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Respirator Studies for the Nuclear Regulatory Commission

October 1, 1977—September 30, 1978

Evaluation and Performance of Open Circuit Breathing Apparatus

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Evaluation and Performance of Open Circuit Breathing Apparatus

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RESPIRATOR STUDIES FOR THE NUCLEAR REGULATORY COMMISSION
OCTOBER 1, 1977-SEPTEMBER 30, 1978
EVALUATION AND PERFORMANCE OF OPEN CIRCUIT BREATHING APPARATUS

by

ALAN HACK, ANDRES TRUJILLO, O.D. BRADLEY AND KEITH CARTER

ABSTRACT

The over-all performance and protection factors provided by 12 NIOSH approved, 30-minute duration, self-contained breathing apparatus were determined while the respirators were worn by a panel of anthropometrically selected test subjects. Demand-type units provide much lower protection factors than do pressure-demand-types. Observations on facepiece pressure, sound level of end-of-life alarms, weight, and comfort are also recorded.

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INTRODUCTION

In 1972 a report[1] issued by the Respirator Research and Development Section (RRDS), Industrial Hygiene Group, Los Alamos Scientific Laboratory (LASL), discussed facepiece leakage of self-contained breathing apparatus (SCBA). This was the first known respirator fit evaluation using both a quantitative leak test method and a selection of test subjects to represent a variety of facial sizes.

The present work differs from the earlier effort in the following points. Air-generated polydisperse dioctyl phthalate (DOP) was used as a challenge aerosol instead of monodisperse thermally generated DOP used in 1972. The latter remains a standard test for filter efficiency but is not used for respirator fit testing because the heat generated aerosol includes a variety of decomposition products. A smaller light scattering photometer has allowed us to reduce the sample rate to 1 L/min instead of the 8 L/min used previously.

Both male and female test subjects were included. It is recognized that males are the overwhelming users of SCBA at this time though women are beginning to enter professions requiring the use of SCBA. In the earlier study the test subjects used were 31 male fire fighters who were experienced in the use of SCBA. The present study utilized the services of male and female subjects selected to fit certain facial size criteria, most of whom were not experienced wearers of SCBA.

RESPIRATOR DESCRIPTION

Every commercially available open circuit 30 minute SCBA unit approved by the National Institute for Occupational Safety and Health (NIOSH), and the Mine Safety and Health Administration (MSHA) was tested.[2] Three European units approved in their respective countries but not in the U. S. were also tested.

The open circuit 30 minute SCBA is the most commonly used respirator by fire departments, rescue squads and industry for entry into, rescue, and escape from atmospheres containing contaminents either unknown or highly dangerous to life, or an oxygen difficiency. The units are remarkably similar in appearance, (Figs. 1-12). All contain a cylinder of compressed air, a backpack with necessary straps to support the unit on the wearer's back, a regulator mounted either on the front of the body or on the mask, and a full face mask. Six of the SCBA are demand-type, requiring the wearer to inhale (produce a negative pressure in the facepiece) before air is delivered. Five are pressure-demand, maintaining a positive pressure in the facepiece at all times. One unit is approved for use in both modes. All of the American units that operate at a bottle pressure of 2000 psi contain a main line valve and bypass valve mounted on the regulator. Every unit tested had a pressure gauge visible to the wearer and an end-of-life alarm. Table I lists all units tested.

1. The MSA 401 Air Mask (Mine Safety Appliances) is approved by NIOSH/MSHA under schedule 13F, approval TC-13F-29. It is a demand type unit. The end-of-life alarm is mounted at the point of connection of the high pressure hose to the cylinder (lower back). Cylinder valves on all SCBA contain a ratchet device to prevent accidental closure; however MSA's ratchet can be moved out of position easily, which is an advantage. The regulator is mounted at the waist in front. Unlike many of the other SCBA, the regulator cover can be removed without tools to inspect the diaphragm for damage. An Ultravue full facemask is standard with this unit, the Clearvue facepiece tested in the earlier study must now be special ordered.

2. The MSA 401 pressure-demand Air Mask, approval TC-13F-30 is almost identical to no. 1. The regulator cover has

a raised dome to contain the spring required to apply pressure on the diaphragm to maintain positive pressure in the facepiece. A spring loaded exhalation valve is included to maintain the positive pressure. Supplied with this respirator is an optional composite cylinder weighing 6.39 kg (14 lbs) when filled with 1.3 m^3 (45 ft^3) of air. This cylinder is made of a thin aluminum liner wrapped longitudinally and circumferentially with fiberglass cords embedded in epoxy. This cylinder, an option for either MSA SCBA, is approximately 4.1-kg (9-lbs) lighter than the conventional steel or aluminum cylinder used in all other units.

3. The Scott Air Pak IIa (Scott Aviation, ATO) approval TC-13F-39, is a demand only unit. An aluminum cylinder weighing 9.79-kg (21.6-lbs) is included. The backpack cylinder clamp can be loosened without being disconnected. This makes it unnecessary to remove the entire unit when replacing the cylinder. The wearer bends over while a second person replaces the cylinder. The end-of-life alarm is located in the chest mounted regulator. In addition to hearing it, the wearer can place his hand on the regulator to feel the alarm. This is useful in a noisy environment to determine if the wearer's unit is indeed the one that is sounding an alarm. The Scottoramic facepiece is the standard full facepiece used in all other Scott respirator configurations.

4. The Scott Presur Pak IIa, approval TC-19C-40, is a pressure-demand unit but otherwise identical to no. 3. The regulator contains a select lever that withdraws spring pressure from the diaphragm to convert the unit into demand. The facepiece exhalation valve contains a balanced pressure bladder to maintain the 1-in (water column) positive pressure. Under negative pressure it automatically becomes a demand exhalation valve. The instructions state that demand mode is to be used only to put on the equipment (donning), and in fact this unit is not approved for use in demand mode. However it is possible to use this unit in demand mode contrary to instructions and approval.

5. The Globe Guardsman (Globe Safety Products) is a demand unit, approval TC-13F-43. A pressure-demand version did not have approval at the time of our testing and was not evaluated. A Sierra Engineering full facepiece is used with the Globe, identical to that used by Norton for air purifying service, and used by Pulmosan and Robertshaw in atmosphere supplying service. The end-of-life alarm is a whistle installed on the chest mounted regulator. It is somewhat difficult for a second person to change the cylinder while the unit is being worn. After the retaining strap is opened, it is necessary to maneuver the cylinder valve and gauge past a narrow wire loop of the backpack.

7. Survivair (U. S. Divers) also offers two versions of their SCBA. The demand unit has TC-13F-44 approval. This unit has a waist mounted regulator, with the end-of-life alarm at the lower back. Replacing the cylinder on the Survivair units is as difficult as on the Globe. This unit was tested with a blue silicone rubber full facepiece.

8. The pressure-demand Survivair unit, approval TC-13F-45, is almost identical to the demand version. Unlike the Scott (no. 4.), this is approved in both demand and pressure-demand modes. To switch between them, a lever on the regulator is moved. Also a knob on the facepiece exhalation valve either engages a spring onto the valve flapper for pressure-demand mode or retracts the spring for demand. Both the regulator lever and valve knob must be adjusted when switching from demand to pressure-demand. This unit uses a black neoprene rubber facepiece. Either the neoprene or silicone facepiece may be purchased with either Survivair SCBA.

11. This is a new unit known as the Scott 4.5, approval TC-13F-73. It differs from other SCBA devices by using 4500 psi air. The aluminum cylinder is fiberglass reinforced like the MSA composite bottle, but wrapped only circumferentially. It is also smaller than the 2000 psi bottles, 164-mm (5.38-in) diameter compared to 171 mm (6.75 in), and weighs 5.5 kg (12 lbs). The first stage regulator is mounted on the backpack, with the second stage regulator mounted on the Scottavista facepiece. The regulator is removeable from the facepiece allowing one to don the facepiece in safe air, and insert the regulator only when the self-contained air supply is needed. The Scottavista facepiece is almost completely transparent with only the sealing edge being of opaque rubber. The four head straps are retained in a sort of hair net with only the two lower straps adjustable. No main line valve is supplied, but there is a bypass valve on the regulator. The end-of-life alarm is a whistle located in the facepiece regulator which sounds only on inhalation.

12. The pressure-demand version of the Scott 4.5 has approval TC-13F-76. The pressure-demand components are entirely contained within the facepiece regulator. The demand unit (no. 11) was purchased when the 4.5 design was quite new. Experience in the field led the manufacturer to make several changes which were included in our pressure-demand unit bought later. Changes made in newer units include details of construction of the back pack, means of connection of the low pressure breathing hose, and some details of the face mask. New purchasers of either demand or pressure-demand units will receive the latest version.

13. The Chubb (Chubb Panorama Ltd., England) is a pressure-demand unit. The first stage regulator is mounted on the backpack with the second stage on the facepiece. A bypass valve permitting continuous flow is installed on the facepiece regulator. A spring loaded exhalation valve is used. This is the heaviest (17.3-kg, 38-lb) unit tested, and contains the largest (178-mm, 7-in diameter) cylinder holding 2000 psi breathing air. The end-of-life whistle is connected to the pressure gauge mounted over the left shoulder.

14. The Auer BD 73 is a demand unit made by Auergesellschaft, Federal Republic of (West) Germany. This unit uses a 300-bar (4500-psi) cylinder of 128-mm (5-in) diameter. The Auer facepiece is a prototype of the MSA Ultravue. Like the Chubb, the Auer first stage regulator is mounted on the backpack, with

the second stage facepiece mounted. A rubber cover in the center of the second stage regulator can be pressed for purging. The end-of-life whistle is mounted on the first stage regulator.

15. The last unit tested is the Drager Model 54/II, Dragerwerk, Federal Republic of Germany. This pressure-demand unit has a backpack mounted first stage regulator and end-of-life whistle, with a 200-bar (3000-psi) cylinder of the same dimensions as the Auer. The second stage regulator, mounted on the facepiece, contains a knob to remove the spring pressure on the diaphragm to prevent air flow while donning. The exhalation valve is spring loaded. A Pananova S full facepiece is used which is similiar to the Auer and Ultravue except for having twin flap seals instead of the single flap seal on the other facepieces.

WEIGHT OF SCBA

Approved U. S. SCBA are limited to 16 kg (35 lbs),[3] presumably the lightest weight obtainable when the regulations were first promulgated. A previous study[4] has shown that excessive weight is the greatest physiological burden on the user, with breathing resistance a secondary consideration. The American units with steel cylinders all weigh approximately 14 kg (31 lbs), while the two conventional Scott units (nos. 3 and 4) with aluminum cylinders weigh 13 kg (28 lbs). The MSA SCBA with optional composite bottle (no. 2) and the Scott 4.5 units all weigh between 9 and 10 kg (21-23 lbs). The foreign systems vary from 13 kg (30 lbs) for the Drager to 17 kg (38 lbs) for the Chubb. Table II shows the weight and size of each unit.

CYLINDERS AND COMPRESSED AIR

All of the American 2000 psi SCBA use the standard Compressed Gas Association CGA 1340 cylinder fitting. Interchanging of bottles between different brands voids the NIOSH/MSHA approval. Such exchange of bottles is common, especially between fire departments of adjoining districts who respond to requests for assistance under "Mutual Aid" agreements. No other components of different manufacturers' SCBA can be interchanged.

In contrast the European units contain a large number of interchangeable parts. All of the cylinder connections are the same on the units tested, even though pressures of 2000, 3000, and 4500 psi are represented in the three different cylinders purchased. Neither cylinder pressure gauges nor relief discs, mandatory in the U. S., are required in Europe. A hazardous condition could easily occur if a cylinder rated for lower pressure was inadvertently filled to a higher pressure. Such a cylinder would not necessarily be destroyed, but could be stressed beyond normal limits, leading to later failure.

There is little risk of connecting a higher pressure cylinder to a U. S. SCBA rated for lower pressure because the screw threads on the Scott 4.5 cylinder and hose are longer preventing connection of a 4.5 bottle to any 2000 psi SCBA. However the 4.5 hose connection at the fill station can mate with a 2000 psi bottle, a potential hazard unless care is taken during filling.

Each of the foreign units has the first stage regulator mounted in the lower backpack connected directly to the cylinder. The second stage in mounted directly on the facepiece by means of a screw fitting which is identical for the three brands allowing any mask to be connected to any regulator. European standards allow or even require such compatability. In the States any replacement with parts not approved originally voids the certification.

Our 2000 psi units were refilled with synthetic air (mixed from nitrogen and oxygen at the LASL gas plant and delivered in tube trailers of 1100 m^3 capacity). For filling the Scott 4.5 as well as the two higher pressure foreign units a Haskell Engineering Model 29653 SafetyAmp booster pump was utilized. This unit, recommended by Scott, uses an air driven ram to boost a starting pressure of 200-2000 psi up to 5000 psi. It is adjustable to any pressure required and was satisfactory for the purpose.

SIZE OF THE UNITS

Fire Departments especially have requested units of lower profile in order to be able to work in close quarters. The depth of the units in Table II was measured with the backpack supported on a block of wood to represent the back of the wearer so that the clearance between the wearer's back and the heighest point of the unit can be estimated. Most of the conventional units range from 184 to 199 mm (7.2-7.8 in). The Scott 4.5 with new design backpack (silver color instead of black), is 165 mm, the smallest profile of all. The German units, because of their narrower cylinders, are close in size to the 4.5.

MASK PRESSURE

Pressures in the facepieces were measured both during the bench tests and while being worn. Test conditions contained in the approval regulations[2] require the use of a breathing machine to exercise the regulator. The breathing machine, using a cam to simulate work at 622 kg-m/min work rate, produces 24 respirations per minute with minute-volume of 40 liters. In a demand mode mask pressure shall not exceed a negative 311 Pa (1.25-in water column height) at the peak flow rate of 120 liters/min. In demand the difference between the peak negative pressure and ambient or zero, when tested to the above conditions, is shown in Table III, column 2. The Globe and Auer require slightly greater negative pressure than the above limit. For pressure-demand SCBA the static pressure shall not exceed a positive 373 Pa (1.5 in), as shown in column 3. The Chubb and Drager exceed this value.

The approval regulations covering exhalation resistance require a continuous 85-L/min flow rate, which is different from the 120-L/min required for inhalation testing. This is inexplicable as the wearer must exhale the same volume as he inhales. We performed a dynamic exhalation test using pulsating flow, column 4, as well as the required steady state test, column 5. Exhalation pressure in demand mode may not exceed 249 Pa (1-in) over ambient. For pressure-demand the facepiece pressure may not exceed 498 Pa (2 in) over static. All respirators tested met these requirements. The difference between the exhalation pressures with a breathing machine and steady state is thought to represent the inertia in forcing the exhalation valve open.

Pressure in the facepiece was measured with a Validyne Model DP-45 pressure transducer while the SCBA was worn by all test subjects. These results are shown in columns 6 and 7. In each case the pressure range shown is less than that created by the breathing machine, reflecting the fact that the test subjects were neither working nor breathing hard, but performing simple head moving exercises. Last year's annual report[5] evaluating air line respirators indicated that subjects preferred small pressure differences, 249 Pa (1 in) or less, between inhalation and exhalation. The pressure differences measured here ranged from 150 Pa (0.6 in) to 498 Pa (2 in).

In addition to the breathing machine tests discussed above, the approval regulations[3] require an air flow capability of at least 200 L/min. Demand units should supply this flow at 498-Pa (2-in) negative, while pressure-demand units deliver the flow at atmospheric pressure. Data for most of the units tested are available in a recent LASL report[6], which indicates that 200 L/min is insufficient for persons performing even moderate work. As our test subjects exercised only slightly above resting levels, high flow rates were not necessary for this experiment.

DONNING AND CONSERVATION OF AIR

Because the air supply of SCBA is limited, the procedure used for donning may effect the duration of supply. Demand units are typically left "on" with both the cylinder and main line valves open with little loss of air. This procedure cannot be used with pressure-demand, as the regulator will release air continuously if the mask is left open to atmosphere. If conservation of air is considered, the easiest pressure-demand unit to don is no. 4, the Scott Presur Pak. By leaving the select lever in "off" or demand mode, air will be conserved until the unit in donned and the facepiece pulled tight. At this point the lever can be turned "on" to create positive pressure in the facepiece. The Drager has a "donning" mode where no positive pressure is maintained. However the spring loaded exhalation valve is still in the circuit, producing a large difference between inhalation and exhalation (872 Pa, 3.5 in), and alerting the wearer to the fact that he must switch on pressure-demand. The Survivair no. 8, requires adjustments on both the regulator and exhalation valve to convert from demand to pressure-demand. Donning is more difficult with the MSA pressure-demand, no. 2, which requires the main line valve to be left closed. Only after the mask is put on, and as the breathing tube is being inserted into the regulator, can the valve be opened.

In contrast it is impossible to conserve air when donning either the Scott 4.5, no.12, or the Chubb. Both of these units use the cylinder valve as the only means of control, and require the user to don the mask while holding his breath until he can reach behind to open the valve. To prevent accidental closure of the cylinder valve, the Scott 4.5 has a spring loaded handle that must be depressed to turn, making it extremely difficult to operate behind one's back.

Users who have long experience with demand SCBA have developed the habit of pulling off the mask frequently to communicate or because they believe that they are in breathable air. Such a practice is dangerous as highly toxic gases may be present that give no warning. When such people change to pressure-demand apparatus without being retrained for the difference in operation, waste of air is inevitable.

WEARING COMFORT

The test subjects were for the most part unfamiliar with SCBA although most of them had worn lighter air purifying or air line equipment in previous experiments. Their subjective comments on comfort must be considered in this light, and are not necessarily the same as those from more experienced wearers such as busy firefighters.

Any discussion of comfort is of necessity subjective. Most of our test subjects wore all of the SCBA units and were able to compare characteristics that they were able to recall from test to test. The most frequent comments related to weight and pres- sure on the back, rather than breathing resistance. Most of the units have waist straps but these do not relieve the pressure on the shoulders that must support all of the weight.

Unlike any of the other units tested, the Scott 4.5 is built somewhat like a camping backpack using the wearer's hips to bear most of the weight of the unit. A broad waist band effectively supports much of the weight. This fact coupled with the low weight of about 23 lbs won high praise from many test subjects. Several people complained that the metal hose connected to the pressure gauge is located within one of the shoulder straps, causing it to dig into the shoulder. There were complaints of the high air flow from the regulator inlet jets into the eyes of some subjects when inhaling hard. Otherwise both 4.5 units were well liked.

The MSA with lightweight bottle drew no complaints about weight, but the conventional bottle units had several complaints about weight and pressure on hips and shoulders. Users of the conventional Scott units had similar complaints, and several women found the chest mounted regulator put excessive pressure on the breasts. In addition to the usual complaints about weight and shoulder pressure the large regulator on the Globe dug into the ribs when the subject bent over. More subjects complained about shoulder pressure on the Survivair units than any other approved ones. There were also complaints about the metal back-pack digging into the spine, and a regulator knob dug into the subjects' ribs when bending over.

The only complaint with the Chubb was excessive weight causing the subjects to become unbalanced when performing the bending over exercises. The Auer, though lighter than the Chubb, produced a very large number of complaints of weight and shoulder pressure. Also the air hose tended to catch on the arm. The Drager had the same hose problem and both units had gauges that were difficult to read. Both units have large regulators that interfere with vision and could catch on objects, but the Chubb regulator is much smaller. Finally there were considerably fewer complaints about the Drager weight then the Auer even though they differ by only a pound.

In conclusion on comfort, we have already stated that weight places a large burden on the wearers' work ability. Their comments indicate a similar effect on comfort, therefore the lighter units are preferred. However comfort is also influenced by the design of the backpack, as some units that were rather heavy drew fewer complaints than others that were lighter.

ALARMS

All of the devices include an end-of-life indicator. These alarms automatically reset when the device is turned on, and provide an audible signal when about 25% of the air remains. The Globe Guardsman, Scott 4.5, and three foreign units use whistles; all of the others use bells. Most of the alarms are located on the backpack where the bottle is connected. The Chubb whistle is connected to the pressure gauge on the left shoulder. Whereas the Scott Air Pak bell is located inside the chest mounted regulator, the 4.5 whistle is located inside the mask mounted regulator where all air vented is used for breathing. The other whistles operate by dumping breathing air to the outside atmosphere. The Scott unit is also unique in that it sounds only on inhalation. All other alarms sound continuously.

The sound level of each alarm was measured in an attempt to determine which could most easily be heard (Table IV). All measurements were taken in an open field to reduce the effects of reverberation. There have been reports of users not hearing the 4.5 whistle, and the whistles in both 4.5 units were 6-10 dB softer at 2kHz than the softest of the other alarms. Wearers who are used to the more familiar sound of the bell may not be prepared for the whistle. All of the whistles produce little or no energy below 2000 Hz, but the whistles other than Scott were perceived to be much louder, even by the wearers who presumably could take advantage of the direct conduction to the head of the 4.5 whistle.

EVALUATION OF PROTECTION FACTORS

The equipment used for leak testing was used previously to test air line respirators.[5] A $16m^3$ chamber is filled with approximately 17 mg/m^3 of 0.6-micrometer polydispersed DOP oil mist generated by air nebulization. Detection of the aerosol is by means of forward light scattering. Data analysis is the same as before, using the following six exercises, normal breathing, deep breathing, side-to-side motion by moving objects from left to right, up-and-down motion by moving objects from a high to a low shelf, talking, frowning and a final normal breathing. The overall protection factor of the device is based on the average of the peaks recorded during each of the six exercises, without counting the frown exercise.

Demand apparatus was tested on 25 subjects selected using the criteria of the Anthropometric Test Panel.[5] Only 10 subjects were used with pressure-demand apparatus.

Performance of the respirator is defined in terms of the protection factor (PF) which is the ratio of the challenge concentration of DOP to the concentration within the mask. The photometer is adjusted to read full scale on the challenge concentration, so for PF calculations the challenge concentration may be considered 100%. If an average concentration of 2% is measured in the mask, this value divided into 100 (the challenge concentration) yields a PF of 50. The test results are shown in Table V.

For pressure-demand, all subjects wearing the MSA and Survivair achieved a PF of at least 20 000, and all subjects wearing the Chubb and Drager made a PF of at least 10 000. With the Scott Presur Pak, only one subject failed to achieve at least 20 000 PF. The Scott 4.5 had two subjects achieve PFs of 20 000, while all achieved 5000.

The quality of facepiece seal determines the protection provided by demand type SCBA, which is reflected in the demand units providing lower PFs than those produced by pressure-demand equipment. Twenty-four of 25 subjects reached a PF of at least 100 wearing the Scottoramic and Auer facepieces; twenty subjects achieved this PF wearing the MSA Ultravue; and nineteen obtained this level of protection wearing the Survivair and Scottavista (4.5) masks. Scott advised us that the Scottavista mask requires a different donning technique from all of the other masks, because of the use of a net type headgear with only the lower strap adjustable. At Scott's request we refitted and retested the seven subjects who had the highest leakages when first tested. Respirator no. 11 in Table V shows the test results for the Scott 4.5 demand unit as first tested. The next line, with "c" superscript, indicates the improved results when the seven subjects who had the highest leakages during the first tests were retested. None of the other masks were retested.

Several of the demand SCBA tested show lower PFs (higher penetration) in this study than in the earlier study.[1] Many of the test conditions are different: use of polydisperse rather than monodisperse aerosol, using women for half of the test panel, the relative inexperience of the subjects, etc. The differences will be studied and the findings will be reported on later.

DISCUSSION

The superior respiratory protection shown by pressure-demand devices in Table V leads to the recommendation that only they be used. Purchasers of new SCBA should only buy pressure-demand, and users of demand equipment are urged to up grade them to positive pressure.

Many of the devices examined had one or more characteristics that were superior. Light weight is clearly a bonus, both from physiological and psychological standpoints.[4] The only way to achieve significant weight reduction at this time is with composite wrapped containers. MSA's composite cylinder will fit all current 2000 psi apparatus though it is not approved by NIOSH for use with other brands. Other manufacturers are now marketing their version of a 4500 psi SCBA, and though all of the higher pressure cylinders will be compatible, interchangeability would have to be specially permitted by NIOSH.

Back packs should put most of the weight onto the waist as does the Scott 4.5. Well designed camping back packs could be used as guides in the design of improved models.

The alarm on the Scott 4.5 should be louder. Users of 30 minute apparatus depend almost exclusively on the alarm rather than the gauge to indicate the need for retreat from hazards, and a loud alarm is preferable, even if it does waste some air.

Persons used to taking off the facepiece of demand SCBA without turning off the air supply must be retrained in the special procedures needed to conserve air when using pressure-demand devices. The Scott Air Pak provides the simplest solution to this problem since the user can switch from demand to pressure-demand with a single lever. However this convenience introduces a problem since the wearer can leave the apparatus is demand mode and it will appear to operate satisfactorily, even though the protection provided is usually less than for pressure-demand. The Drager unit also provides a demand mode for donning to minimize the loss of air, however the spring loaded exhalation valve creates a high exhalation resistance thereby warning the user that he is in "donning mode" and must switch to pressure-demand for use. Both the Scott Air Pak and the Surviv-air devices could be converted to this system by providing a spring loaded exhalation valve with no means to remove the spring pressure.

To conserve air on the MSA pressure-demand unit while donning requires several turns of the main line valve (waist mounted). A suitable quick operating control, such as a quarter turn valve, is needed. The Scott 4.5 is the most difficult unit with which to conserve air, because the only control available is a spring loaded valve handle on the cylinder itself. This is very difficult to operate, but if not shut off will cause the loss of excessive air when removing the regulator from the mask.

It is recommended that the requirement for a lock on the cylinder valve be removed or a ratchet that can be defeated be supplied. This will aid in rapid shut off of air when necessary. Also the device to hold the cylinder should support the cylinder when loosened to make it easy to change cylinders while the SCBA is being worn.

A further concern with the Scott 4.5 facepiece is the elastic straps supplied. It is possible that these will permit the mask to be knocked loose if the head should strike something. This is less likely with the more rigid straps on the other facepieces.

All of the devices should be easy to clean either by hand or machine, and should provide instructions for examination and maintenance of at least the second stage regulator including the diaphragm. Many of the units tested were not easy to maintain or did not come with adequate instructions. Only on the MSA can the diaphragm be checked without tools.

The foreign SCBA were examined to determine if they incorporated any desirable features not found in U. S. equipment. The Drager pressure-demand donning feature has been already discussed. The Chubb uses the smallest mask mounted regulator of all which interferes least with movement and vision. In contrast the rather large regulators on the Drager and Auer are likely to snag on objects and interfere with use of the devices. Drager does include an effective quick disconnect that allows the regulator and mask to be changed quickly. The interchangeability of most parts on the foreign units seems to be a feature that NIOSH should consider for its approval procedures.

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TABLE I

RESPIRATORS TESTED

(30 MINUTE SELF-CONTAINED BREATHING APPARATUS)

No.	Manufacturer	TC-13F[a]	Facepiece	Type
1	MSA 401 Air Mask 457152	29	Ultravue	Demand
2	MSA 401 Air Mask 463861	30	Ultravue	Pressure-Demand
3	Scott Air Pak IIa 900000-00	39	Scottoramic	Demand
4	Scott Presur Pak IIa 900014-00	40	Scottoramic	Pressure-Demand
5	Globe Guardsman 2540	43	Sierra Neoprene	Demand
7	Survivair 9838-02	44	Silicone	Demand
8	Survivair 9038-22	45	Neoprene	Demand/ Pressure-Demand
11	Scott 4.5 900450	73	Scottavista	Demand
12	Scott 4.5 900455	76	Scottavista	Pressure-Demand
13	Chubb No. 1	b	Chubb	Pressure-Demand
14	Auer BD 73	b	Auer	Demand
15	Drager PA 54/II	b	Pananova S	Pressure-Demand

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[a]TC-13F-XX is NIOSH/MSHA approval number.

[b]Not approved in the United States.

TABLE II

WEIGHT AND SIZE OF SCBA

(30 MINUTE SELF CONTAINED BREATHING APPARATUS)

Size-mm, Weight-kg (nearest pound)

Unit	Length[a]	Depth[b]	Complete		Facepiece	Cylinder Full	Cylinder Empty
MSA							
1	565	187	14.08	(31)	0.540	10.67	9.37
2	565	184	10.10[c]	(22)	0.835	6.39	5.27
Scott							
3	610	187	12.71	(28)	0.890	9.79	8.38
4	610	187	12.83	(28)	0.965	9.75	8.35
Globe 5	572	189	14.03	(30)	0.835	10.41	9.07
Survivair							
7	597	199	13.87	(30)	0.620	11.11	9.75
8	597	199	14.00	(30)	0.680	11.15	9.80
Scott 4.5							
11	565	189	9.86[c]	(21)	0.285	6.95	5.51
12	565	165[d]	10.53[c]	(23)	0.290	6.86	5.44
13 Chubb	565	188	17.34	(38)	0.500	13.79	12.32
14 Auer	645	176	14.18	(31)	0.515	12.02	10.16
15 Drager	692	165	13.42	(29)	0.546	9.43	7.80

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[a]Length is the longest dimension, usually the cylinder.

[b]Depth is measured with the backpack supported on a block of wood, cylinder on top, highest point above the table, simulating anterior-posterior depth while worn.

[c]Composite cylinder, aluminum cylinder or liner with fiberglass epoxy wrapping.

[d]Improved backpack and other changes, now standard on all units.

TABLE III

FACEPIECE PRESSURE

Inches Water Column
(30 MINUTE SELF-CONTAINED BREATHING APPARATUS)
(D = Demand, P = Pressure-demand)

Respirator	Breathing Machine[a] Inhal	Breathing Machine[a] Static	Breathing Machine[a] Exhal	Steady State[b] Exhal	Respirator Worn[c] Inhal	Respirator Worn[c] Exhal	Respirator Worn[c] Delta P
1 MSA-D	-0.6	-	0.7	0.5	-0.71	0.34	1.05
2 MSA-P	0.6	1.2	3.2	3.0	0.51	2.55	2.04
3 Scott-D	-1.0	-	0.5	0.3	-0.88	0.08	0.96
4 Scott-P	0.2	1.0	2.8	2.2	0.36	2.32	1.96
5 Globe-D	-1.3	-	0.6	0.4	-0.97	0.28	1.25
7 Survivair-D	-0.9	-	0.6	0.4	-0.87	0.31	1.18
8 Survivair-P[d]	-0.9	-	0.8	0.4	-0.68	0.39	1.07
8 Survivair-P[d]	0.5	1.0	2.9	2.7	0.74	2.40	1.66
11 Scott 4.5-D	-0.6	-	0.5	0.3	-0.63	0.29	0.92
12 Scott 4.5-P	0.4	0.8	2.4	2.3	0.28	1.68	1.40
13 Chubb-P	1.5	2.0	2.7	2.5	1.50	2.10	0.60
14 Auer-D	-1.3	-	0.9	0.6	-1.10	0.42	1.52
15 Drager-P	1.2	1.7	2.6	2.5	1.00	2.20	1.20
Drager-D	-0.9 (donning only, see text)						

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[a]Breathing machine tests from 30 CFR 11, Subpart H. Approximately 24 respirations per minute, inhalation of 120 L/min (4.2 cfm), resistance not to exceed 311 Pa (1.25 inch water column). Static pressure measured only for pressure-demand units, may not exceed 373 Pa (1.5 inch).

[b]Exhalation resistance under steady state at flow of 85 L/min (3 cfm), in demand mode resistance not to exceed 249 Pa (1 inch); for pressure-demand resistance shall not exceed 2 inch over static.

[c]Mask pressures measured while unit worn, average for all test subjects, 25 subjects for demand, 10 for pressure-demand.

[d]Survivair no. 8, approved for demand and pressure-demand, tested in both modes.

TABLE IV

SOUND LEVEL OF END-OF-LIFE ALARMS

SCBA	Octave Band Hz 250	500	1000	2000	4000	8000
	Bell Alarm dB					
MSA	49	52	62	73	87	100
Scott AirPac	59	63	57	70	75	78
Survivair	-	49	59	76	81	88
	Whistle Alarm dB					
Globe	-	-	-	67	76	56
Scott 4.5 Dem	-	-	-	60	66	63
Scott 4.5 PD	-	-	-	56	63	57
Chubb	-	-	-	66	77	63
Auer	-	-	55	78	92	85
Drager	-	-	52	84	94	68

Measurements taken outdoors in open field.
Octave band analysis done with GR 1558 BP held 2 feet from alarm.

TABLE V

NUMBER OF PERSONS ACHIEVING STATED PROTECTION FACTOR
WEARING SELF-CONTAINED BREATHING APPARATUS

D = Demand - 25 Subjects Tested
P = Pressure Demand - 10 Subjects Tested

Respirator		Protection Factor Attained									
		10	20	50	100	500	1k	2k	5k	10k	20k
1 MSA 401	D	24	24	22	20	12	9	5	2	1	*
2 MSA 401	P	-	-	-	-	-	-	-	-	-	10
3 Scott	D	-	25	24	24	10	6	1	1	1	*
4 Scott[a]	P	-	-	-	-	-	10	9	9	9	9
5 Globe	D	22	18	14	12	3	1	*	*	*	*
7 Survivair	D	24	22	21	19	7	3	1	1	*	*
8 Survivair[b]	D	23	21	19	17	8	4	1	1	1	*
8 Survivair[b]	P	-	-	-	-	-	-	-	-	-	10
11 Scott 4.5	D	20	19	16	15	7	7	5	3	*	*
11 Scott 4.5[c]	D	23	23	20	19	8	7	5	3	*	*
12 Scott 4.5	P	-	-	-	-	-	-	-	10	7	2
13 Chubb	P	-	-	-	-	-	-	-	-	10	8
14 Auer	D	-	25	24	24	16	12	5	2	*	*
15 Drager	P	-	-	-	-	-	-	-	-	10	8

[a]Scott demand mode not approved, used only for donning.

[b]Survivair is approved for both demand and pressure-demand, and tested in both modes.

[c]The seven subjects who had the lowest PF were retested after donning the mask according to the special instructions of the manufacturer. The results that they achieved during the retest were combined with the results of the 18 subjects not retested and are shown on this line.

Fig. 1. MSA (401) Demand

Fig. 2. MSA (401) Pressure-Demand

Fig. 3. Scott Air Pak IIa
Demand 90000000

Fig. 4. Scott Pressure Pak IIa
Pressure-Demand 90001400

Fig. 5. Globe Guardsman Demand

Fig. 6. Survivair Demand

Fig. 7. Survivair Demand/Pressure Demand

Fig. 8. Scott 4.5 Demand (900450)

Fig. 9. Scott 4.5 Pressure Demand (900455)

Fig. 10. Chubb Pressure-Demand

Fig. 11. Auer Demand

Fig. 12. Drager Pressure-Demand

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