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XF: RESPIRATR-4/

Interoffice Communication

To Safety Directors

From Tom Grumbles

Date March 12, 1984

Subject ESCAPE RESPIRATOR STUDY

For your information, enclosed is a study of five commercially available escape respirators done by Haskell Laboratory. This report is worthwhile reading if you're planning on buying any such units in the near future.

Thomas G. Grumbles

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Enclosure

HASKELL LABORATORY

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ESCAPE RESPIRATOR STUDY
(Haskell Lab Report No. 573-83, MR-5526)

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January 24, 1984

C. F. REINHARDT, M.D.
CR&D
HASKELL LABORATORY

ESCAPE RESPIRATOR STUDY
(Haskell Lab Report No. 573-83, MR-5526)

I. SUMMARY

Five escape type respirators were compared under moderate stress conditions on a panel of 16 male volunteers. Length of test, protection factor, carbon dioxide (CO_2) buildup, oxygen (O_2) depletion and pulse rates were measured. Ease of donning, reliability and comfort were also studied. There was a large variation in the capability of the five brands of respirators to complete the test within the parameters chosen. Low airflow into the respirators appeared to be the critical factor for those units which most often did not meet the criteria for the tests. An overall summary of test results is given in Table 11. The chemical resistance of the respirator hood materials, although not investigated in this study, is considered in the Recommendations Section on page 17.

II. BACKGROUND

Several types of respirators have been developed for use in escaping from hazardous concentrations of air contaminants or from oxygen deficient atmospheres. They range from simple mouthbit air purifying types for escape from low concentrations of chlorine to self contained breathing apparatus types. The choice of a given escape respirator depends on the anticipated hazardous situation. One type of escape respirator that is becoming popular employs a hood with a five- or fifteen-minute supply of air. These hood type supplied air escape respirators have several attributes which led to their popularity. They can be used in both contaminated and oxygen deficient atmospheres, can be used equally well by bearded and nonbearded persons, are relatively simple to don and use and are compact and storable for long periods of time.

A survey of Du Pont plants in 1982(1) showed that several hundred hood type escape respirators were distributed for possible use at various sites. The predominant brand was the Robertshaw Air Capsule® with a few Survivair escape units also in use. Other escape respirators were the more traditional face mask/air cylinder type. Since that time, another unit (ELSA®) has also been purchased by at least one plant site. One fact brought out in the survey report was that there were no documented instances where any of the hood type units had actually been used in an emergency. Although this is the hoped-for experience, it also meant that there were no field data that could be used to evaluate

the performance of the respirators in actual use. A purchasing decision had to be made based on vendor claims, National Institute of Occupational Safety and Health (NIOSH) certification and a few published reports.

NIOSH certification for escape respirators is described in 30 CFR Part II, Subpart H. It involves many tests, including four man-tests and a dummy head/breathing machine test for CO_2. The man tests include running, climbing and working in various combinations, and results are subjective, in that no measurements are taken. The respirator simply has to "satisfy the respiratory requirements of the wearer for the classified service time." CO_2 tests are done mechanically with a breathing machine which "exhales" air containing 5% CO_2 into the respirator facepiece. The respiration rate is 14.5 respirations per minute with a minute-volume of 10.5 liters (10.5 Lpm breathing rate). Maximum allowable CO_2 concentration in the "inspired" air is 2.5% averaged over 3-4 respirations. The averaged respirations are not taken at any particular time during the five minutes.

Respirator manufacturers may specify a minimum temperature at which their respirators are to be tested. All of the manufacturers of the hood type units used in this study requested a 20°F test temperature. Therefore, the NIOSH certifications for the four hood models indicates that they are "approved for respiratory protection during escape only from oxygen deficient atmospheres, gases and vapors at temperatures above 20°F." The Ska Pak® model (full face mask/air cylinder type) was tested at and certified for temperatures above -25°F.

Studies on escape respirators have been done by Los Alamos Scientific Laboratory (LASL), National Aeronautics and Space Administration (NASA) and the Air Force. One LASL study(2) compared ten escape respirators, including two hood types, for weight, comfort, ease of use and protection factor. CO_2 and O_2 inside the masks or hoods were not measured. The report recommended that face mask type escape respirators be used in the pressure demand mode only. Hood type respirators provided less protection but had the advantages of being quickly donned and providing protection for bearded persons.

NASA has done some testing(3) of hooded escape respirators during which the test subjects were stressed on a treadmill. Measurements of O_2 and CO_2 in the hoods were taken continuously. A qualitative fit test was done at the end of the walking exercise. In the NASA tests the ELSA® unit was found to be effective and simple to use, the Survivair unit was found to be acceptable even though CO_2 concentrations were as high as 6%. The Robertshaw unit did not provide the protection that the other units did and was not considered acceptable for the particular escape conditions expected at the Kennedy Space Center.

The Air Force conducted a study(4) in which a hood type escape respirator (Robertshaw) was used to simulate an actual escape from a space launch complex. During the simulated escape, the test subjects' pulse rates were monitored, but no attempt was made to monitor CO_2 enrichment or protection factor. The report concluded that the Robertshaw Air Capsule® was suitable for a slow (4 min., 19 sec.) escape from the complex but did not have enough air flow to allow for a rapid escape.

Our research involved the direct comparison of five escape respirators (four of the hood type) under a specific set of test conditions. By placing a treadmill inside a quantitative fit test booth, it was possible to measure the protection factor, CO_2 buildup, O_2 depletion and pulse rate while the test subjects were under stress.

III. MATERIALS AND METHODS

Choice of Respirators

Four currently available hood type escape respirators and one mask/air cylinder type were tested:

- Robertshaw Model 5000 Air Capsule® (referred to in report as "Robertshaw").
- Survivair Five-Minute Emergency Escape Unit (referred to in report as "Survivair").
- Scott Scram® Emergency Escape Breathing Device (referred to in report as "Scram").
- ELSA® Emergency Life Support Apparatus (referred to in report as "ELSA").

- Scott Ska-Pak® (referred to in report as "Ska Pak").

See Figures 1-5 for pictures and detailed descriptions of the five respirators.

Test Equipment

The test equipment is illustrated schematically in Figure 6. A Dynatech-Frontier (DF) Model 259 H-1 Laskin-type nozzle generator was used to generate a polydisperse di(2-ethyl-hexyl)phthalate (DEHP) aerosol (mean diameter 0.55 μm, standard deviation 0.20 μm), maintained at approximately 25 + 5 mg/m^3 in a 243 cubic foot DF Model 222-8/A test chamber containing a Trotter Model 320M Treadmill. A DF Model 259 H-2 Forward Light Scattering Photometer was used to detect the ratio of chamber (C_o) and respirator (C_i) DEHP concentrations, resulting in a reported protection factor (PF)=C_o/C_i. Sampled air from the respirator worn in the chamber was analyzed for CO_2 and O_2 content using Beckman Model 864-38 Non-Dispersive Infrared Analyzer calibrated for CO_2 and Beckman Model 755-02 paramagnetic O_2 Analyzer.*

The sample air was drawn at approximately 3.5 L/min. by the photometer pump and 1 L/min. from this primary line was HEPA-filtered and fed to the CO_2 and O_2 detectors at 0.8 and 0.2 L/min., respectively, via a Du Pont Model P-4000 personal sampling pump. Flowrates of the sample, calibration and zero gasses were measured with an external rotameter/manifold system. Two standard gases were used to calibrate the CO_2 and O_2 detectors; one had 2.06% CO2 and 5.2% O_2, while the other had 4.97% CO_2 and 18.8% O_2. In addition, ambient air was used as a third calibration point for O_2. A Beckman Model ET-1204 audible alarm was tied into the O_2 Detector and set to go off as O_2 fell below 18%. The CO_2 and O_2 analyzers were connected to a Hewlett-Packard Model 7100B-14-24 dual pen strip chart recorder. The photometer was connected to an Omniscribe Model B5116-1 strip chart recorder and interfaced with Hewlett-Packard Model 2645A personal computer terminal via a Fluke Model 8502A Multimeter (analog to digital converter). Both strip charts and computer program hard copies were obtained for all but three of the total 80 respirator tests. For these three tests computer hard copies were retained. A Computer Instrument Corporation Model 2867-4067 pulse rate meter with

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* Note: To address possible H_2O interference associated with the CO_2 detector, tubing which contained water droplets was used to collect an ambient air sample; no interference was seen.

fingertip sensor was used to monitor subject pulse rates. When checked against the standard method of taking pulse, the pulse meter was accurate to within ± 2 beats per minute.

Test Panel

A panel of 16 men with facial dimensions representative of the male working population as described by Hack, et al.(5,6) for testing full-face respirators assembled from a pool of volunteer Haskell Laboratory employees is demonstrated in Figure 7, Anthropometric Panel (full-face). Anthropometric sliding and spreading calipers were used to measure face width and length.* The numbers in each box of Figure 7 represent the number of men required to be within that facial dimension range. The small number of female volunteers precluded the possibility of assembling a male-female panel.

Du Pont medical records for each volunteer were reviewed by the Corporate Medical Division to confirm the abilities of subjects to withstand physical stress conditions presented by the test protocol. All volunteers were granted medical approval based on a combination of spirometric, x-ray & blood pressure and other records. Prior to testing, the test apparatus and laboratory were reviewed and approved by a Process Hazards Review Committee; and the test protocol was approved by the Human Studies Committee.

The subjects attended an orientation meeting designed to explain the objectives of and their roles in completing the study. The test protocol was explained and informed consent obtained. Each individual was then trained on the treadmill with and without a respirator (no DEHP aerosol was used), in order to select a treadmill speed which would approximate 60-80% of their individual maximum allowable pulse rates, based on age.(7) Ages of the test subjects ranged from 25 to 58, with a mean of 32 years. Fifteen of the men were tested at 4 mph, 0% grade; and one was tested at 3.2 mph, 0% grade.

Test Conditions

The objective in setting up the test conditions for this study was to determine how the respirators would perform while the test subjects were under stress, and yet not create an unsafe condition inside the test chamber. Walking on the treadmill at 4 mph and 0% grade was judged to

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* Face Width = widest distance from cheek bone to cheek bone.
Face Length = distance from fleshy area under chin to point of lowest nasal depression between eyes on profile.

be a "fast walk" by the test subjects. However, the stress level and resultant breathing rates were less than those for climbing stairs at a fast pace or running.

Based on medical consultation and published literature the following test conditions were set. If any of the test conditions were exceeded, the test was stopped.

Time

A test time of 3.5 minutes on the treadmill was chosen to allow 1.5 minutes for donning the respirator, entering the booth, attaching probes and exiting after the test.

Treadmill Speed

A brisk walk (4 mph) was used for 15 of 16 test subjects. The sixteenth subject used a lower treadmill speed of 3.2 mph to keep his heartrate below the 80% of maximum (based on age) that was allowed.

Carbon Dioxide Buildup

If CO_2 inside the mask or hood exceeded 3%, the test was stopped. The 3% limit was specified by our medical consultant to avoid excessive stress. The TLV®-STEL for CO_2 is 1.5% and the NIOSH Criteria Document (1976) for CO_2 (8) recommended a top excursion value of 3% based on a 10-minute sampling period. In five supplemental tests under medical supervision the CO_2 limit of 3% was raised somewhat.

Oxygen Depletion

The cutoff point for oxygen chosen for the study was 18% minimum inside the mask or hood. The normal concentration of oxygen in air is 20.9% and OSHA requires at least 19.5% in any work environment. Impairment of mental performance is soon detected at a partial pressure of 120 torr, equivalent to 15.8% at sea level(9).

Protection Factor (PF)

As with all quantitative fit testing, the test was not continued if the respirator failed to maintain a PF of at least 10 during any part of the test. That PF was used to ensure test subjects were not exposed above the 5 mg/m^3 AEL for the DEHP in the test booth.

Protocol

The test protocol used in this study is given in Appendix A.

IV. RESULTS

Reliability & Quality Control

In all 80 tests, none of the respirators malfunctioned or had any quality control defects which affected their use. There were some small brown spots on the hoods of some of the ELSA® units, but they did not affect visibiity. The airflows lasted for at least as long as advertised by the manufacturers.

Ease of Donning

Generally, the respirators were easy to remove from their cases and don, except for persons wearing glasses. The elastic or rubber neck bands were hard to pull over glasses, especially glasses with large frames.

The Robertshaw unit carrying case had a Velcro® fastener that looked like it was part of the shoulder strap; several subjects had difficulty locating the fastener without prompting. Also, the Robertshaw model had a drawstring around the neck area that was difficult to operate and appeared unnecessary.

The Survivair unit has an activating ring that can accidentally be pulled when the hood is removed from the case. That actually happened prior to the test program when one of the units was being unpacked to install the Quantitative Fit Test (QNFT) probe.

Donning the Ska Pak® unit was slow in some cases because hair had to be held away from the facepiece.

Completed Tests

Table 1 is a summary of the test results. It shows that the number of completed tests ranged from 0 of 16 for the Robertshaw model to 13 of 16 for the Scram®. Reasons for not completing the test are also shown in Table 1. The principal reason for terminating tests was that the 3% CO_2 limit was exceeded; 14 Survivair unit tests were stopped because of CO_2 only, while 14 of the Robertshaw Air Capsule® tests were stopped because of both CO_2 and O_2 limits being exceeded simultaneously and 2 because of CO_2 only.

The number of tests not completed because of CO_2 buildup or oxygen depletion seems to be directly related to airflow as can be seen by Table 1A.

Protection Factors

Table 2 summarizes the protection factors achieved by the respirators during the tests. All of the hood type devices achieved PF's of at least 100 with 83% of them having at least a 1000 PF. The Ska Pak's protection factors covered a wide range with three failing to provide a PF of 10 and one providing a PF of more than 10,000.

Personal Preference

In addition to the measurements of respirator fit and breathing air analysis, the subjects rated the respirators by personal preference; they were asked which would be preferred in an emergency situation. Scores assigned by subjects to the respirators are tabulated in Table 3 - Personal Preference of Test Subjects. The mean scores are listed in the last row. The significance of the rating scores will be discussed later.

Individual Respirator Results

ELSA®

Table 4 summarizes the test data for the ELSA® respirator. Twelve of sixteen subjects completed the 3 1/2-minute test within the parameters chosen. Of the tests that were not completed, one was stopped because of low oxygen and three were stopped because of excess CO_2. The minimum protection factor for the ELSA® was over 3000 with the median value being > 10,000*. Users found the ELSA® unit to be easy to don and relatively comfortable, although some complained of the tightness of the neck strap. The units, using regular 2216 psig air cylinder, were simple to refill and clean, which eases the training burden.

Robertshaw Air Capsule®

Table 5 summarizes the test data for the Robertshaw model respirator. None of the test subjects completed the 3 1/2-minute test within the parameters chosen. In most (12/16) of the cases,

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*All measured values for PF over 10,000 are reported as 10,000 in this report, since this respresents the reliable limit of sensitivity of the photometer.

the oxygen depletion to below 18% and the carbon dioxide buildup to more han 3% occurred nearly simultaneously. Since none of the Robertshaw units completed the original tests, the question was raised as to how they would perform against less stringent criteria. Under constant medical supervision one of the test subjects tested three additional Robertshaw respirators beyond the previous CO_2 and O_2 limits. In these tests there was no DEHP in the QNFT booth and the doors were left open. All three tests were terminated in two minutes or less when the O_2 level dipped below 16%. At that point the CO_2 levels were between 4.7 and 5.1%. The test subject was somewhat uncomfortable at the end of the tests and felt relieved after removing the hood, but he was not dizzy or unduly stressed. See Table 6 for data from supplementary tests.

As mentioned previously, the Robertshaw was somewhat difficult to remove from the case and don. Most of the test subjects complained of a choking sensation while wearing the unit, due to the tight elastic neck band. Many had to be prompted on how to loosen the added drawstring around the neck at the end of the test.

Since the Robertshaw uses a 5000 psig steel tubing air supply resevoir, it can be refilled only with special equipment. The training model has a start/stop valve but the regular unit cannot be turned off once it is activated.

The protection factors for this respirator ranged from 350 to 10,000, with the median value being 2600.

Survivair Respirator

Table 7 summarizes the test data for the Survivair unit. Fourteen of sixteen subjects did not complete the test because of CO_2 buildup exceeding 3%. The oxygen levels all remained over 21% because this respirator utilizes air enriched to 28% O_2. As with the Robertshaw respirator, some supplemental tests were run on the Survivair. A test subject tested two additional units under constant medical supervision (Table 6). In one case, because of a timing error, the test was stopped at 3 1/4 minutes. At that point the CO_2

level was 4.3% and the O_2 level was 23.2%. In the second test, the levels after 3 1/2 minutes were 2.9% for CO_2 and 25.3% for O_2. The supplemental tests indicate that there probably would have been an increase in the number of Survivair units completing the original tests, if the allowable CO_2 level could have been safely extended to 4 or 5%.

The protection factors for the Survivair respirators were excellent, with just one unit below the 10,000 level. The median protection factor was > 10,000.

Generally, the respirators were easy to don and comfortable. The twin cylinders are not refillable and must be replaced each time the unit is used.

Scram®

Table 8 summarizes the test data for the Scram® respirator. This unit had the highest number (13/16) of completed tests. The three tests not completed were stopped because of CO_2 buildup. In all cases the O_2 level remained at or above 21%.

Protection factors for the Scram® were variable. The range was from 113 to 10,000 with a median value of 2550.

The Scram® unit was easy to don. Almost universally the subjects complained of the heat buildup in the hood because of the oxygen generating reaction.

The Scram® unit is not rechargeable, although the manufacturer does sell a training model that allows the trainee to pull a resettable pin and place the hood over his/her neck. No air or oxygen is flowing in the test unit, but holes in the neck grommet allow air to enter the hood during the training exercise.

Ska Pak®

Table 9 summarizes the test data for the Scott Ska Pak®. Ten of sixteen persons completed the 3 1/2-minute test. The Ska Pak® was the only respirator which failed to achieve even a 10 PF for some test subjects (3 of 16). The PF's ranged from less than 10 to more than 10,000 with a median value of 320.

Those who did achieve a good fit seemed to like the Ska Pak®, and some mentioned that they felt "secure" using it.

This unit uses a refillable 2216 psig cylinder and a standard full face mask.

Ranking of Respirators

The test results for CO_2, O_2, time, PF and personal preference were evaluated using Friedman's Test(10,11), a nonparametric technique for comparing more than two matched groups. Matching was considered important due to conditioning and individual differences among the test subjects. Using this test, a significant difference was found to exist among the five respirators in their performance during the tests and in the personal preference for them by the test subjects. The Studentized Range Test(12) was then used to determine which respirators ranked higher and which ranked lower. Table 10 shows the ranking groups.

V. DISCUSSION

All escape respirators have a single purpose: to provide respirable air for a short period of time in emergency situations. The quality of the air in the respirator need not necessarily remain the same as normal air over the entire escape period, but it has to be good enough to allow for escape under stressful conditions without permanent after effects. It was not the purpose of this study to determine just how poor the air inside a respirator can get and still be useful for escape, but to see how various escape respirators performed under moderate stress conditions within a common set of criteria. The results allow us to make some useful observations:

- Airflow into a hood is critical in maintaining low carbon dioxide content (see Table 1A) for respirators that do not scrub out the CO_2. The use of oxygen enriched air allowed the Survivair unit (28 Lpm airflow) to maintain the O_2 level in the hood but did not prevent the CO_2 level from exceeding the 3% limit. The Robertshaw model had the lowest airflow (25.5 $\pm$ 2 Lpm). It did not complete any tests.

- Comfort is relatively unimportant unless it gets to the point where potential users would shun a particular respirator in an emergency. The Scram® respirator drew almost universal complaints from the test subjects because of heat buildup inside the hood, but it also had the highest percentage of completed tests. The very short use time for this type of respirator may allow us to discount the temporary discomfort involved.

- Training is very important in any program which uses emergency escape respirators. Not only how to use them but when to use them, should be addressed. Training is necessary to overcome the natural apprehension about using a device which covers the head and to provide information about the limitations of the devices.

- The protection factors provided by the escape respirators varied considerably. The adequacy of the PF depends on the anticipated use of each device.

- The results of these tests point out the inherent problem with mask type respirators used for escape (Ska Pak®). They do not provide a universal fit. To be useful, mask type units should be used only by those individuals who have passed a fit test. Beards and other interferences with a good seal make consistently passing such a test difficult. For those who do get a good fit, the mask/air cylinder escape respirator still appears to be a good choice.

- The fact that the hood type respirators were certified by NIOSH for use above 20°F raises the question about their use in very cold locations. The useful low temperature for these devices may be much lower than 20°F; this issue must be addressed when making a decision about their use.

VI. RECOMMENDATIONS

- Each potential purchaser of escape respirators should determine the anticipated time required to escape from a typical emergency situation and the required protection factor.

- The information in Table 11 should be used to determine the best candidate respirators for the intended use. The cost per unit is summarized in Table 12.

- If one of the tested respirators is already in use or is being considered for purchase and the median values in Table 11 for time and PF do not meet those required for the intended use, then a field test should be done to determine its adequacy. The field test should be done only after consulting with the departmental occupational health coordinator.

- Haskell Laboratory's monograph Chemical Resistance of Protective Clothing should be consulted for use situations where chemical resistance problems are anticipated. Haskell Laboratory can assist if additional chemical tests are required.

VI. ACKNOWLEDGEMENT

The work of L. F. Percival in the initial planning and coordinating of this study is acknowledged, as is the assistance of R. L. Trivits in conducting the testing, the assistance of G. J. Graepel in doing statistical analyses and the work of J. A. Perry in computerizing the fit test readings.

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Report by:

James M. Kayser
Consultant -
Industrial Hygiene

K. Frieda Fisher
Industrial Hygienist

Approved by:

Stephen W. Dixon
Section Supervisor -
Industrial Hygiene

Frank A. Bower
Associate Director -
Field Services Division

J. Robert Gibson
Assistant Director -
Haskell Laboratory

JMK/KFF/dar
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Attachments: Appendix A, Tables 1-10, Figures 1-7
Number of pages in this report: 40

APPENDIX A

TEST PROTOCOL

1. Determine that subject has completed preliminary requirements:

   a. Medical Approval

   b. Consent Form

   c. Orientation

   d. Training

   e. Maximum pulse rate for age determined.

2. Require subject to have resting pulse rate checked at Medical.

3. Determine from random number chart the order in which the five respirators will be tested for the particular subject.

4. Explain test to subject.

5. Check instrumentation.

6. Perform QNFT:

   a. Record "baseline" at anticipated use range.

   b. Record "full scale" (100% range).

   c. Have test subject don respirator, enter booth and plug in. Note any problems with donning and record time when respirator was activated.

   d. Have test subject start treadmill and begin walking.

   e. Record "normal breathing" at range used for baseline for 3.5 minutes.

   f. Stop test short if:

      1. Requested by subject for any reason.

      2. Respirator or equipment malfunctions.

      3. Oxygen level falls below 18%.

4. Carbon dioxide levels goes above 3.0%.

5. Pulse rate goes above 80% of maximum allowable.

g. After 3.5 minutes, ask test subject to "unplug," leave booth and remove respirator

h. Record baseline as in #1 above.

i. Immediately record full scale.

j. Record the time that the respirator has a noticeable drop off in air supply.

7. Note:

a. Ease & quickness of donning.

b. Special training requirements.

c. Vision restrictions, fogging.

d. Comfort.

8. Allow 5-10 minutes rest between respirator tests.

9. After all tests are done, ask the subject to rate the respirators from 1 to 6, personal preference. Note comments.

JMK/KFF/dar
HL 573-83

TABLE 1

DATA SUMMARY: NUMBER OF COMPLETE/INCOMPLETE TESTS
(15 total tests)

		Reason for Incomplete Test			
Respirators	Complete Test	PF (only)	O_2 (only)	CO_2 (only)	Both O_2 and CO_2
ELSA[a]	12	0	1	2	1
Robertshaw	0	0	0	2	14
Survivair	2	0	0	14	0
Scram[a]	13	0	0	3	0
Ska Pak[a]	10	3	1	1	1

TABLE 1A

RELATION OF AIRFLOW TO INCOMPLETE TESTS

Respirator	Airflow (vendor data)	Tests Not Completed Because of O_2, CO_2 or Both
Ska Pak[a]	On demand	3
Scram[a]	50 Lpm (recirculated)	3
ELSA[a]	38 Lpm (continuous)	4
Survivair	28 Lpm (continuous)	14
Robertshaw	25.5 ± 2 Lpm (continuous)	16

TABLE 2

PROTECTION FACTOR (PF) DISTRIBUTION

	< 10	10-100	101-1,000	1,001-10,000	> 10,000	Approximate Median PF Values
ELSA[a]	0	0	0	2	14	10,000
Robertshaw	0	0	3	11	2	2,600
Survivair	0	0	0	1	15	10,000
Scram[a]	0	0	8	2	6	2,600
Ska Pak[a]	3(2)*	3(1)	4(1)	5(0)	1(0)	300

*Number in parentheses shows those in group with beards.

TABLE 3

PERSONAL PREFERENCE RANKING

Subject	ELSA®	Robertshaw	Survivair	Scram®	Ska Pak®
1	1	4	3	5	2
2	1	4	3	5	2
3	2	4	3	5	1
4	2	5	3	4	1
5	3	4	2	5	1
6	2	5	3	4	1
7	1	3	2	4	5
8	4	5	2	3	1
9	1	5	2	4	3
10	2	5	3	4	1
11	3	5	1	4	2
12	3	4	2	1	5
13	2	4	3	5	1
14	2	4	1	5	3
15	2	4	1	5	3
16	1	5	2	4	3
	2.00	4.38	2.25	4.19	2.19 Mean

Score

1 = most preferred
5 = least preferred

TABLE 4

INDIVIDUAL TEST RESULTS FOR THE ELSA® RESPIRATOR

Subject No.	Time (min.)	CO_2 (Max. %)	O_2 (Min. %)	PF
1	2.73	2.75	17.9	10,000
2	3.50	1.45	19.8	10,000
3	3.50	1.95	19.5	4,780
4	2.33	3.15	18.0	10,000
5	3.50	2.45	18.7	10,000
6	3.50	1.75	19.6	10,000
7	3.50	2.90	18.2	10,000
8	3.50	1.80	19.4	10,000
9	3.50	1.20	20.0	10,000
10	3.50	1.15	19.8	10,000
11	3.50	2.30	18.6	10,000
12	1.45	3.10	17.8	3,448
13	3.50	1.95	19.2	10,000
14	3.50	1.52	19.4	10,000
15	2.65	3.25	18.0	10,000
16	3.50	2.50	18.8	10,000
	Median = 3.50			Median = 10,000

TABLE 5

INDIVIDUAL TEST RESULTS FOR THE ROBERTSHAW AIR CAPSULE®

Subject No.	Time (min.)	CO_2 (Max. %)	O_2 (Min. %)	PF
1	0.83	3.35	17.2	8,333
2	1.11	3.30	17.2	5,263
3	1.00	3.30	17.3	2,083
4	1.23	3.75	16.5	351
5	0.95	3.20	18.0	7,692
6	0.45	3.20	18.5	935
7	0.62	3.30	17.5	1,667
8	0.30	3.30	17.9	3,226
9	1.03	3.55	17.5	1,613
10	1.08	3.25	17.2	6,250
11	1.12	3.20	17.6	1,220
12	0.67	3.60	16.5	1,351
13	0.38	3.55	17.9	10,000
14	1.63	3.20	17.5	5,556
15	0.60	3.40	16.5	943
16	0.96	3.20	17.0	10,000
	Median = 0.96			Median = 2,600

TABLE 6

SUPPLEMENTARY TESTS FOR O_2 & CO_2

(one test subject, treadmill only, no DEHP, medical supervision)

Test	Time, Minutes	O2, %	CO2, %
Robertshaw 1	2	15.5	4.7
Robertshaw 2	2 1/4	15.5	4.7
Robertshaw 3	2	15.5	5.1
Survivair 1	3 1/4	23.2	4.3
Survivair 2	3 1/2	25.3	2.9

TABLE 7

INDIVIDUAL TEST RESULTS FOR THE SURVIVAIR ESCAPE UNIT

Subject No.	Time (min.)	CO_2 (Max. %)	O_2 (Min. %)	PF
1	1.43	3.15	21.2	10,000
2	2.15	3.25	21.5	2,500
3	3.50	2.80	21.4	10,000
4	1.04	3.80	22.5	10,000
5	2.51	3.30	21.0	10,000
6	2.80	3.30	21.6	10,000
7	2.13	3.35	21.5	10,000
8	1.74	3.10	21.3	10,000
9	3.50	2.78	21.5	10,000
10	2.15	3.30	21.0	10,000
11	3.50	4.90	22.5	10,000
12	2.07	3.30	22.0	10,000
13	1.85	3.20	21.4	10,000
14	1.98	3.35	21.5	10,000
15	1.08	3.60	21.3	10,000
16	1.71	3.05	21.4	10,000
	Median = 2.10			Median = 10,000

TABLE 8

INDIVIDUAL TEST RESULTS FOR THE SCRAM® RESPIRATOR

Subject No.	Time (sec.)	CO_2 (Max.%)	O_2 (Min. %)	PF
1	3.50	3.20	21.1	10,000
2	3.50	2.30	21.5	4,800
3	3.50	1.85	21.0	749
4	1.75	3.50	21.0	588
5	3.50	0.65	21.4	363
6	3.50	2.90	21.6	377
7	0.96	3.95	21.5	10,000
8	2.05	3.10	21.4	500
9	3.50	2.90	21.5	163
10	3.50	1.95	21.0	10,000
11	3.50	2.00	22.0	485
12	3.50	2.20	21.8	4,348
13	3.50	2.15	21.3	10,000
14	3.50	1.60	21.0	10,000
15	3.50	2.60	21.0	113
16	3.50	2.80	21.0	10,000
	Median = 3.50		Median =	2,500

TABLE 3

INDIVIDUAL TEST RESULTS FOR THE SKA PAK® RESPIRATOR

Subject No.	Time (min.) (complete test = 3.5 min.)	CO_2 (Max. %)	O_2 (Min. %)	PF
1	3.50	2.15	18.9	736
2	1.50	2.70	17.5	22
3	1.69	3.55	17.9	10,000
4	2.50*	2.50	18.2	758
5	3.50	2.10	19.2	1,282
6	3.50	2.40	18.7	9,836
7	0.50	2.15	19.5	< 10
8	3.50	2.30	18.5	2,058
9	0.00	1.90	19.5	< 10
10	3.50	2.45	18.3	4,369
11	3.50	2.30	18.5	133
12	3.50	2.30	19.0	503
13	3.50	2.45	18.4	1,358
14	3.50	1.90	18.6	12
15	3.50	2.65	18.2	24
16	2.08	2.00	18.7	< 10
	Median = 3.50			Median = 320

*Ran out of air because face mask was difficult to don. O_2 and CO_2 and PF were okay at the end of the test time (2 1/2 min.).

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TABLE 10

GROUPINGS OF STATISTICAL SIGNIFICANCE

Tested Condition	Groupings*		
	← Best		Worst →
Personal preference	ELSA® Ska Pak® Survivair	Robertshaw Scram®	
Protection factor	ELSA® Survivair	Robertshaw Scram®	Ska Pak®
CO_2 buildup to 3%	Ska Pak®	ELSA® Scram®	Robertshaw Survivair
O_2 depletion to 18%	Scram® Survivair	ELSA® Ska Pak®	Robertshaw
Time (complete tests)	ELSA® Ska Pak® Scram®	Survivair	Robertshaw

*Each group is significantly different from the next, but there is no significant difference between respirators within a group.

TABLE 11

TEST TIME AND PROTECTION FACTOR SUMMARY

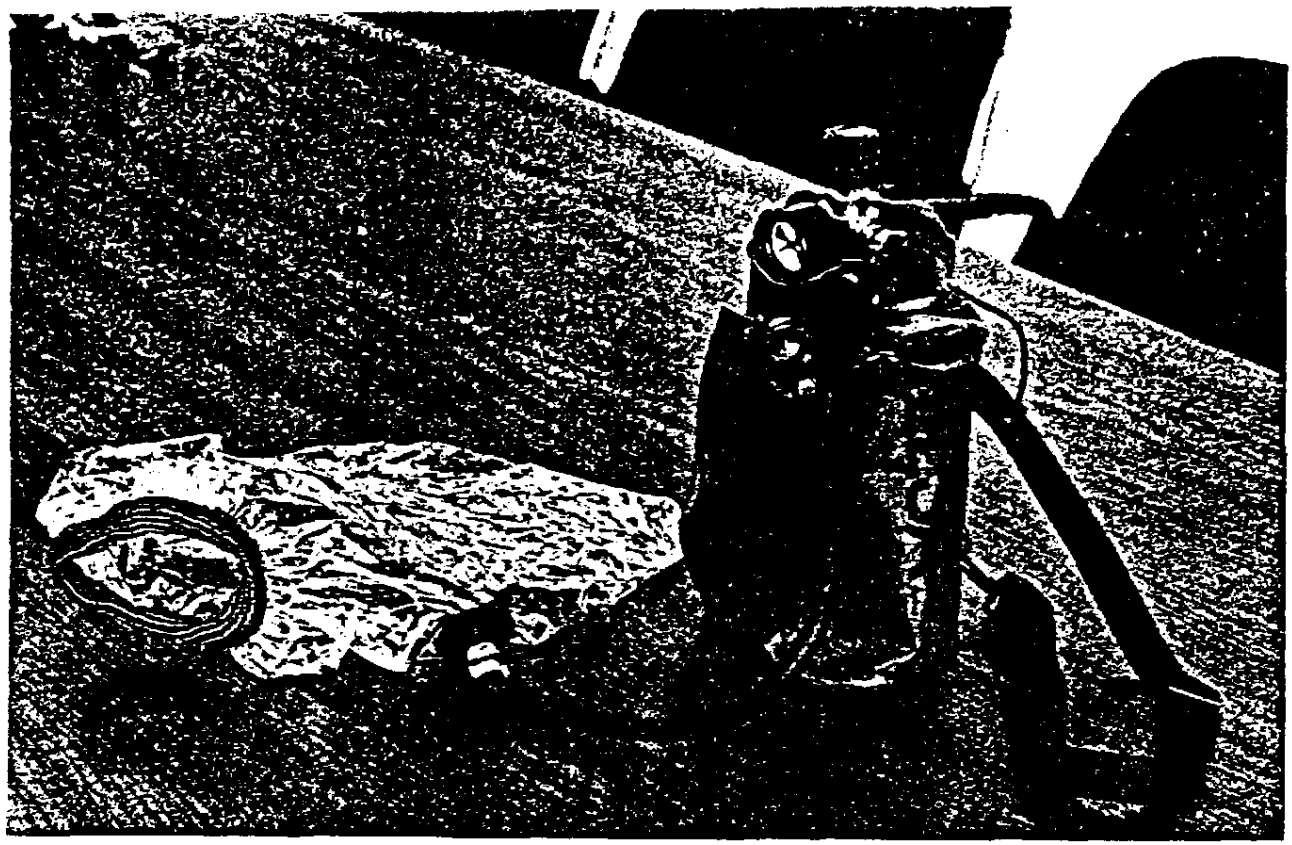
	Time Within Test Criteria (3.5 minutes max.)		Protection Factor		
	Range (minutes)	Median	Range	Median	Temperature at which Certified
ELSA®	1.45-3.50	3.50	3450-10^4	10^4	Above 20°F
Robertshaw	0.30-1.63	0.96	350-10^4	2660	Above 20°F
Survivair	1.04-3.50	2.10	2500-10^4	10^4	Above 20°F
Scram®	0.46-3.50	3.50	110-10^4	2550	Above 20°F
Ska Pak®	0.0-3.50	3.50	< 10-10^4	320	Above -25°F

Test Criteria - 3.5-minute brisk walk (4 mph), > 18% O_2, < 3% CO_2, PF > 10, no malfunctions, adequate comfort.

TABLE 12

ESCAPE RESPIRATOR COSTS

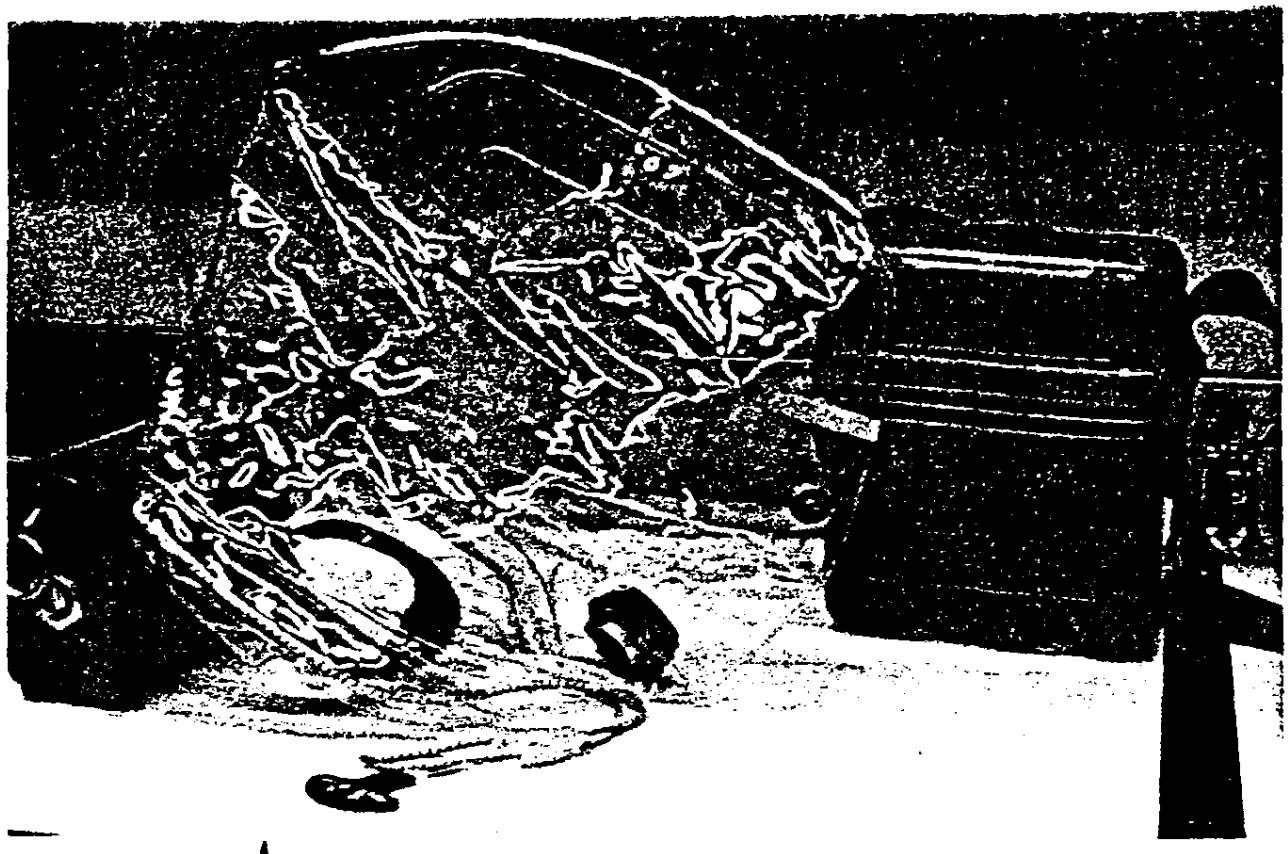
Respirator	Approx. Unit Cost (1984)	Approx. Service Cost Per Use
ELSA®	$217	$10 (on site)
Robertshaw	$215	$12.50 (vendor refill)
Survivair	$236	$38.00 (new cylinders & cleani
Scram®	$225	(not reuseable)
Ska Pak®	$485	$10 (on site)



ELSA - Emergency Life Support Apparatus P/N 707.117.0

Manufacturer:	International Safety Systems, Inc. 480 Perry Street Lawrenceville, GA 30245
NIOSH Certification:	TC-13F-111
Serial Numbers of Test Units:	02906, 03775, 04536, 04041, 03725, 03757
Description:	A five-minute compressed air breathing apparatus consisting of an aluminum cylinder containing 7 $ft.^3$ of air at 2216 psig; a valve arrangement consisting of an on/off handwheel, reducing valve, pressure gauge, and flow control oriface; a flexible supply hose; and a clear polyurethane hood with an elastic collar. The entire unit is stored in a bright red flexible bag with a Velcro® closure. The air flow to the hood is 38 liters/min. Polyvinyl chloride hood also available.

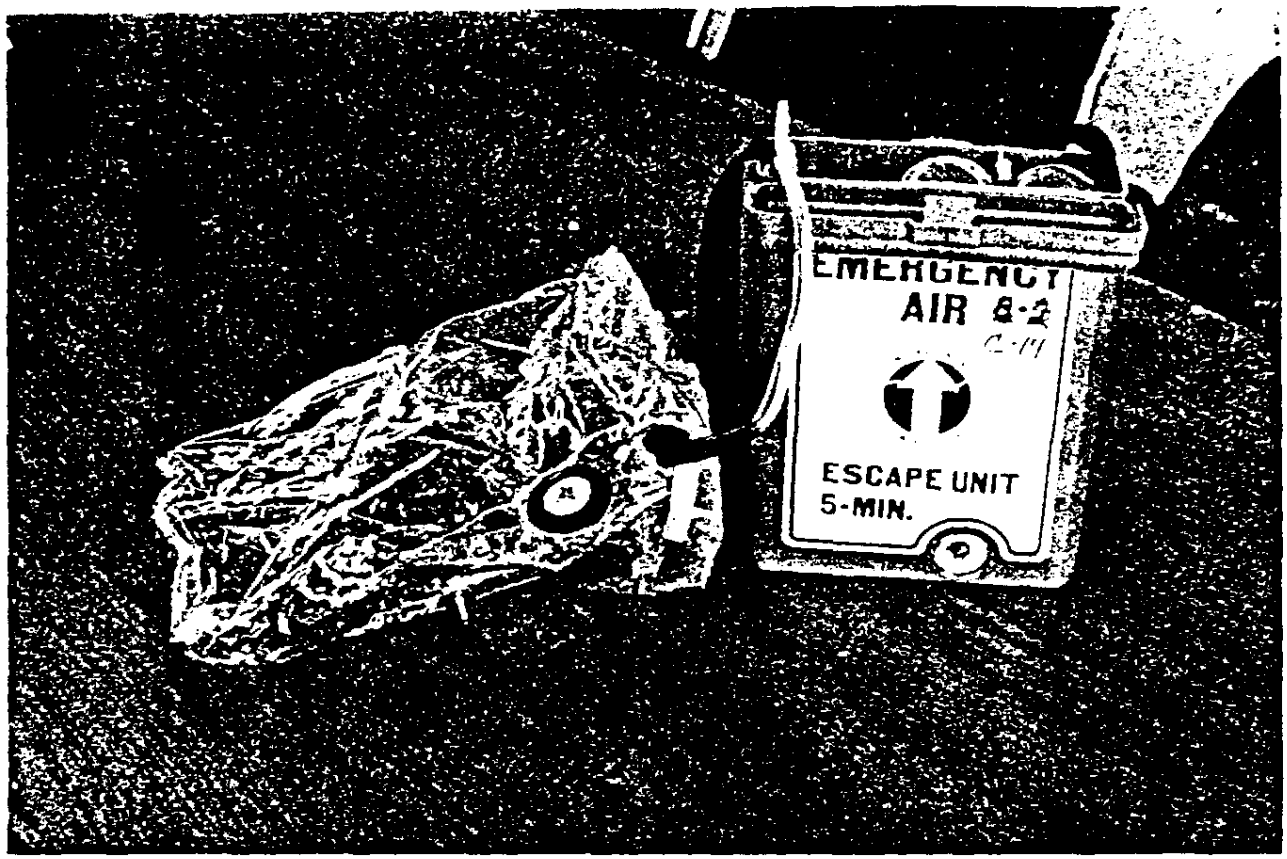
Figure 1



Robertshaw Air Capsule Model 5000

Manufacturer:	Robertshaw Controls Company 333 N. Euclid Way Anaheim, CA 92803
NIOSH Certification:	TC-13F-28
Serial Numbers of Test Units:	3090015 through 3090020
Description:	An escape device that supplies five minutes of air to the user through a clear, polyurethane hood, which has an elastic neck closure as well as a draw cord. The breathing air is stored in coiled, stainless steel tubing at an operating pressure of 5000 psig. Airflow to the hood is actuated by pulling a start ring. The Air Capsule is stored in a rigid plastic case with a Velcro® closure. The flow rate of air is 25.5 + 2 liters/min. at 1000-5000 psig. The unit is reuseable but requires special equipment to recharge to 5000 psig. Polyvinyl chloride hood also available.

Figure 2



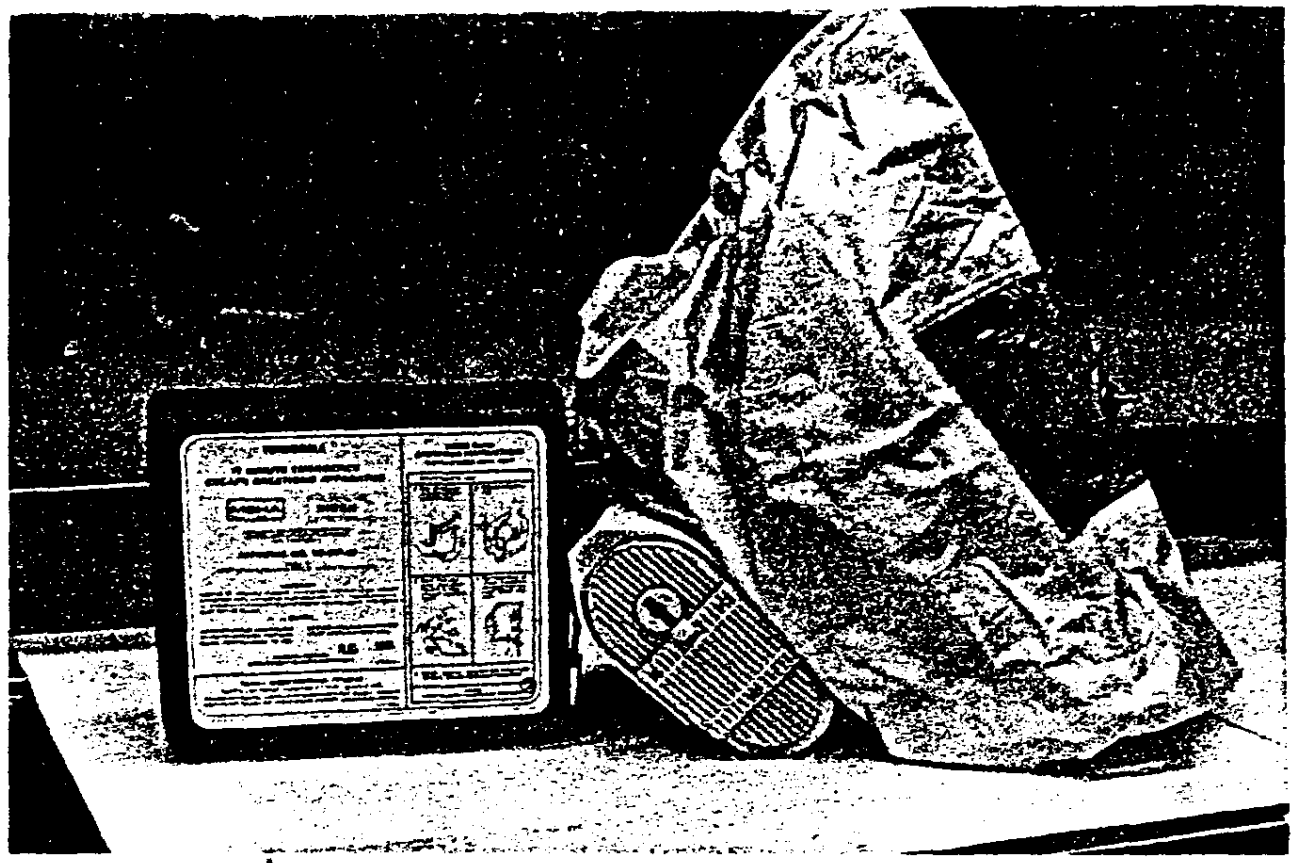
Survivair Five-Minute Emergency Air Escape Unit P/N 0028-00

Manufacturer:	U.S.D. Corporation Survivair Division Santa Ana, CA
NIOSH Certification:	TC-13F-86
Serial Numbers of Test Units:	None - all from Lot #17530

Description:

The emergency escape unit consists of a transparent polyurethane hood, an integrated cylinder manifold and regulator assembly and a protective case. (Both hard case and soft case models are available.) The twin cylinders are prefilled with 28% oxygen enriched air. When initially assembled, the outlet of each air cylinder is sealed with a frangible copper disc. When the user pulls the actuating ring, a cam-accuated activating piston pierces this disc and allows air to flow into the pressure reducing regulator. The regulator maintains a constant outlet flowrate of approximately 28 liters of air per minute, which is then directed into the hood. Once the actuating ring has been pulled, the unit will provide a constant flow of air into the hood until the cylinders are depleted. New cylinders must than be purchased.

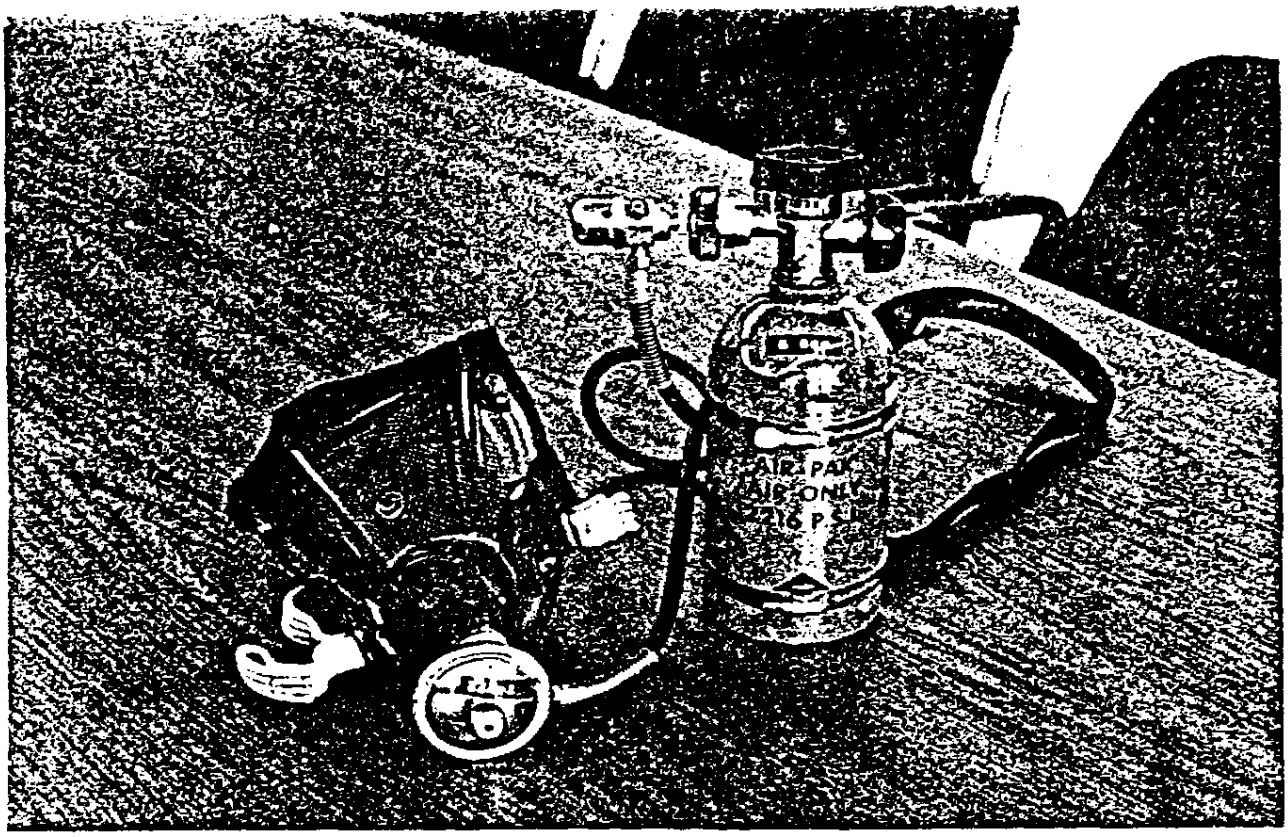
Figure 3



Scott Scram® Emergency Escape Breathing Device P/N 802300-02

Manufacturer:	Scott Aviation (Division of ATO) Lancaster, NY 14086
NIOSH Certification:	TC-13F-88
Serial Numbers of Test Units:	Not serialized.
Description:	A 15-minute escape device consisting of a loose fitting Teflon®-coated fiberglass hood attached to a life support unit. In the life support unit low pressure oxygen is produced by an exothermic reaction which produces sodium chloride and oxygen from a sodium chlorate core. The oxygen is fed to the primary nozzle of an ejector device which aspirates CO_2-laden hood gases from the hood through a lithium hydroxide scrubber, moisture absorber and filter; then back to the hood. Oxygen duration is 15 minutes, O_2 output is 90 liters and the circulation rate is 50 liters/minute. The unit is not reuseable. It is stored in a rigid plastic case. A training model is available.

Figure 4



Scott Ska-Pak P/N 900055-52

Manufacturer:	Scott Aviation (Division ATO) Lancaster, NY 14086
NIOSH Certification:	TC-13F-68
Serial Numbers of Test Units:	No serial number on mask. Cylinder serial numbers were A31048, A33092, A32602, A32059, A32546 and A32582
Description:	A five-minute escape device consisting of a cylinder containing 7 ft.^{3} of air at 2216 psig, pressure regulator, flexible hose, Scott-o-vista mask with mask-mounted regulator operating in the demand mode. To operate, turn on the cylinder valve, place the mask on the face and breathe normally.

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Figure 5

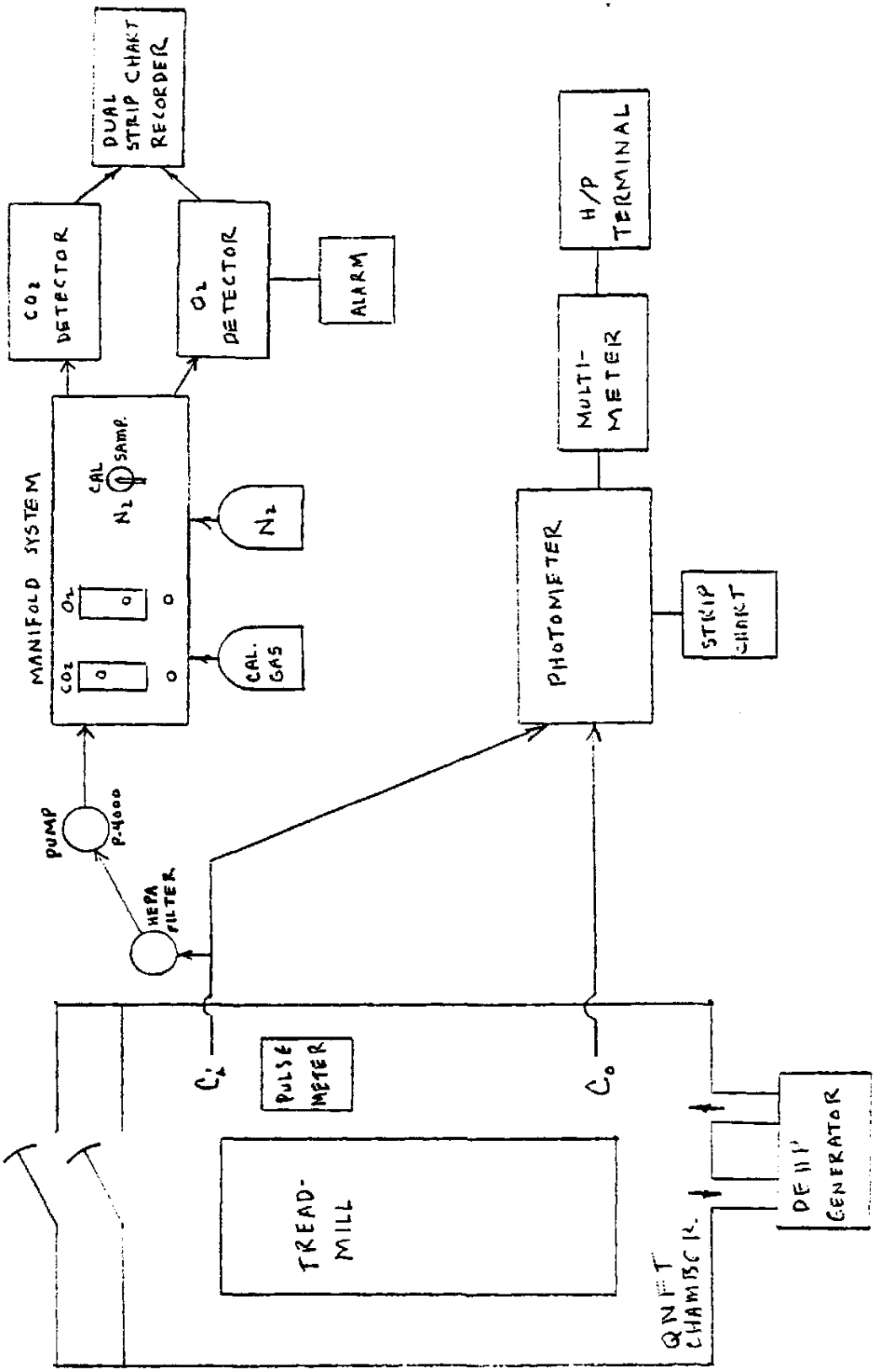

Figure 6

Schematic of Apparatus

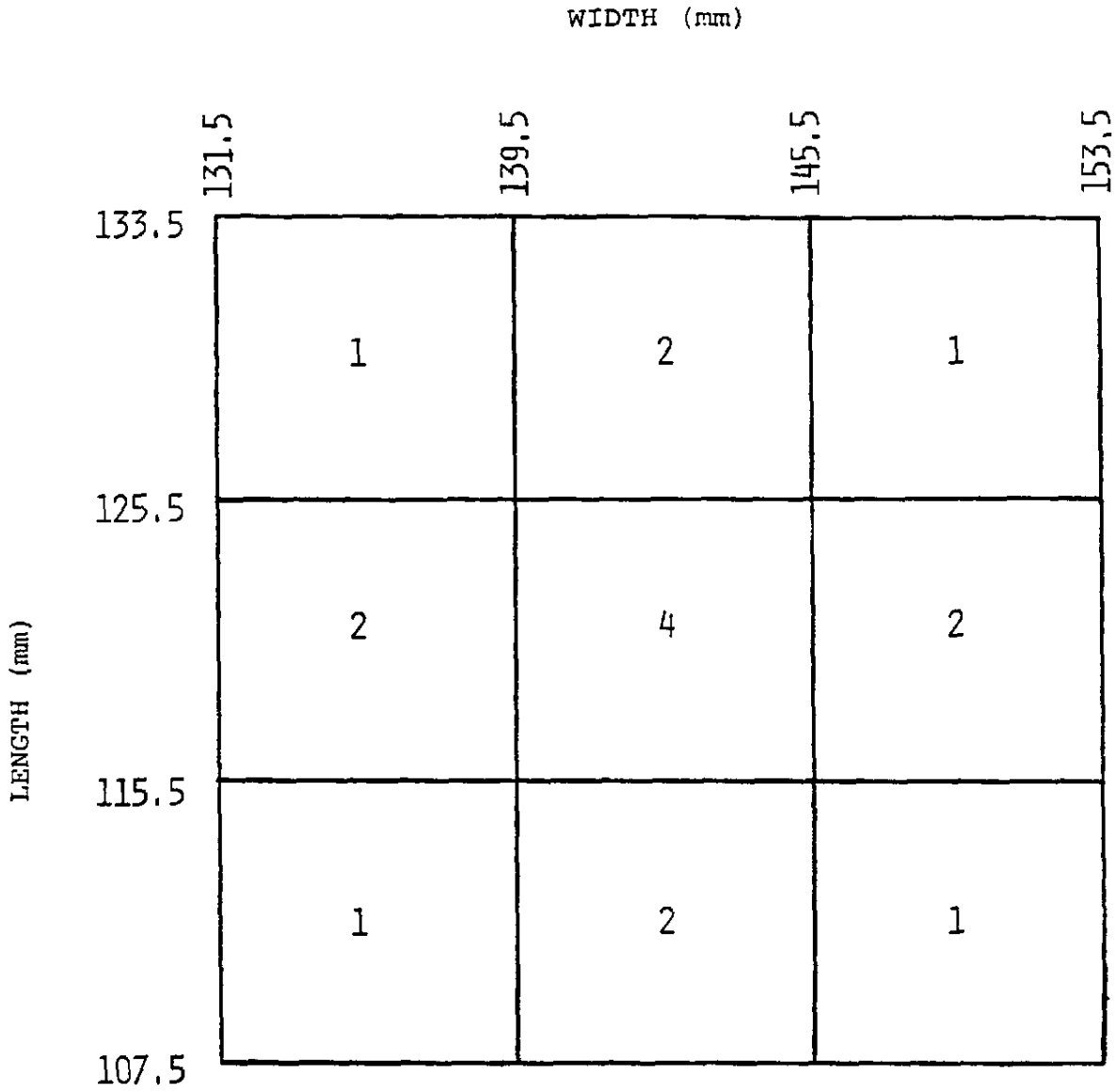

Figure 7

Anthropometric Panel (Full-face)