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October 1, 1978—September 30, 1979

Evaluation and Performance of Escape-Type Self-Contained Breathing Apparatus

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Evaluation and Performance of Escape-Type Self-Contained Breathing Apparatus

by

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ABSTRACT

The performance of escape type breathing apparatus was evaluated for weight, comfort, ease of use, and protection factor (calculated from facepiece leakage). All of the devices tested provided a self-contained air supply of 5- to 15-min duration. Five of them have the provision to connect an air line but allow the use of the self-contained supply for safe egress. The air supply was stored in cylinders, tubing, or disposable containers. Respiratory inlet coverings were half masks, full facepieces, hoods, and mouthpieces. An estimate is given for the ease of quick donning. Recommendations for conditions of use of the equipment are given.

INTRODUCTION

In recent years the Los Alamos Scientific Laboratory (LASL), Respirator Research and Development Section (now the Worker Protection Study Section), has been studying the operating characteristics and protection factors of atmosphere supplying respirators. This work is funded by the Nuclear Regulatory Commission for the purpose of determining the quantitative protection provided by respirators already certified by the National Institute for Occupational Safety and Health/Mine Safety and Health Administration (NIOSH/MSHA). Such certification indicates that the equipment has met limited criteria for quality control and supplies certain airflows for a known duration. However, the testing cannot generate the information necessary for the user to select individual respirators based on the protection provided.

Earlier reports in this continuing effort discussed the performance of air-line respirators[1] and evaluated 30-min open-circuit breathing apparatus (SCBA).[2] These two reports as well as an earlier one[3] showed the superior protection provided by positive pressure respirators as compared to negative pressure devices and recommended that negative pressure devices not be used in hazardous environments. This report discusses escape type breathing apparatus. Such equipment is lighter and smaller than 30-min apparatus, but has a shorter duration, from 5 to 15 min. Some of the units combine air-line operation with the self-contained mode. Such combinations are described in the section on self-contained breathing apparatus in the certification regulations.[4]

DEVICE DESCRIPTION

Negative pressure atmosphere supplying respirators require the wearer to inhale and consequently reduce the pressure in the facepiece below atmospheric before a regulator will admit air. Most air-purifying respirators are negative pressure also. Positive pressure respirators are either of the continuous flow mode, which have constant outward flow of air, or use a pressure-demand regulator along with a spring-loaded exhalation valve to maintain a constant positive pressure, approximately 1-in. water column, at all times. It is possible for a person performing hard work to force a pressure-demand device negative, but this is typically for a brief time during the breathing cycle. Devices tested include the following:

1. Scott Aviation Ska-Pak, No. 900055-01, is a demand mode unit with a nominal 5-min rating. The second-stage regulator is mounted directly on the mask. The air bottle is worn on the hip with the first-stage regulator on the bottle. This unit and all systems approved for less than 15 min (escape only) do not have end-of-service alarms.

2. MSA (Mine Safety Appliance Co.) Air - Scape unit, No. 456989, demand mode and 5-min duration. This demand unit uses the Comfo half mask with a mask mounted second-stage regulator. The cylinder can be worn on the hip or in back at the waist.

3. MSA Air Escape, No. 76753, 5-min duration. The regulator is located on the hip mounted cylinder. This device contains two features to assure quick activation, a mouthpiece instead of facepiece, and no control valve. The demand mode regulator is always on line and will supply air immediately on inhalation.

4. Scott Ska-Pak, No. 900055-13. A Scottoramic full facepiece is supplied, with a mask mounted regulator. This and all of the pressure-demand respirators tested are combination units which have both a supplied-air fitting and a self-contained air supply. Pressure-demand operation is used with the facepiece pressure remaining positive during normal breathing. The air-line mode can be used for entry, work, and escape, but the self-contained 5-min supply may only be used for escape. All of the combination units tested require manual operation of a valve to start the self-contained air supply.

5 & 6. Robertshaw Ram 15, 900-002-267-01 and -11. These pressure-demand units contain a flat back-mounted pack 19 x 12 x 3 in. and may be ordered with a Sierra Engineering full (No. 5) or half (No. 6) face mask. The regulator is mounted on the mask. Air-line mode is offered, although because of the 15-min duration, entry is permitted using the self-contained supply. A switch with locking lever, located on the right underside of the pack, controls the self-contained supply. Air is stored in coiled tubing inside the pack. There is a pressure gauge clamped to the straps visible while wearing the apparatus, an end-of-service whistle, and a regulator bypass control. The bypass creates a continuous flow condition and cannot be shut off. All of the Robertshaw units require 5000 psi air.

7 & 8. Robertshaw Ram 5, 900-002-262-01. These 5-min units are pressure demand, use the same masks as Nos. 5 and 6 and have air-line provisions. The self-contained supply, once activated by a pull ring, cannot be stopped. The plastic case mounts on the hip. There is no end-of-service alarm as the air supply is to be used for escape only.

9. Robertshaw air capsule 5000. This 5-min unit is for escape only using a hood and continuous airflow to provide protection. It is stored in a plastic case hung over the shoulder. For use the entire unit is removed from the container (which can be carried or discarded), the clear plastic hood is pulled over the head, and a pull ring is used to actuate airflow. The air reservoir rests on the back of the neck. Once air is flowing it cannot be shut off and the reservoir will empty completely.

10. The Survivair Escape Unit is similar to the Robertshaw hood discussed above and of 5-min duration. Breathing air slightly enriched to 28% O_2 is stored in a pair of disposable cylinders each containing 3.2 ft.^{3} of gas at 2800 psi. The unit is worn on the chest suspended from the neck. For use, the hood is withdrawn from the container and pulled over the head. The air supply is actuated by a pull ring and flows until depleted. The carrying case containing the air cylinders remains around the wearer's neck.

Data on each of the units are summarized in Table I.

EVALUATION OF AIRFLOWS AND MASK PRESSURE

Escape devices must meet the test conditions established for SCBA in 30 CFR 11.[4] The standard breathing machine described in the regulations is a reciprocating dual piston pump. It is used with a cam that simulates a 662 kg-m/min work rate, producing a minute volume of 40 L at 24 respirations/min. The respirator mask is sealed onto a head form and the pressure in the facepiece is measured as a function of flow into and out of the mask. Pressures are measured with

TABLE I

RESPIRATORS TESTED

Manufacturer	Approval TC-13F-	Mode	Mask	Weight kg	Air Source
1. Scott Ska-Pak	66	Demand (5 min)	Willson Half mask	3.67	SCBA
2. MSA Air E-Scape	61	Demand (5 min)	Comfo	4.18	SCBA
3. MSA Air Escape	55	Demand (5 min)	Mouthpiece	3.57	SCBA
4. Scott Ska-Pak	68	Pressure-demand (5 min)	Scottoramic	4.53	SCBA+Air Line
Robertshaw		Pressure-demand	Sierra		
5. Ram 15 (minute)	63		Full face	11.11	SCBA+Air
6. Ram 15 "	63		Half mask	10.71	Line
Robertshaw		Pressure-demand	Sierra		
7. Ram 5 (minute)	64		Full face	4.39	SCBA+Air
8. Ram 5 "	64		Half mask	3.96	Line
9. Robertshaw 5000	28 (5 Min, air stored in tubing)	Continuous flow	Hood	2.46	SCBA
10. Survivair 2878	86 (5 min, 28% O_2 in two disposable cylinders)	Continuous flow	Hood	2.88	SCBA

a Validyne DP-45 pressure transducer. Under these test conditions demand units are allowed to develop negative pressure in the facepiece. Pressure-demand respirators are not permitted to go negative. All respirators studied for this report met the certification requirements.

A recent study[5] shows that the requirements for air by humans at near maximum work rates exceeds the flow capabilities of approved breathing apparatus. The main effect of these high work rates is to draw the mask pressure negative even in pressure-demand apparatus. The high protection factors shown for pressure-demand apparatus in this study may not hold during heavy work, but this effect will be studied in the future.

The mask pressures recorded in Table II include values generated by the breathing machine and also by test subjects wearing the devices. Pressures were recorded for all respirators except the MSA Air Escape mouthpiece unit because of the difficulty of mounting a second probe on the device. The other respirators had two probes mounted on the facepieces, for aerosol leakage measurements as well as pressure.

The three demand units show negative pressures in the facepiece during inhalation, up to a maximum of -1.0-in. water column, while none of the pressure-demand facepieces were driven below ambient pressure in our tests.

The Survivair and Robertshaw hood are continuous flow devices for which there is no description in 30 CFR 11.[4] Supplied-air hoods are required to deliver at least 6 cfm, which is relatively easy to supply from compressors through hoses. The limited storage capacity of a self-contained air supply however, makes it impossible to deliver as much as 6 cfm to an escape hood. Airflows were accordingly limited by the manufacturers to just over 1 cfm and the hoods were made tight fitting with an elastic or drawstring closure and an exhalation valve. The result of the availability of only 1 cfm is that either of these hoods can be overbreathed by a person doing hard work such as running. Under these conditions the hood will collapse against the face leaking outside contaminants inside and restricting the heavy breathing required during running. Such conditions can cause inward leakage and reduce the wearers work capacity. Informal running tests that were performed confirm this.

REFILLING

Unlike the 30-min open-circuit SCBA, some of these units require special fittings for refilling. The Scott and MSA Air Escape respirators use the standard CGA 1340 fitting also used on all 30-min SCBA. The MSA Air Escape uses a special fitting that must be obtained from MSA.

Most prefilled large cylinders or tube trailers contain only 1900-2000 psi when delivered, making it impossible to completely fill the MSA unit which requires 2310 psi. However, service life will be much shorter if the bottle is not completely filled to the prescribed pressure. For these tests we filled each cylinder to the required pressure.

For filling the Robertshaw units a special fill tool is required and a source of 5000 psi air. Robertshaw sells a special booster compressor, and Haskell Engineering Co. sells an air-driven booster pump. Both fillings systems are adequate for the task. Survivair avoids filling by using disposable cylinders costing $18 per pair.

QUANTITATIVE FITTING TEST RESULTS

The test equipment and methods are identical to those described in previous reports.[1,2] A LASL constructed chamber of 16 m^3 was used for all tests. Airflow into the chamber is 2.1 m^3/min (75 cfm). A polydisperse aerosol of di-2-ethylhexylphthalate (DOP) is generated using air nebulization, with a single-stage impactor used to remove the large particles. The aerosol particle size is ~0.6-μm MMAD, and the concentration is ~20 mg/m^3 of air. A sample of 1 L/min is

TABLE II

OPERATING CHARACTERISTICS OF ESCAPE DEVICES
Mask pressure inches water column
(SCBA mode)

Device	Average All Test Subjects Respirator Worn Inhal	Average All Test Subjects Respirator Worn Exhal	Machine tests Breathing Machine Inhal	Machine tests Breathing Machine Static	Machine tests Breathing Machine Exhal	Machine tests Steady State Exhal	Machine tests Duration Min
Demand							
1. Scott Ska-Pak	-0.9	0.4	-1.0	---	0.5	0.4	9.25
2. MSA Air E-Scape	-0.8	0.5	-0.9	---	0.7	0.5	7.55
3. MSA Air Escape	---	---	-0.7	---	0.7	0.4	5.54
Pressure Demand							
4. Scott Ska-Pak	0.2	1.9	0.3	0.6	2.1	2.0	6.60
Robertshaw Ram 15							
5. Full face	0.8	2.4	0.7	1.3	2.5	2.5	17.90
6. Half mask	0.8	2.3	0.6	1.1	2.3	2.0	16.45
Robertshaw Ram 5							
7. Full face	0.4	1.8	0.4	1.2	1.6	1.5	---
8. Half mask	0.3	1.7	0.3	0.7	1.9	1.6	5.00
Continuous Flow							
9. Robertshaw Air Capsule	-0.1	0.8	(Flow rate 1 CFM)				5.30
10. Survivair Escape Device	0.1	0.9	(Flow rate 1.2 CFM)				6.58

Mask pressures measured while unit worn, average of all subjects tested. Breathing machine tests from 30CFR11, Subpart H. Machine rate approximately 24 respirations per minute. At peak inhalation rate of approximately 4.2 cfm (120 L/min) demand units are not to exceed a resistance of 1.25 inch (311 Pa), pressure-demand units not to go below ambient. The static pressure for pressure-demand units cannot exceed 1.5 in (373 Pa). At a steady exhalation of 3 cfm (85 L/min), the pressure for demand units may not exceed 1 inch (249 PA), for pressure-demand units it may not exceed 2 inch over static. Duration is measured on the breathing machine.

removed through a probe sealed onto the facepiece and measured in a forward light-scattering photometer. This LASL built instrument is similar to commercially available equipment.

Test subjects were selected according to the anthropometric scheme developed for NIOSH in 1973.[6] The facial dimensions of the panel were taken from measurements of Air Force personnel (male and female) measured in 1967-68. We selected the limits to include 90-95% of the military population on the assumption that this would represent civilian populations.

Originally this test protocol called for selection of test subjects for half masks by face length and lip width. More recent work has indicated that lip width is not as important as previously thought and accordingly the full face panel shown in Appendix A was used for both full face masks and half masks.

The scheme calls for different numbers of subjects (male and female) in 10 different size box categories. The two demand mode half mask respirators were tested on 25 persons as shown. For pressure-demand equipment, only 10 persons, one from each size category, were chosen. Face size is of less importance with positive pressure because the faceseal is aided by an outward flow of air should a leak occur. There are at present no anthropometric criteria for subjects to test mouthpieces or hoods, so five LASL personnel selected for availability were used for these tests.

The test exercises used were: normal breathing, deep breathing, moving small discs from side to side on a frame, moving blocks from a high to a low shelf, talking, running in place, and a final normal breathing.

For the two hoods and mouthpiece unit, facial movements are of less importance, so the following exercises were used instead: normal breathing, touch toes, run in place, and a final normal breathing.

The photometer, adjusted to read full scale on the challenge aerosol concentration, provides a direct reading of the per cent penetration into the mask. The peak penetrations measured for each test subject during each exercise are averaged to arrive at a penetration value for the exercise. Penetration values for each exercise are then averaged to arrive at an overall average for the test subject wearing the particular apparatus. Respirator performance is reported as protection factor (PF), a ratio of the challenge atmosphere (100%) divided by the overall average per cent penetration of the challenge aerosol into the mask. (A PF of 1000 is 0.1% penetration, the average of all of the exercises performed.)

Table III indicates the PF achieved by each test subject wearing each mask. The table indicates cumulative protection, that is, a subject who achieved a PF of 1000 is also counted as achieving 500, 200, etc. The two demand half mask respirators provided a PF of at least 10 to all subjects. This agrees with published results for half masks in air-purifying mode,[7] but is not acceptable for protection against the potentially high concentrations of toxic materials created in an emergency escape situation.

The mouthpiece respirator tested (also a demand device) provided a PF of 200 for four of the five subjects tested, with the remaining subject achieving a PF of 20. LASL has no data on previous mouthpiece fitting, but a recent Dow Chemical study[8] reported the results of fitting several thousand chlorine workers. The test conditions in this study differ considerably from ours, using a 1000-ppm challenge of refrigerant 12 (dichlorodifluoromethane), with detection by means of a Gas Tech halide meter. Because it is difficult to adsorb freon, the Dow mouthpiece respirators were modified by removal of the cartridges and the addition of a breathing hose to bring in fresh air from a demand regulator. Sampling was done downstream of the exhalation valve, which measured contaminant that had been inhaled and then exhaled. LASL testing measures the concentration in the facepiece at all times during the breathing cycle. Despite these differences in technique, LASL's results showed that four out of five (80%) achieved a PF of 200, while Dow reported 90% of the workers could achieve 1% (10 ppm) or less leakage for a PF of 100. It should be noted that the Dow employees are trained to use the mouthpiece respirators without the nose clip. The devices are approved with nose clips which LASL's subjects wore.

TABLE III

ESCAPE TYPE SCBA
NUMBER OF PERSONS ACHIEVING STATED PROTECTION FACTOR
(Demand Mode)

	Protection Factor Attained										
Less Than–	10	20	50	100	200	500	1k	2k	5k	10k	20k
Demand Mode											
1. Scott Ska-Pak Half mask 25 subjects	25	17	14	9	9	6	6	6	3	2	1
2. MSA Air E-Scape Half mask 25 subjects	25	19	13	5	-	-	-	-	-	-	-
3. MSA Air Escape Mouthpiece 5 subjects	-	5	4	4	4	3	-	-	-	-	-
Pressure-Demand Mode 10 Subjects Tested											
4. Scott Ska-Pak (full face)			-	-	10	9	9	9	9	7	6
5. RobertShaw Ram 15 (full face)				-	-	-	-	-	-	10	8
6. RobertShaw Ram 15 (half mask)				-	-	-	-	-	10	9	5
7. RobertShaw Ram 5 (full face)				-	-	-	-	-	-	-	10
8. RobertShaw Ram 5 (half mask)					-	-	-	10	8	7	4
Continuous Flow Hood 5 Subjects Tested											
9. Robert Shaw Air Capsule		-	-	-	5	3	3	1	1	-	-
10. Survivair	-	-	-	-	-	-	-	5	4	4	3

All of the pressure-demand units can be operated in either air-line or SCBA mode. As the pressure delivered to the mask was almost identical in either mode, only the SCBA test results are reported. The Scott pressure-demand Ska-Pak provided a PF of 5000 to 9 of 10 subjects; the 10th subject achieved only 200. All subjects with the Robertshaw full face masks achieved PF of 10 000 or better. With the half masks, 9 out of 10 achieved 10 000 with the 15-min unit, and 7 of 10 subjects reached a 10 000 PF wearing the 5-min system.

There are large differences in the protection provided between the two hoods. This is a relatively new type of device for which there are no published PFs. The Survivair gave a PF of 2000 to all five subjects, the Robertshaw only 200, significantly less.

DISCUSSION AND CONCLUSIONS

There are other SCBA and combination air-line units available, however the 10 systems evaluated here are typical. All previous studies of atmosphere supplying devices have shown the superior protection of pressure demand or continuous flow over demand devices. Our results confirm this.

In terms of use there are three different types of devices that have been tested. (1) Devices for escape only, the two half masks, the mouthpiece and the two hoods; (2) combination air line/SCBA of less than 15-min duration; and (3) combination units of 15 or more minutes duration.

Escape-only devices have a single use: to allow a person working in a normally safe location sufficient time to escape from a sudden hazard. Examples could include a release of toxic gas from a chemical reactor or column, a dumping of carbon dioxide or inert gas for purposes of fire extinguishment, or perhaps a sudden fire condition. The need for an escape device must be determined for each potential use. It may be decided that fleeing towards an area of fresh air such as an outdoor exit or corridor may be safer than remaining in the dangerous area for the time required to don and activate the escape breathing apparatus.

The MSA Air Escape mouthpiece unit may be operated in 1 to 5 s and provides comparable protection to the other demand half mask units, but less than the pressure demand and escape hood systems. Half masks may require 15 to 30 s, while full face masks a little longer, especially to remove eyeglasses, etc. Hood type units will require approximately 10 to 20 s to activate. All hoods share the advantage of fitting on all size faces, over beards and eyeglasses. The Survivair hood is somewhat easier to don because the neck seal is a soft rubber rather than the elastic seal of the Robertshaw unit. Users with eyeglasses, for instance, can put on the Survivair hood without disturbing their glasses. The lifetime of the hoods with continuous flow operation is limited by capacity of the stored air supply, about 6.5 min for the Survivair and 5.5 min for the Robertshaw.

Air-line equipment is not permitted in areas immediately hazardous to life because of the possibility of interruption of the air supply. Likely causes of air failure include compressor failure or damage to the air hoses. A combination breathing apparatus of less than 15-min duration provides an unlimited air supply with the immediate availability of the self-contained reservoir if needed. Examples are the Scott Ska-Pak and Robertshaw Ram 5. This equipment allows the use of an air-line type respirator in atmospheres immediately hazardous to life.

The Robertshaw Ram 15 and similar longer duration devices may be used for entry while using the self-contained air supply. This mode of entry may be necessary because of the distance to be traveled, the terrain to be covered, or the necessity of closing doors or air locks to reduce the spread of contamination. Once at the work site the wearer can connect to an installed air line and work for as long as necessary. Leaving the work place is accomplished in SCBA mode. This class of apparatus is the most versatile of all at a cost comparable to 30-min SCBA.

RECOMMENDED WORK PRACTICES (Based on the data developed in this and previous reports and work experience)

1. Do not purchase demand type escape devices with facepieces. Equipment already in use should be replaced as funds are available or converted to positive pressure if possible. Demand mouthpiece escape SCBA are represented by the single example discussed above, but they do have the advantages of very quick donning, which can offset the lower protection of negative pressure respirators.

2. Determine if an escape type device is needed in the work place, or if escape is possible without the equipment. It may be preferable, depending on the geometry of the work place, to immediately flee to fresh air rather than take the time required to obtain and don an escape device. Competent engineering, safety, industrial hygiene or health physics advice will be needed to make the correct decisions. The degree of protection required must be weighed against the ease and quickness of donning and operating the device. Hoods can be put on quickly over any size face, beards, and eyeglasses. They provide lower protection than do the pressure-demand respirators, which may be tolerable for the 5 min allowed to escape.

3. If entry and normal retreat require the use of SCBA, then select a pressure-demand full facepiece combination air line and SCBA with 15 or more minutes of service life.

4. For work in hazardous environments where an air line would normally be used for entry, work, and escape, select a combination unit of less than 15-min duration. Here the SCBA would only be used for escape in case of interruption of the air supply.

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1. Scott Ska-Pak

2. MSA Air E-Scape

3. MSA Air Escape

4. Scott Ska-Pak

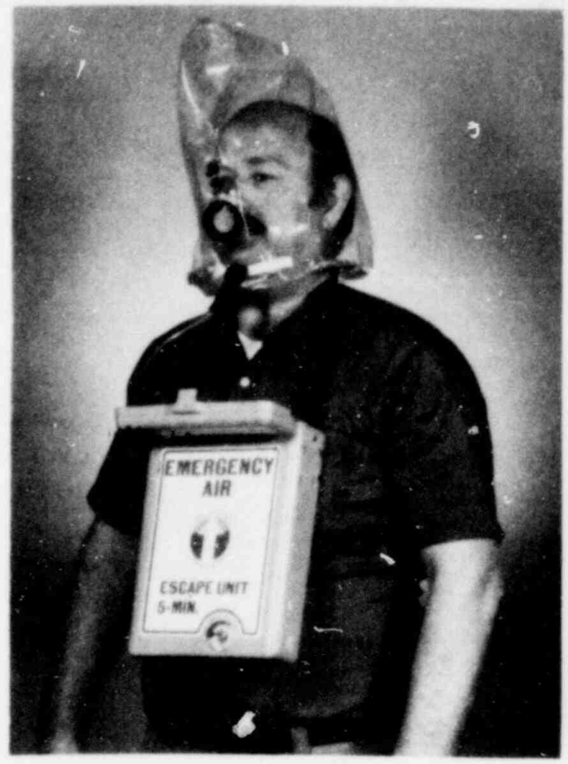
5. Robertshaw Ram 15

6. Robertshaw Ram 15

7. Robertshaw Ram 5

8. Robertshaw Ram 5

9. Robertshaw 5000



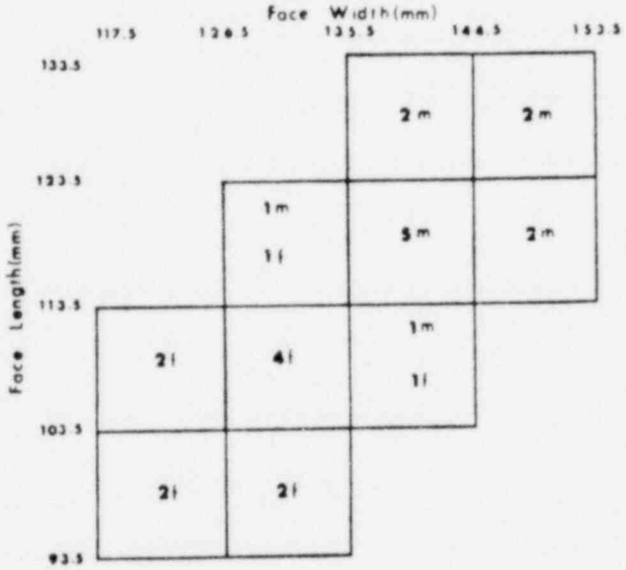
10. Survivair 2878

Appendix A

FULL FACE ANTHROPOMETRIC TEST PANEL

(from LA-5488, reference 3.)

MALE-AND-FEMALE, 25-MEMBER PANEL FOR TESTING OF FULL-FACE MASKS



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