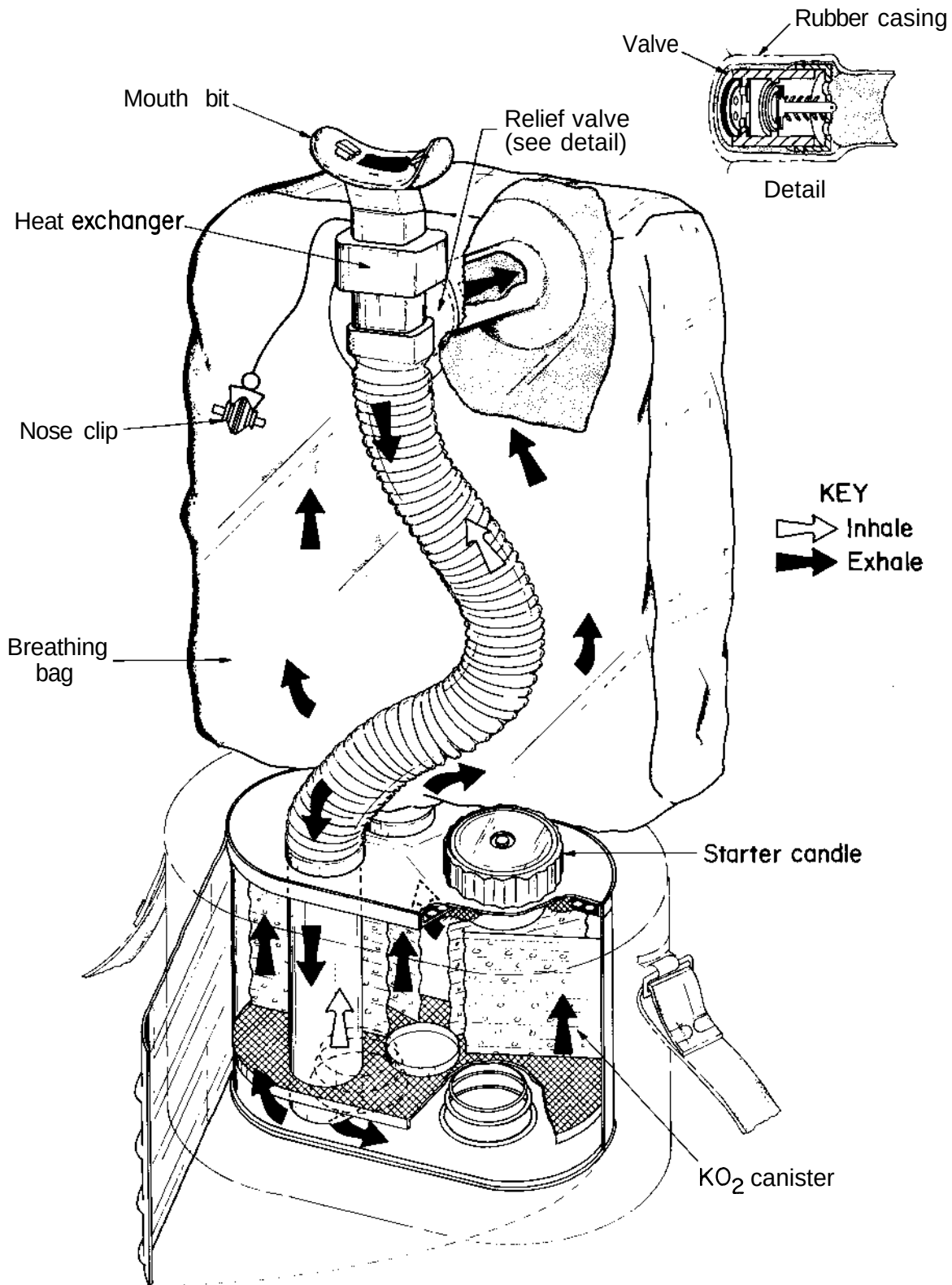


82-83
739

14. Auer SSR-90 schematic,.....



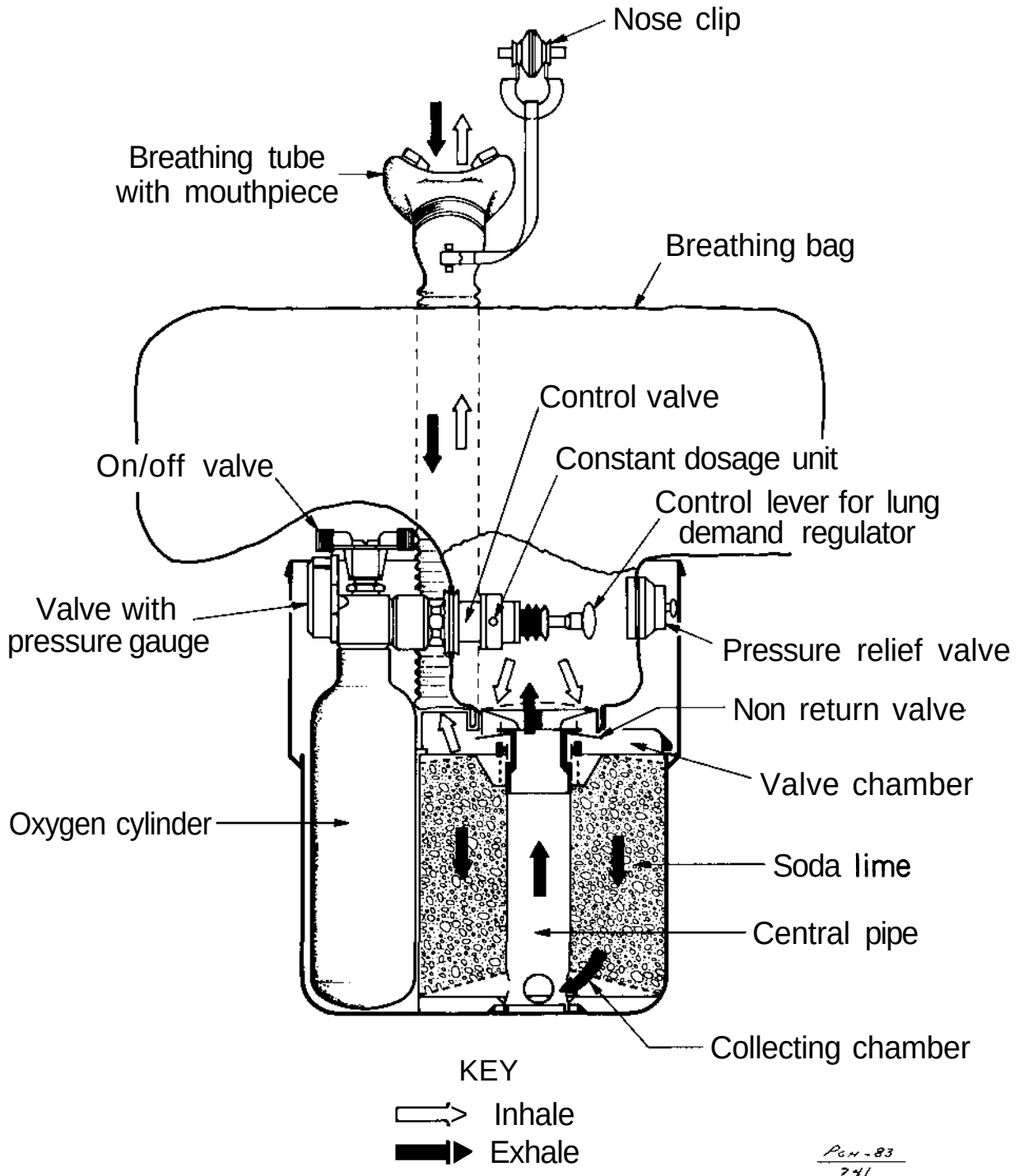
15. AZG-40,



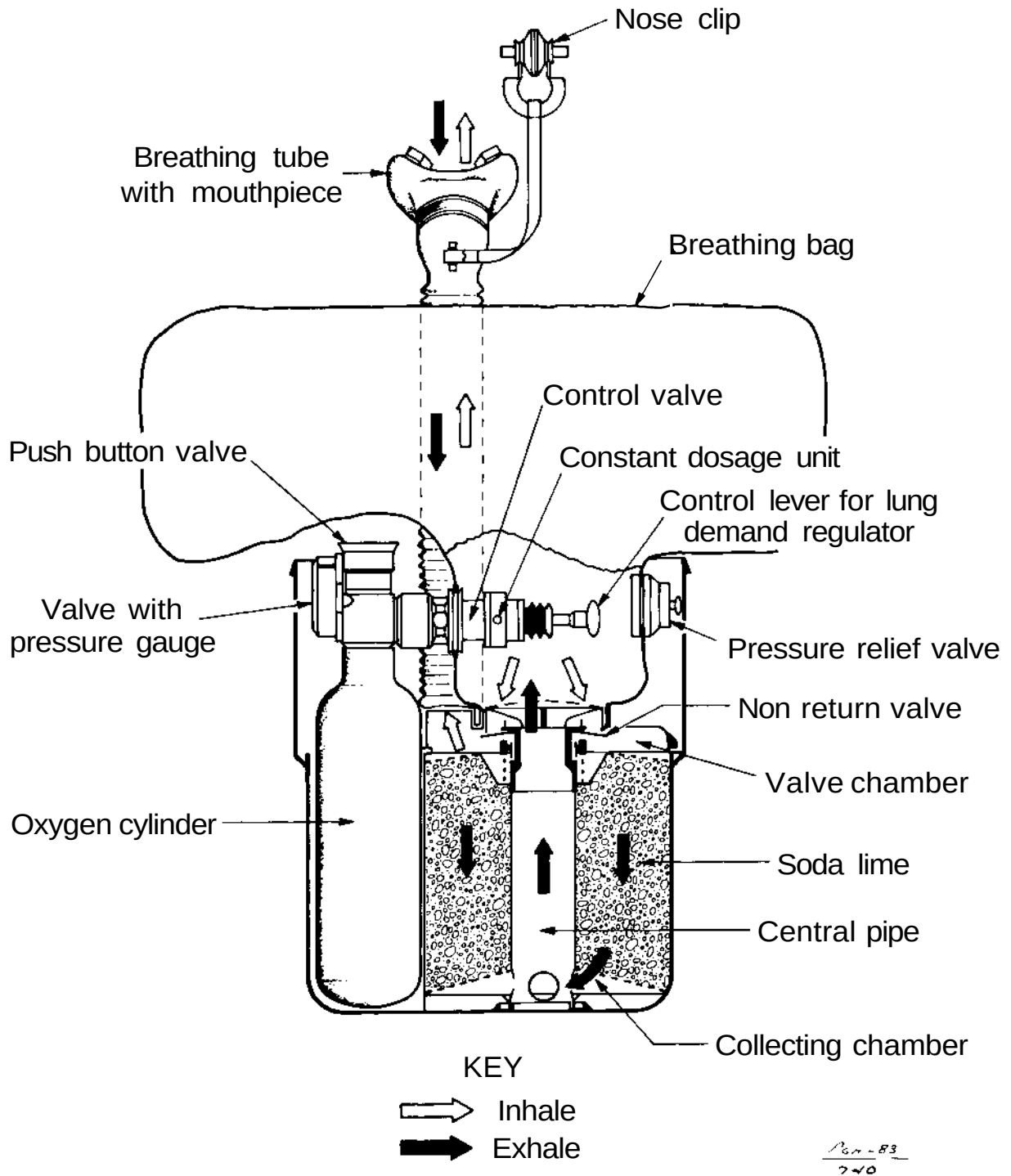
16. AZG-40 schematic.....



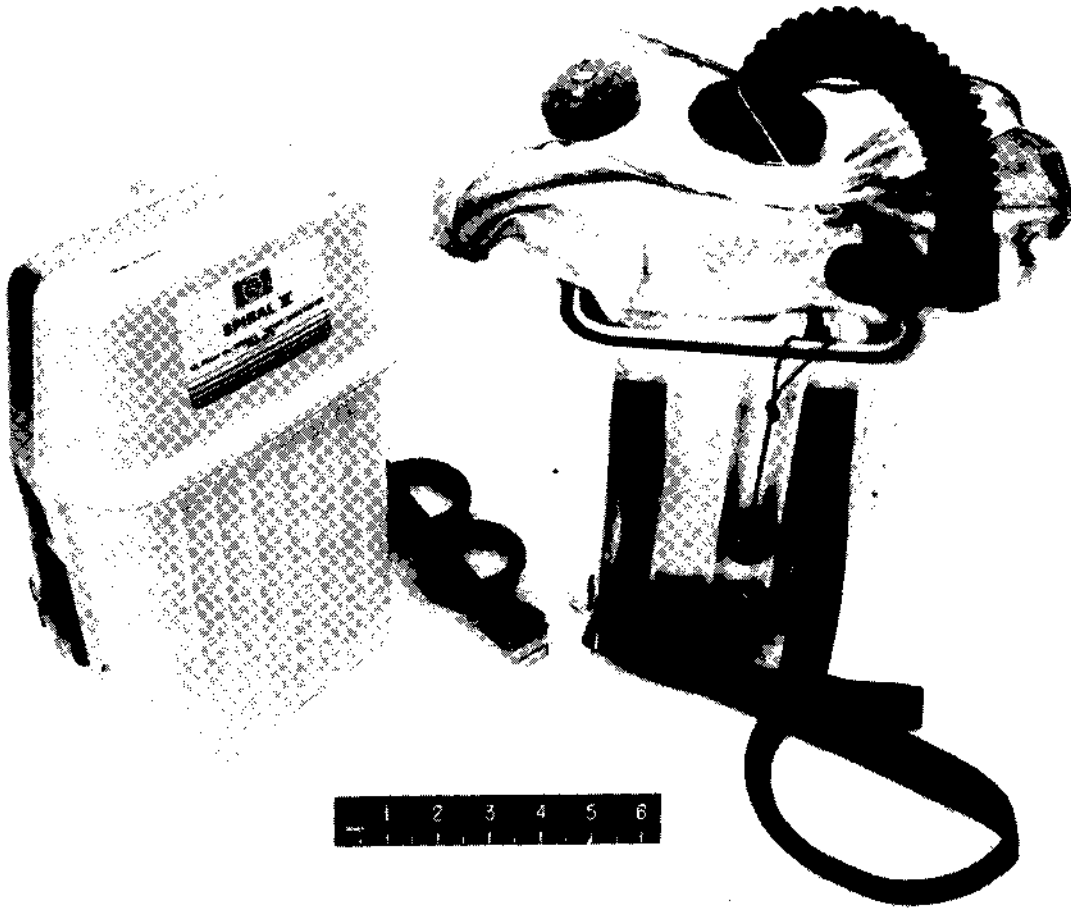
17. Draeger OXY-SR 30.....



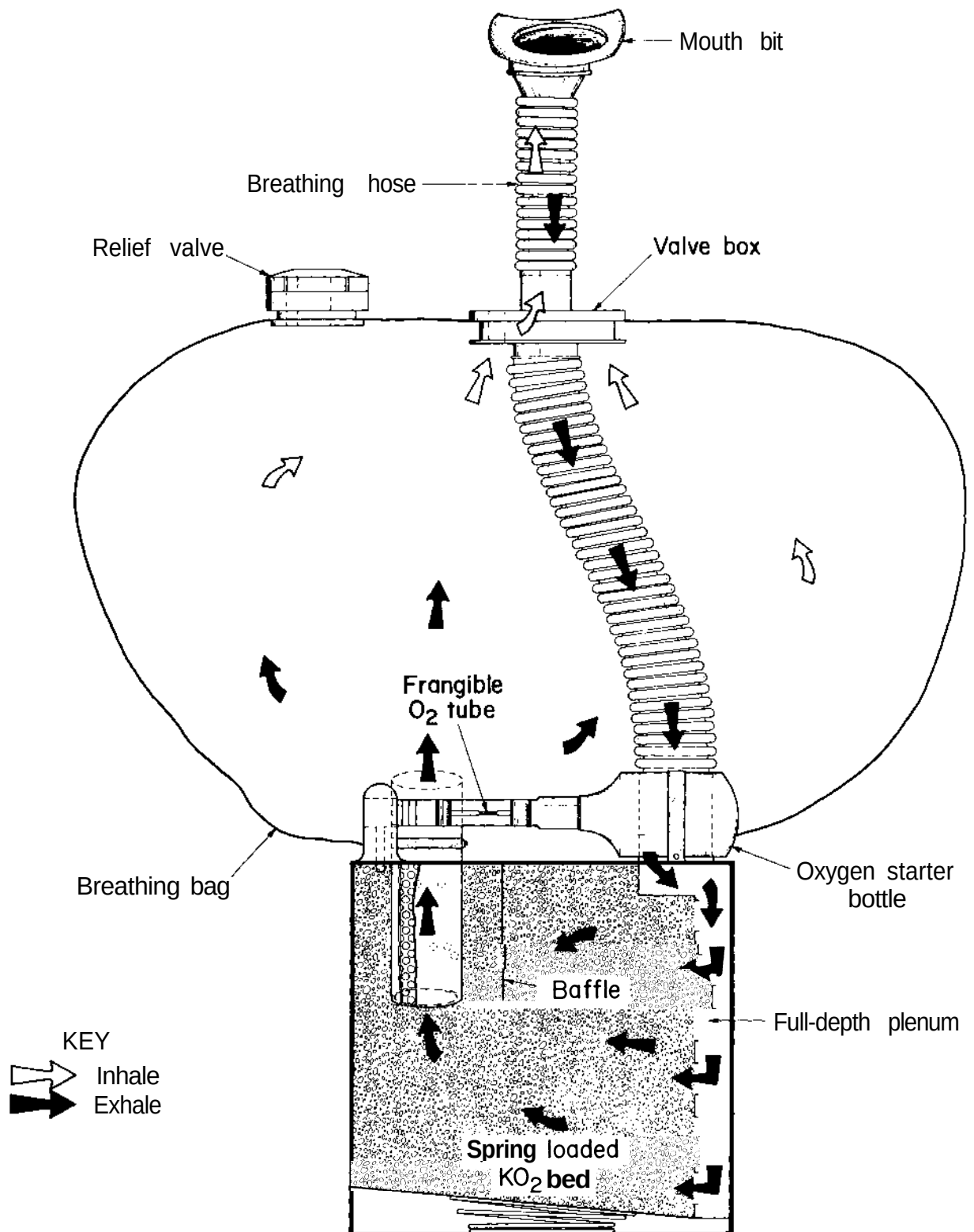
18. Draeger OXY-SR 30 schematic,.....



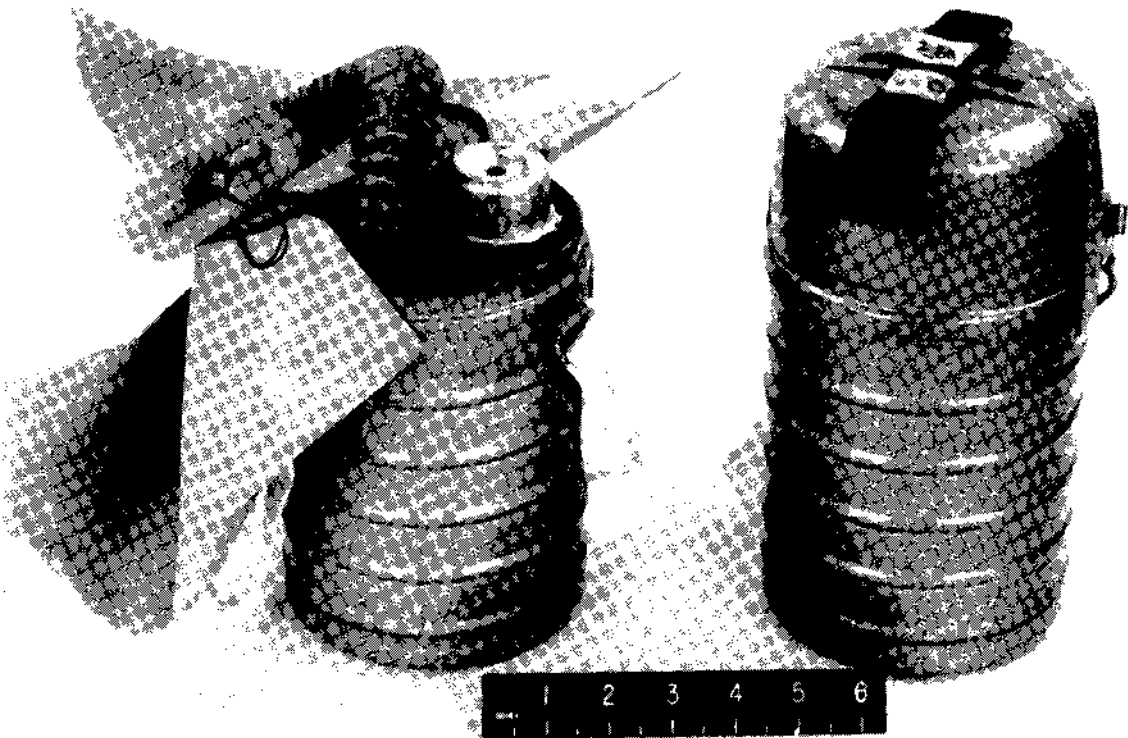
19. Draeger OXY-SR 45 schematic,



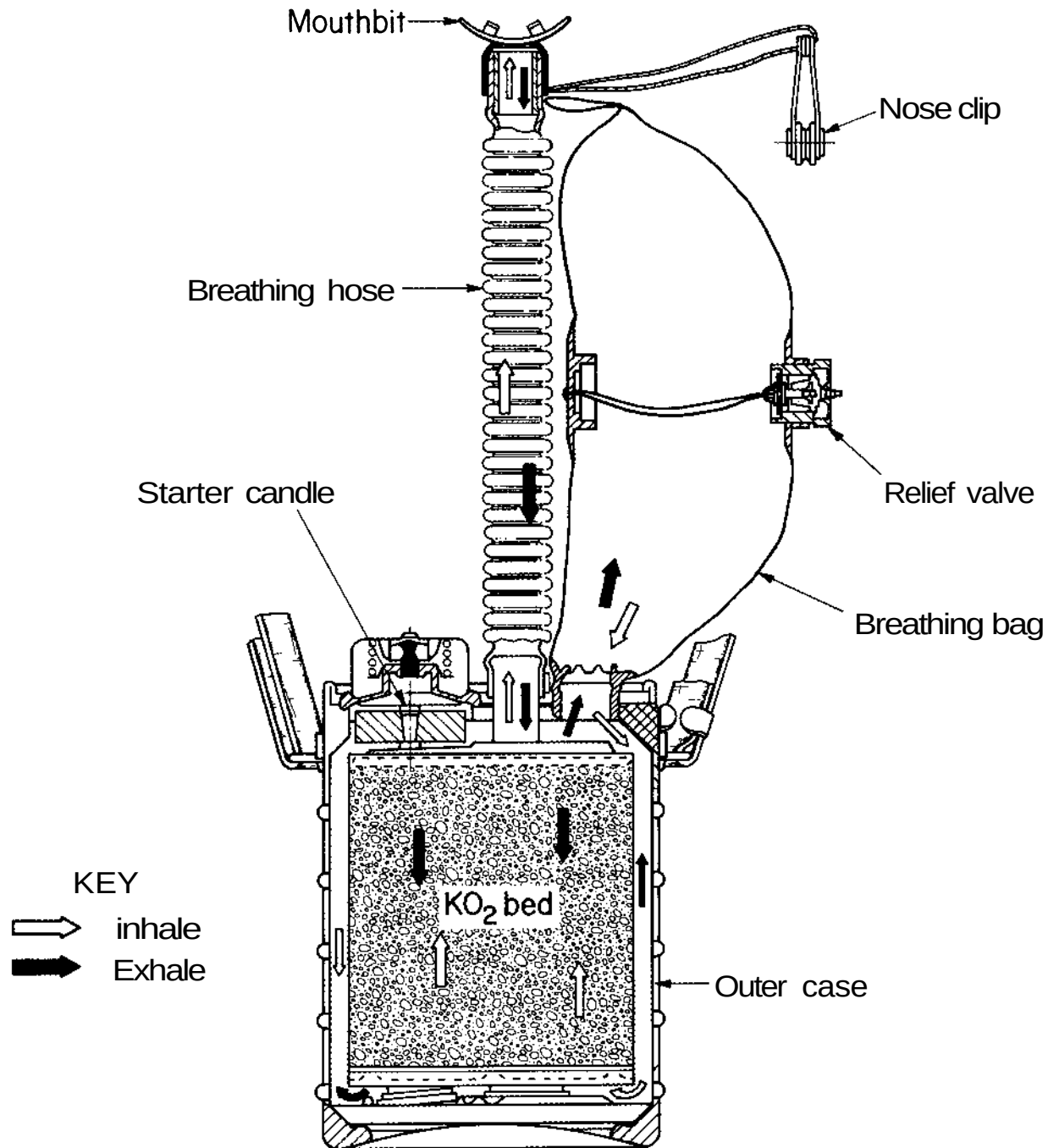
20. Fenzy Spiral II.....



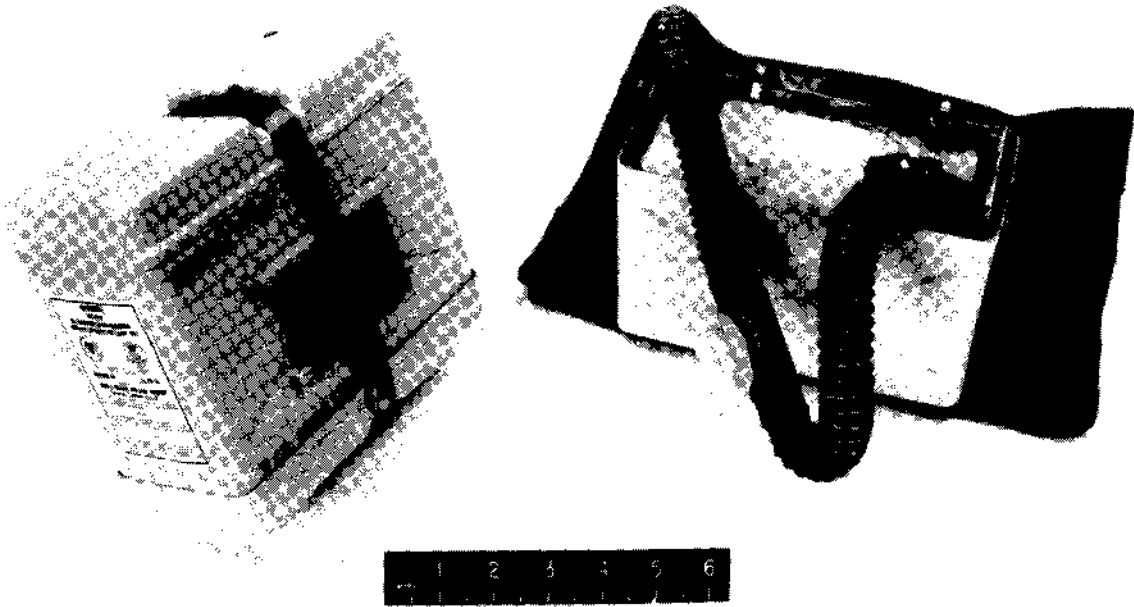
21. Fenzy Spiral II schematic.....



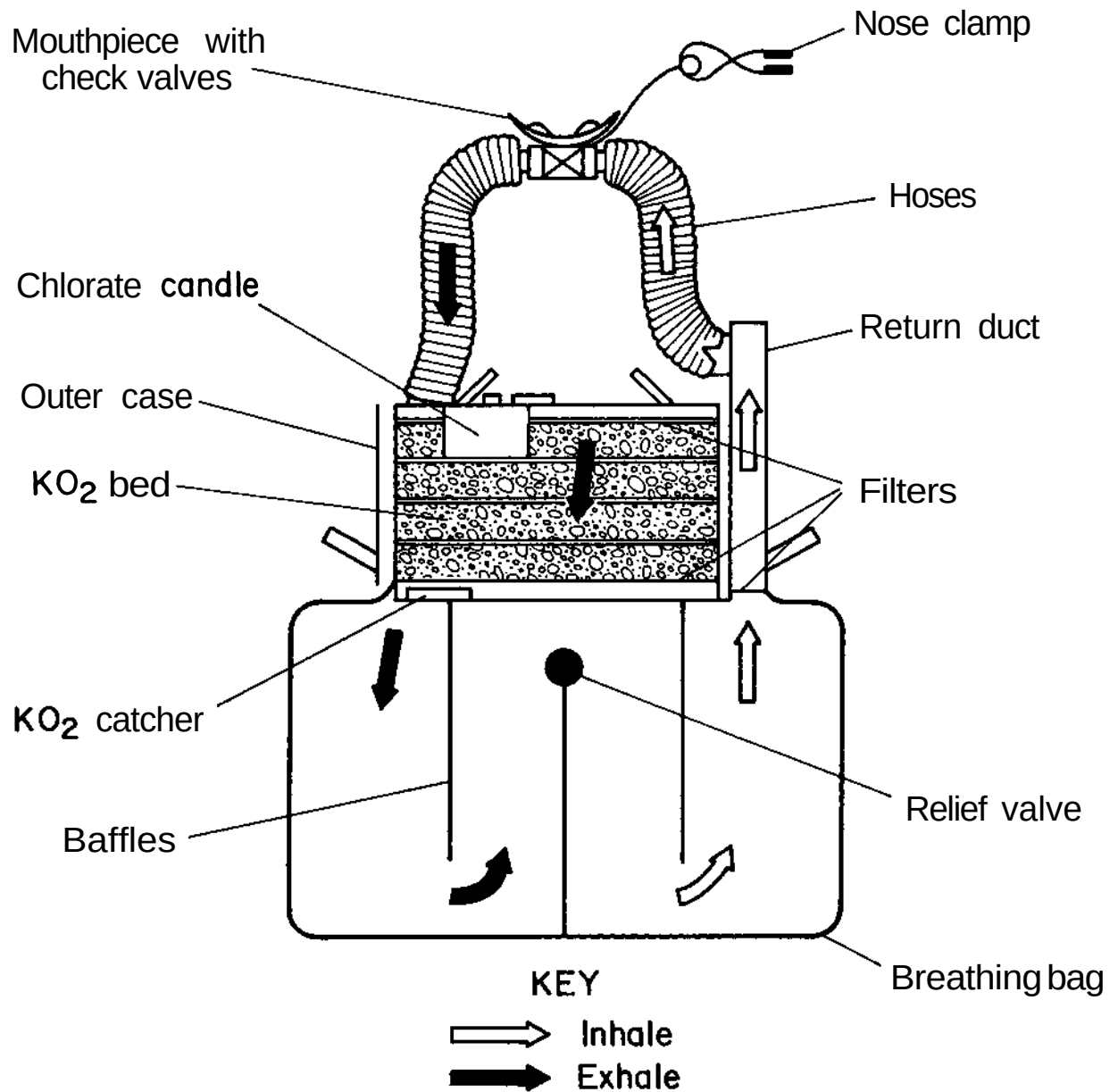
22. WC-7.....



P6N - S3
7 3S



24. Lockheed PBA.....

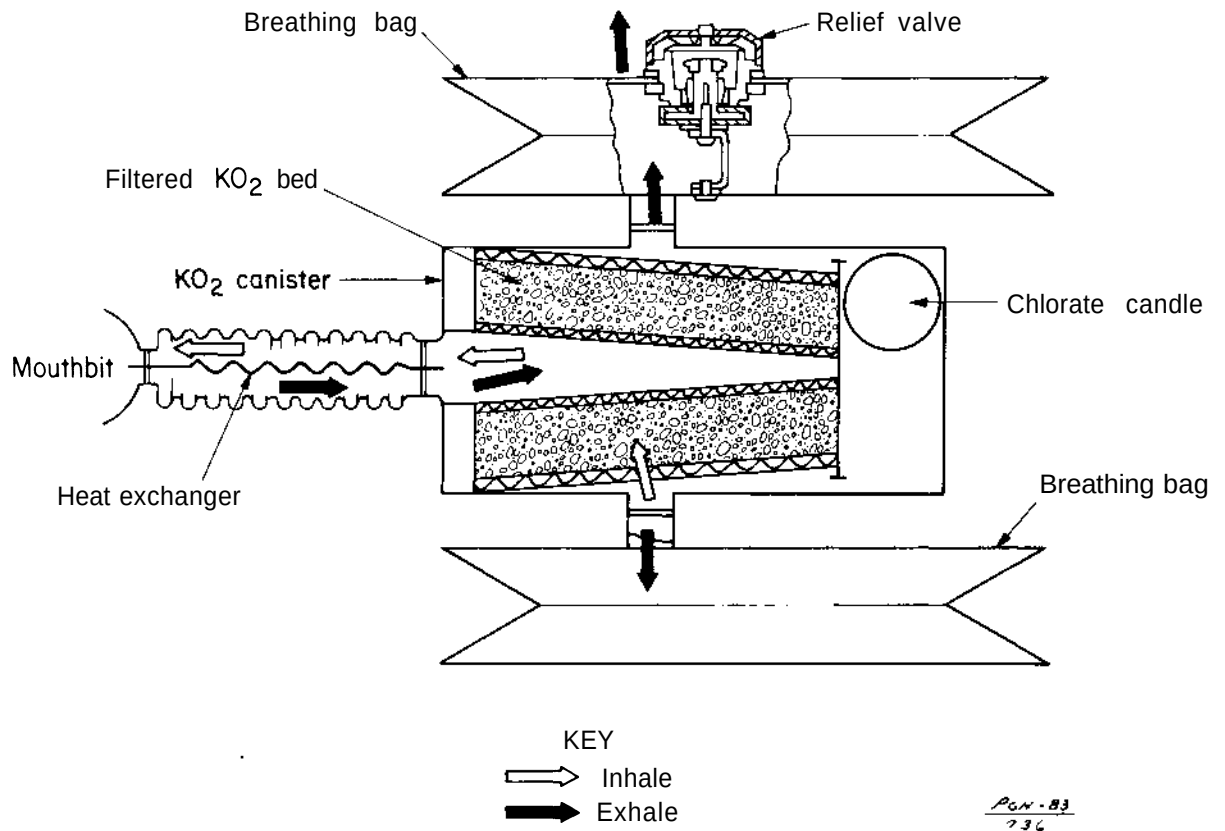


P&H-83
737

25. Lockheed PBA schematic,.....



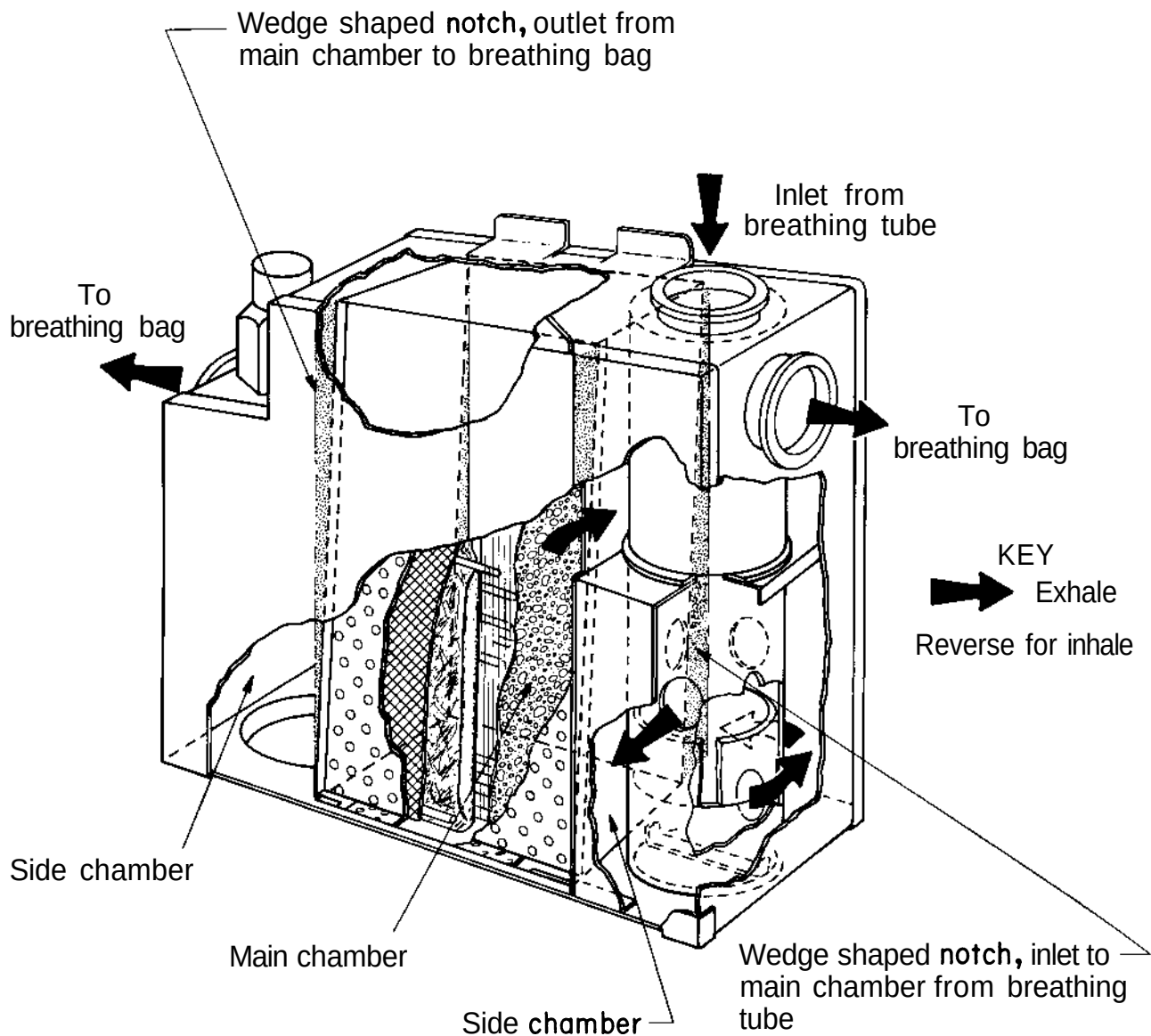
26. MSA 10-min PBA.....



27. MSA 10-min PBA schematic,.....

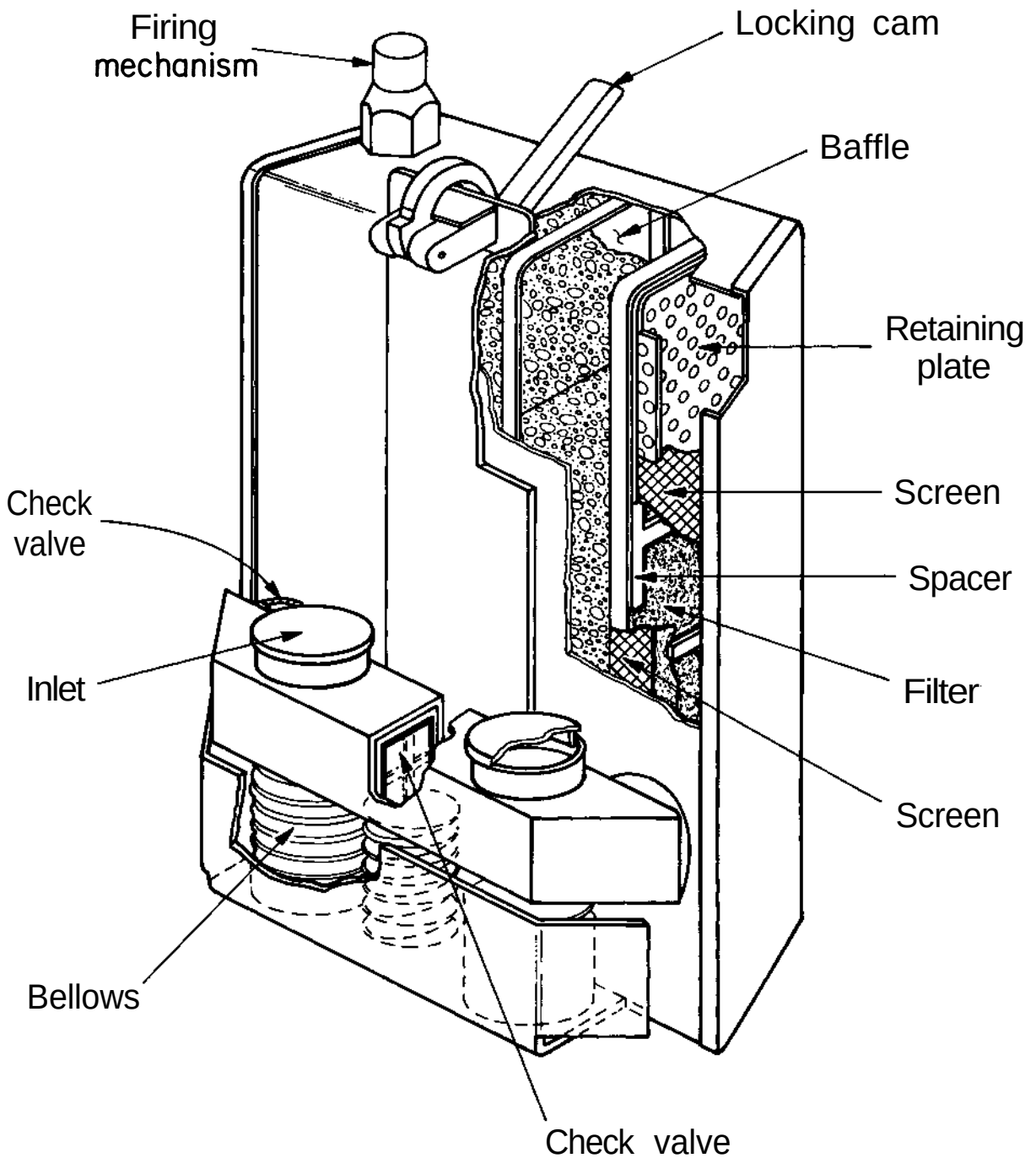


28. MSA 10/60 oxygen self-rescuer system,.....



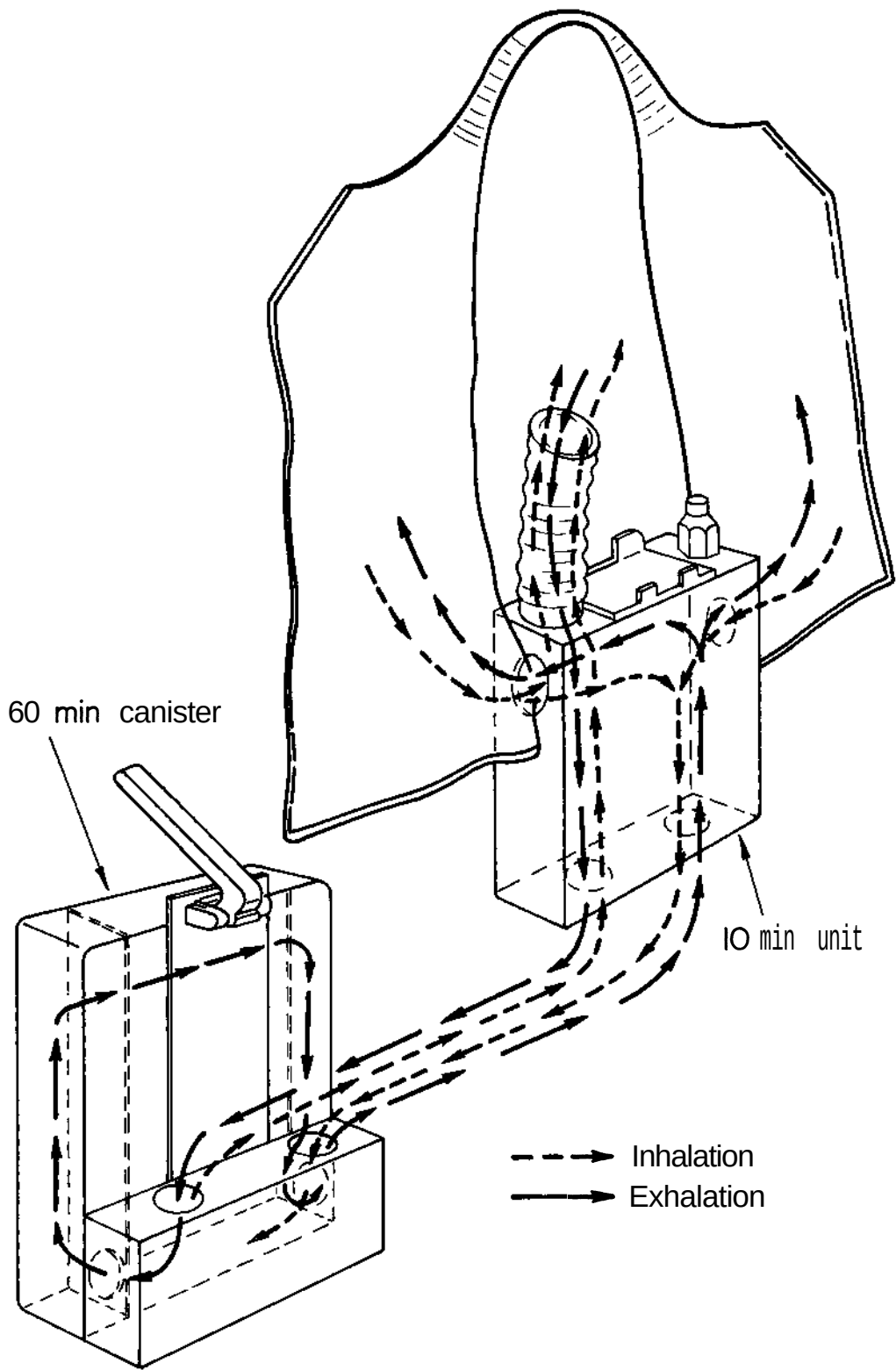
PGN-83
 7/1/64

29. MSA 10/60: 10-min apparatus schematic.....



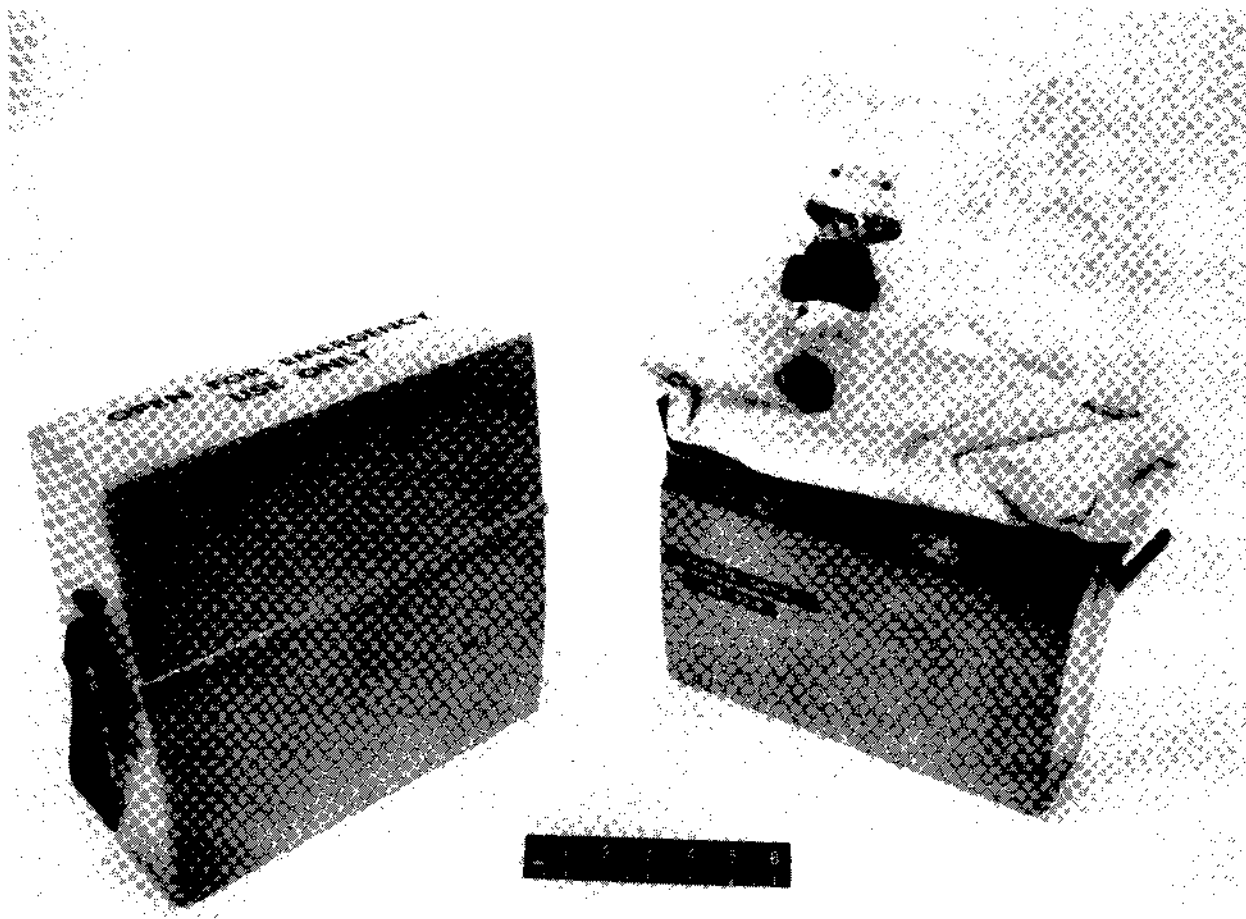
PGN - 83
743

30. MSA 10/60: 60-min canister schematic,.....

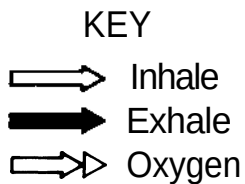


PGH-77
332

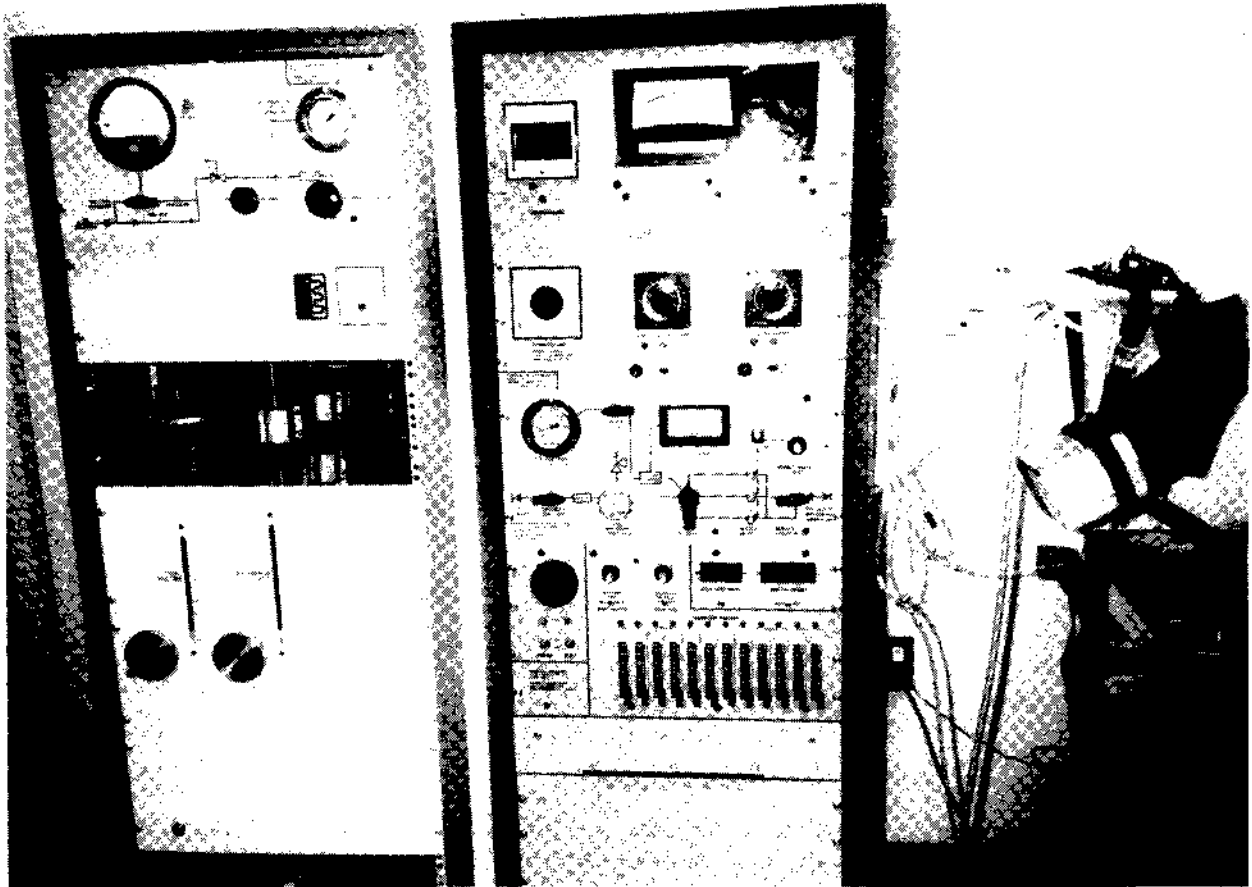
31. MSA 10/60: system schematic.....



32. Westinghouse PBA,.....



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34. Breathing and metabolic simulator.....