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Summary Report on the Navy Emergency Escape Breathing Device

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SUMMARY REPORT ON THE NAVY EMERGENCY
ESCAPE BREATHING DEVICE

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INTRODUCTION

The problem of shipboard safety of Navy personnel during peacetime as well as during wartime operations is a major concern of the Navy. During the 1960's, serious fires that resulted in the loss of life or serious injury to sailors due to suffocation and/or asphyxiation occurred aboard ships. As a result of these fires, the Chief of Naval Operations (CNO) appointed a committee, headed by Admiral Russell (Ret.), to investigate the disasters and recommend ways of improving the survivability of ships and personnel. One recommendation of the Russell Panel was to develop a breathing device that would permit sailors to escape from hazardous lower deck areas to weather deck areas during emergency conditions.

In March, 1968, a joint conference was held between members of the Office of the Chief of Naval Operations (OPNAV) and the Navy Materials Command (NAVMAT) to establish the operational characteristics for an emergency escape breathing device (EEBD). The availability of devices to meet these requirements was determined by canvassing manufacturers of emergency breathing devices. Although not meeting all the performance requirements, the results of early developmental tests indicated that the Survival Support Device (SSD), manufactured by Lear Siegler, would be adequate as an interim device. A production contract for 115,300 units was awarded in 1973.

As a continuation of the development program, a final invitation was made to industry to submit EEBD candidate devices for testing under the requirements of SHIPS-B-5669. A technical

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evaluation (TECHEVAL) of the devices was begun and consisted of a series of tests performed at the Naval Research Laboratory (NRL), Washington D.C.; the Navy Medical Research Institute (NMRI), Bethesda, MD; the Weapons Quality Engineering Center (WQEC), Yorktown, VA; and the David Taylor Naval Ship Research and Development Center (DTNSRDC), Annapolis, MD. As these tests were being completed, the interaction with the fleet personnel was increased and the requirements for the performance of the devices were enhanced. When the TECHEVAL was completed, the devices were subjected to an operational evaluation (OPEVAL) in smoke and fire conditions by the Navy Operational Test and Evaluation Force (OPTEVFOR), Norfolk, VA.

Based on the results of the TECHEVAL and the OPEVAL, the Navy decided to purchase the Scott Aviation Emergency Escape Breathing Devices. A total of 450,000 devices are scheduled to be purchased over a five year period. This report presents a general overview of the Scott device and summarizes the results of the tests conducted at the Navy laboratories.

OVERALL OPERATION

The Scott EEBD consists of an air-tight hood, a neck seal that is attached to the hood and prevents the gases in the environment from entering the hood, and a plastic housing that contains canisters to generate the breathing gas and to purify the recirculated gas. The device produces pure oxygen (O_2) and uses a venturi to recirculate unused and expired gases through the purifier. A rubber pressure relief valve, located in the plastic housing, prevents the pressure within the hood from exceeding 0.5 inches (in) of water above the ambient pressure.

The EEBD is provided in a vacuum sealed bag that is packed in a plastic carrying case. The sealed bag is removed from the case, opened, and the EEBD removed. The firing pin is pulled and the device is donned by inserting your head through the neck seal opening. While in use, the EEBD rests on the top of the user's shoulders, behind the individual's neck. The device provides sufficient O_2 for the user to conduct medium to heavy work for a minimum of 15 minutes. An added advantage of the device is that it can easily be placed on unconscious individuals to provide them with respiratory protection.

OXYGEN GENERATION

Rather than rely on high pressure gas storage, the Scott EEBD provides chemically generated O_2 to the user. The O_2 is formed in a canister by the thermal decomposition of a solid cylinder (or "candle") of sodium chlorate ($NaClO_3$), which also produces sodium chloride ($NaCl$) or common salt:

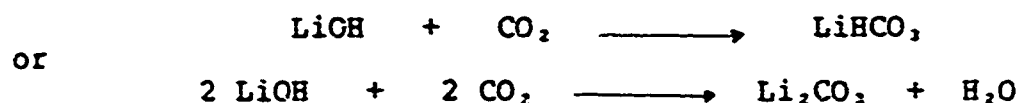


Iron is added to the candle formulation to help produce the heat needed to sustain this reaction. The heat forms by the reaction of the iron with some of the O_2 to generate iron oxides. The heat required to initiate the reaction is derived from a small specially formulated "cone" of $NaClO_3$, that has higher levels of iron. The cone, which is ignited when the firing pin is pulled, burns much hotter and forms oxygen more quickly. To prevent high pressures of O_2 from forming in the canister, the canister is equipped with a pressure relief valve that is set at 60 pounds per square inch (psi).

AIR PURIFICATION

A major problem with a breathing device that recirculates breathing air is that as an individual exhales, the level of carbon dioxide (CO_2) in the breathing gas can reach high levels¹ unless the CO_2 is removed. As the level of CO_2 in the inspired air exceeds ~1%, an individual can undergo respiratory stimulation, although levels of 3% are considered safe for 10 minutes. Levels of CO_2 that exceed ~7.5% are reported to cause an individual to feel oxygen starvation (dyspnea), dizziness, and to develop headaches.¹ As the level of CO_2 approaches ~10%, the possibility of loss of consciousness becomes significant, and levels of ~17% are life threatening.

If the normal level of expired CO_2 (~5%) and the small size of the hood are considered, the amount of time needed to approach these values can be measured in minutes. Therefore, a device that recirculates air must have an efficient method of scrubbing CO_2 from the inspired air. The Scott EEBD provides for air purification by passing the recirculated air through a lithium hydroxide ($LiOH$) scrubber. The scrubber reduces the CO_2 level by forming either lithium bicarbonate ($LiHCO_3$) or lithium carbonate (Li_2CO_3):



PERFORMANCE TEST RESULTS - UNMANNED TESTING

OVERALL CHARACTERISTICS

The EEBD specifications were designed to provide a light-weight, easily stored, and conveniently used device that would have a minimum shelf-life of 5 years. The average overall weight of the device in the storage case is 2250 grams (g) or 4.96 pounds (lbs), and the average weight of the EEBD as used is 1561 g or 3.66 lbs. When stored, the average dimensions of the case are 23.9 x 21.9 x 11.0 centimetres (cm) or 9.4 x 8.6 x 4.4 in.

The major components of the device that are not related to generating O₂ are the hood, the face shield, and the housing. The housing is made from a polysulfone plastic to provide good impact and thermal resistance. The design of the housing provides some convective cooling of the O₂ generator when the device is in a vertical position. Although the device will work equally well in a horizontal position, the cooling effect is reduced and the hood may provide additional insulation to trap heat. This heat can be sufficient to melt the polysulfone case, therefore if the device is placed on someone who is unconscious or immobile, the individual should not be left in a prone position and air circulation over the canister should not be restricted.

Because the EEED develops an almost pure O₂ environment within the EEED hood, the hood and face shield must be extremely resistant to ignition. Coupling this requirement with the need for a hood to be air-tight to prevent the external air from mixing with the breathing air presented a major problem in developing the hood and face shield.

These problems were overcome by using a dual-hood design. The inner hood is an air-tight hood made from woven glass coated with tetrafluoroethylene (Teflon) and has a transparent face shield made from fluorinated ethylene-propylene polymer (FEP). A thin, rubber neck seal is attached to this hood to provide an air-tight neck seal. The outer hood is the flame resistant hood and is attached to the bottom, outside of the inner hood. The outer hood is made from a flame resistant polymer (Kynol), and has a face shield made from transparent poly(vinyl chloride) (PVC).

FLAME RESISTANCE OF THE HOOD

The original specifications for the EEED required that the device protect the user from smoke, toxic gases, and burning embers in the fire environment. As part of the enhanced requirements developed from interactions with fleet personnel, this test was up-graded to also provide protection from direct contact with flames.

Because "standards" do not exist, the concept of a "standard burning ember" or "standard flame" is difficult to apply in these tests. In recent tests the "standard burning ember" has been defined as a 4.2 cm (1.7 in) wooden match, but "standard flames" have not been defined. For these tests the "standard flame" was a blue flame from a National Welding 3A Blowpipe torch equipped with an N-1 nozzle and using a mixture of natural gas and air.

The device was tested using a brass head-form and an O₂ concentration greater than 90% inside the hood; in some cases the interior of the inner hood was sprayed with diesel fuel. Burning embers were placed on the hood material and the facepiece and allowed to burn completely. The flame test involved placing the

torch head approximately 10 (in) from the hood and facepiece and allowing the flame to burn inst the material for 3 seconds. In each test the dual hood gave sufficient protection to prevent a burn-through.

WARNING: The complexity and diversity of fire scenarios are such that scientifically meaningful tests to evaluate the fire resistance of a hood under all situations is not possible. Variations in the amount of contact between the hoods could seriously affect the amount of heat transferred into the inner hood and, thereby, affect the fire resistance. The inner hood environment of pure O₂ will significantly enhance the combustability of all materials. Every effort must be made to avoid burning areas.

OXYGEN PURITY AND QUANTITY

Although chlorate candle technology has been used for many years aboard submarines, the candles occasionally have been reported to form high levels of chlorine (Cl₂) within the first minute of operation, and high levels of carbon monoxide (CO). Normally, the Cl₂ gas is removed by reacting it with small quantities of barium peroxide (BaO₂), which is present in the candle formulation, to give O₂ and solid barium chloride (BaCl₂):



Other catalytic materials can be placed external to the candle to reduce CO levels by converting the CO to CO₂. As a result of these controls, the O₂ produced by the chlorate candles on a submarine is very pure.

Unfortunately, all the added precautions taken aboard a submarine cannot be incorporated into a compact emergency breathing device. Although BaO₂ is used in the Scott EEBD candle, even small levels of Cl₂ in the restricted environment of the EEBD hood could be very serious, and CO is not converted to CO₂ in the EEBD. Therefore, the levels of these gases must be determined to be sufficiently low that they would not present a hazard to the user.

The presence of Cl₂ in the effluent gas was measured using specific-chemical detector tubes designed and calibrated to detect Cl₂ levels below 1 part per million (ppm). The presence of Cl₂ in the EEBD breathing gas could not be detected at the lowest indicating level (0.2 ppm). The allowed NIOSH level² is 0.5 ppm for 15 minutes, with a ceiling value of 1.0 ppm.

The levels of O₂, CO₂, CO and nitrogen (N₂), were determined by capturing gas samples in stainless steel cylinders and analyzing the material by gas chromatographic techniques. In addition, the level of CO was monitored by an in-line technique using a continuous CO analyzer. The average overall composition of the breathing gas from the chlorate candle O₂ generator was

determined to be:

CO	<	2 ppm
CO ₂	<	0.5%
N ₂	<	0.5%
O ₂	>	99.0%

The EEED device is designed to support a metabolic rate of 1.7 litres per minute (lpm) of O₂ for 15 minutes of exertion equivalent to medium-to-heavy work condition for a man weighing 160 lbs. Therefore, the 1.7 lpm value must be considered as a minimum allowable flow rate of O₂ formed by the candle. The average flow rate calculated or measured for the devices was 4.8 lpm, and the average life-time of the device was 17.5 minutes. During the unmanned tests, the lowest measured flow rate was 3.8 lpm, and the shortest life-time was recorded as 17.1 minutes.

EASE OF OPERATION

Emergency situations, especially those that limit respiratory and visual abilities, require emergency equipment that is easily used. The requirement for the EEED is that the device can be activated and donned in less than 30 seconds. Because the activating and donning procedures for the Scott device are simple, the required time limit is easily met by well-trained individuals. But, we initially found that individuals who wore eyeglasses were less able to meet this time limit. The difficulty arose from incorrectly opening the neck seal before the individual inserted their head and, as a result, their eyeglasses fell from their face; this problem can be corrected by more detailed training.

A second aspect of operating an emergency breathing device is that the device have a distinct indication that the emergency air supply is expended. The Scott device has a built-in indicator in that the sound of the air entering the hood is loud enough to be easily heard by the user. When the candle stops generating O₂, the absence of the sound indicates that the device is expired. The level of noise produced by the device was measured at DTNSRDC as 85 decibels. During the manned-testing, the noise produced by the device was found to interfere with the user's ability to hear instructions given at a normal voice level, but individuals were able to communicate by speaking in a louder voice.

ENVIRONMENTAL CONSIDERATIONS

The unique operating environment of Navy ships presents potential problems for the long-term storage of breathing devices. As a result of these concerns, half of the devices initially tested in each phase of the TECHEVAL and OPEVAL were subjected to environmental stresses as outlined in the

appropriate Military Standard Test. The tests were conducted at WQEC and the stresses included: temperature variations (-20°F to +140°F), shock and vibration, salt-fog atmospheres, and accelerated aging. The Scott EEBD passed each of these tests and only exhibited normal oxidation of the metal pieces on the outer carrying case. The inner, vacuum-sealed bag protected the device from oxidation. Additional metallurgical testing done at DTNSRDC confirmed the ability of the inner bag to protect the device from the environment.

SHIPBOARD SAFETY CONSIDERATIONS

The potential consequences of the EEBD burning in a fire or being struck by shrapnel were considered. Tests were conducted at WQEC to simulate these conditions by shooting the device with 2 rounds of 30-caliber ammunition and by placing the device on a grill in an open oil fire. When the fire was ignited the case began to burn, then produce a considerable amount of smoke; the smoke was due to the burning plastics used in the carrying case and the vacuum-sealed bag. When the heat reached the O₂-generating chemicals, the candle was activated. The O₂ that formed caused the intensity of the fire to increase in the area around device until the candle completely burned; significant problems were not encountered. The results from this test and the 30-caliber shell impact tests indicate that the device would not explode during fire or under combat conditions.

Having passed the initial unmanned testing, the Scott EEBD was approved for manned testing at the Navy Medical Research Institute.

PERFORMANCE TEST RESULTS - MANNED TESTING

The manned-testing aspects of evaluating the Scott EEBD were conducted at NMRI in the Environmental Biosciences Department of the Heat Stress Division. Four servicemen assigned to this division volunteered as test subjects and their physical characteristics are summarized in Table 1.

The baseline cardiovascular and pulmonary parameters were established for each subject prior to each test (rest period). Then, the control values were determined by having the subject walk on a treadmill to establish a standard 1.7 lpm O₂-demand level before the device was activated and donned (control period). The subject exercised on the treadmill at this rate for the life-time of the device (on-device period). After removing the EEBD (post-device period), the subject continued to exercise for 5 minutes at the same rate to determine if any post-device recovery was apparent. The subjects were monitored for an additional 30 minutes to ensure their safety. In addition, "sham" tests were conducted in which the entire procedure was followed without using an EEBD. Lastly, two devices were tested with an initial metabolic O₂-demand of 2.0 lpm rather than the required 1.7 lpm. But, physiological differences were not

observed in these tests as compared to the required 1.7 lpm tests.

SAMPLING, INSTRUMENTATION, AND DATA ANALYSIS

The hood of the Scott device was modified to allow gas sampling of the breathing atmosphere and the subjects were instrumented and monitored for a variety of biological functions. Specific-chemical detector tubes were used to monitor the levels of CO and CO₂ in the breathing gas during the manned-testing, and gas samples were collected and returned to NRL for analysis of O₂, N₂, CO₂, and CO by gas chromatographic methods. Although in some cases the CO levels were above the maximum "allowed" levels, the high CO levels were easily correlated with the individuals who smoked tobacco products. The high level of O₂ in the breathing gas displaces the CO from the CO-hemoglobin complex and this CO is expired by these individuals. The data (Table 2) indicates that the Scott EEED successfully maintained an acceptable breathing environment throughout the tests.

The functions that were monitored included O₂ consumption and minute respiratory volume, which were determined before and after the on-device period; electrocardiograms (EKG), taken 10-15 cm below each axilla; systolic and diastolic blood pressure, recorded via Korotkoff sounds; and inspiratory pressure and expiratory pressure, taken as pressure change within the hood. In addition, temperatures were recorded at the following locations: the breathing air, measured in the hood; the device temperature where the case made contact with the skin; the temperature of the O₂ generator; and the temperature of the skin, where the device made contact with the skin. The heart rates were determined from the EKG recordings and the mean arterial blood pressure was calculated from:

$$AP = DP + (2/3)(SP - DP)$$

The results were analyzed using a one-way analysis of variance (ANOVA). The data was considered significant if the probability of random variation was less than 5% ($p < 0.05$), or highly significant if the random variation was less than 1% ($p < 0.01$). The reported values are given as the mean + the standard error of the mean (SEM).

Because a special facemask is used to determine the O₂ consumption (O₂ CON) and minute respiratory volume (MRV), these parameters could only be measured before the EEED was donned and during the post-device period. The mean O₂ CON for the rest periods was 0.46 ± 0.02 lpm and for the control periods the mean O₂ CON 1.71 ± 0.01 lpm. At 1 and 5 minutes post-device for the Scott, the mean values were 1.68 ± 0.06 and 1.69 ± 0.09 lpm, respectively, while the mean values corresponding to the "post-device" period for the sham run were 1.84 ± 0.19 and 1.83 ± 0.18 lpm. The lower O₂ CON for the Scott post-device period is believed to result from the high O₂ levels in the breathing air inside the breathing

hood. As a result of the high O_2 levels, the amount of O_2 dissolved in the user's blood is increased and initially, the individual does not sense a need for extra O_2 when the device is removed.

The various temperatures that were monitored during the manned-testing are summarized in Figure 1. The mean temperature of the breathing air (T_a) was measured as $95 \pm 2^\circ F$. Because this temperature is reached within the first 5 minutes after the device is activated, the user senses the hot gas throughout the life-time of the device. The maximum T_a for any Scott device was $108^\circ F$, which is below the maximum allowed value of $110^\circ F$ for moisture saturated air. The mean maximum temperature for the part of the device in contact with the subject's skin (T_i) was $106 \pm 4^\circ F$. This is approximately the same temperature found for the temperature of the subject's skin beneath the device (T_{sk}), which was $105 \pm 1^\circ F$. The increased T_{sk} irritated the subjects' skin and a moderate erythema was noted after the device was removed. But, the redness disappeared within a few minutes and skin damage did not occur.

Relative to the pressure outside the EEBD hood, the mean respiratory pressure measured during inspiration (IP) was -5 ± 1 mm H₂O and during expiration (EP) the pressure was 6 ± 0 mm H₂O. These values are well within the maximum allowed IP and EP values of 35 mm and 40 mm H₂O, respectively.

The physiological data from the tests that were run at an initial O_2 demand of 2.0 lpm did not differ significantly from the tests run at the required 1.7 lpm rate. Therefore, with the exception of the respiratory parameters, these values were included in the data summarizing the Scott performance at 1.7 lpm. The data indicates that the life-time of the device is governed by the rate of burn of the chlorate candle and not by the O_2 demand. This is a benefit in that the device will support higher O_2 demands without adding stress on the individual. But, if little O_2 demand is required, the extra O_2 that is being generated cannot be saved.

Although the mean heart rate (HR) of the subjects on the Scott device and at the 1 minute post-device period was higher than the sham run, the HR was approximately constant during the test (Figure 2). The HR is sensitive to person's emotional state and the higher rate during the test and at the end of the test is believed due to the anxiety of the individual in using the device and anticipating the end of the device.

The mean arterial pressure (AP) for subjects using the Scott device was statistically different at the 15 minute mark (Figure 2) as compared to the sham run. While this may be interpreted as indicating a stress on the subject, a more commonly used index for physiological stress during exercise is a decrease in the diastolic pressure (DP) accompanied by an increase in the systolic pressure (SP). In the tests with the Scott device, the

DP and the SP are essentially unchanged and were not considered to be statistically different than in the sham run (Figure 3).

IN-LEAKAGE TESTING

The original test procedure required that in-leakage tests be conducted using a breathing machine; the Scott device initially failed this test. Because the test uses a head-form, we were concerned that the neck seal was not comparable to that formed on an individual. Therefore, manned-tests were conducted at the National Institute for Occupational Safety and Health (NIOSH) research facility in Morgantown, WV. The tests were conducted using an NaCl aerosol generator and the subjects were required to breathe deeply (simulating a work-load placed on the device) while conducting a variety of neck and head motions designed to challenge the neck seal. The in-leakage is measured by the protection factor (PF), which is defined as

$$PF = 100\% / (\text{average overall } \% \text{ in-leakage})$$

The allowable in-leakage was 0.75%, or a PF of approximately 133. The Scott device passed these tests and the results summarized in Table 3.

The effect of hair in the neck seal is evident by the values for the PF found during tests using unbearded, bearded, and long-haired subjects. The individual who volunteered as the bearded and long-haired subject had a beard that extended down his throat and could interfere with the neck seal; his hair extended approximately 4 inches below the top of his shoulders. Individuals who use any emergency breathing device, especially people who have beards or very long hair, should be extremely careful to prevent a breach of the neck seal by their hair. Once the seal on any breathing device is broken, the ability of the device to protect the individual from toxic gases in the environment is seriously reduced.

GENERAL COMMENTS DURING MANNED-TESTING

In addition to providing physiological data to assess the performance of the Scott device, manned-testing also provides the opportunity to subjectively evaluate the device based on the user's comments. The individuals who tested the device commented that the device was "real hot and foggy". Both observations are related to the temperature of the breathing air in the device. At the work loads tested, the warm air and the enclosed air-tight environment around the subject's head causes extensive sweating. In one test an attempt was made to measure the amount of moisture in the neck seal; a total of 23 millilitres (~3/4 ounce) was collected. Also, the high moisture level within the hood caused a considerable amount of condensation on the facepiece. The condensation seriously hampered the vision of individuals who wore eyeglasses because their glasses also became fogged.

The need for extensive training in using the device was demonstrated by the range of times required by the subjects to don and activate the device. The average time was 42.6 ± 6.0 seconds, but the range was from 23.4 to 61.8 seconds. As mentioned previously, part of the problem in the donning procedure relates to individuals who wear eyeglasses, but a second problem results from individuals improperly placing their head in the head harness within the hood. Individuals who did not have their head correctly placed in the head-harness complained that the device moved about their head and that this motion was distracting.

While using the Scott Emergency Escape Breathing Device, the subjects did not feel additional stresses. They did not report any signs of respiratory distress nor discomfort from the quantity or temperature of the breathing gas.

Having passed the TECHEVAL and the controlled manned-testing, the Scott EEBD was tested under actual smoke and fire conditions.

RESULTS FROM THE OPERATIONAL EVALUATION

The OPEVAL tests were designed to determine the operational effectiveness and suitability of the EEBD under real-life conditions.

OPERATIONAL EFFECTIVENESS

The OPEVAL tests were conducted using 26 Scott devices. The devices were donned and activated aboard the USS America (CV 66) or in a smoke chamber. Although not part of the specifications, the subjects donning and activating the device in the smoke chamber proceeded to fight a Class B fire. **WARNING: The individuals who tested this device were undergoing training for firefighting and were in a controlled situation. This device is designed to escape from fires and must not be used to fight fires.** During these tests, the donning time, life-time of the device, ability of the device to remove smoke irritants, the subject's visibility and evaluation of the amount of O₂ available was recorded.

The time required to activate and don the device was clearly related to the training that the individual received. Subjects who received "hands-on" training had an average time of 23.4 sec (standard deviation (SD) = 1.3 sec). Individuals who received a training lecture had an average time of 60.0 sec (SD = 25.9 sec), and individuals who did not receive any training had an average time of 64.3 sec (SD = 23.7 sec). Clearly, if individuals are expected to use the EEBD efficiently, they must receive regularly spaced, detailed hands-on training.

The Scott EEBD successfully eliminated smoke irritants that were trapped in the hood when the device was donned in the smoke chamber. The average life-time of the device was 16.5 min

with a 1.1 min standard deviation. Although 5 subjects complained of insufficient O₂ while fighting the fire, the devices provided more than sufficient O₂ to permit the individuals to escape from a toxic, smoke filled room. Based on comments by the subjects, approximately 75% stated that their visability was hampered by condensation on the face-piece. But, few problems with visability were recorded when the visability in the area was good.

OPERATIONAL SUITABILITY

Of the 75 devices tested during the TECHEVAL and OPEVAL programs, only 1 failed; this gives a reliability of 0.99. The devices do not require maintainance beyond a semi-annual inspection of a dessicant strip to ensure that the inner plastic bag has not failed.

Some individuals again complained of the hood slipping from their head, especially when they were sweating. This problem was reported during the manned-testing at NMRI and is related to the material used for the head harness. The problem was remedied by changing to an elastic material that fit the head more snugly. Occassionally, subjects also reported a discomfort in their eyes caused by the warm breathing air passing across their face. This was remedied by relocating the exit for incoming air.

TABLE 1
PHYSICAL CHARACTERISTICS OF TEST SUBJECTS

SUBJECT	AGE (years)	HEIGHT (inches)	WEIGHT (pounds)	BODY SURFACE AREA (metres ²)	BEARD	EYE- GLASSES	PHYSICAL CONDITION
1 ¹	31	70.0	272	2.65	Yes	Yes	Fair
2 ¹	23	73.0	213	2.21	No	Yes	Good
3	33	68.5	184	1.98	Yes	Yes	Good
4	36	65.0	135	1.67	No	No	Excellent

1. Indicates that this individual smoked tobacco products.

TABLE 2
ANALYSIS OF BREATHING GAS SAMPLES¹

TIME FRAME OF SAMPLE (MINUTES)	ON-SITE SAMPLES (INDICATOR TUBES)		CYLINDER SAMPLES (%)		
	CO ₂ (%)	CO (ppm)	CO ₂	O ₂	N ₂
< 7	1.7±0.4	78.3±1.7; 5.0±0.0;	1.9±0.4	42.3±5.6	55.9±2.2
> 7	2.1±0.5	85.0±7.6; 2.8±2.2;	3.0±0.8	92.5±0.6	4.6±0.3

1. Sampling ports were located at different sites; values are reported as the average + SEM
2. Average value for subjects who smoked tobacco products.
3. Average value for subjects who did not use tobacco products

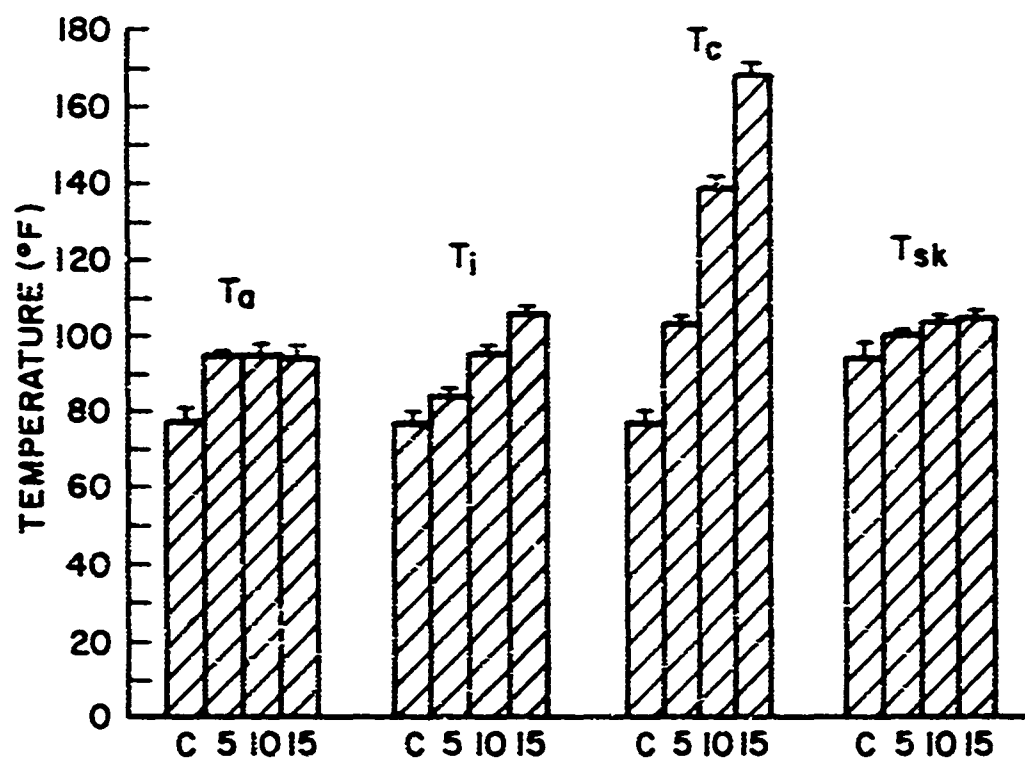


FIGURE 1

MEAN TEMPERATURE DURING THE CONTROL (C) AND ON-DEVICE PERIODS (MINUTES) FOR THE BREATHING AIR (T_a), THE CASE IN CONTACT WITH THE SUBJECT'S SKIN (T_i), THE O_2 GENERATOR (T_c), AND THE SUBJECT'S SKIN UNDER THE DEVICE (T_{sk}). THE MAXIMUM ALLOWED TEMPERATURE FOR T_a IS 160°F, AND FOR T_i IS 170°F

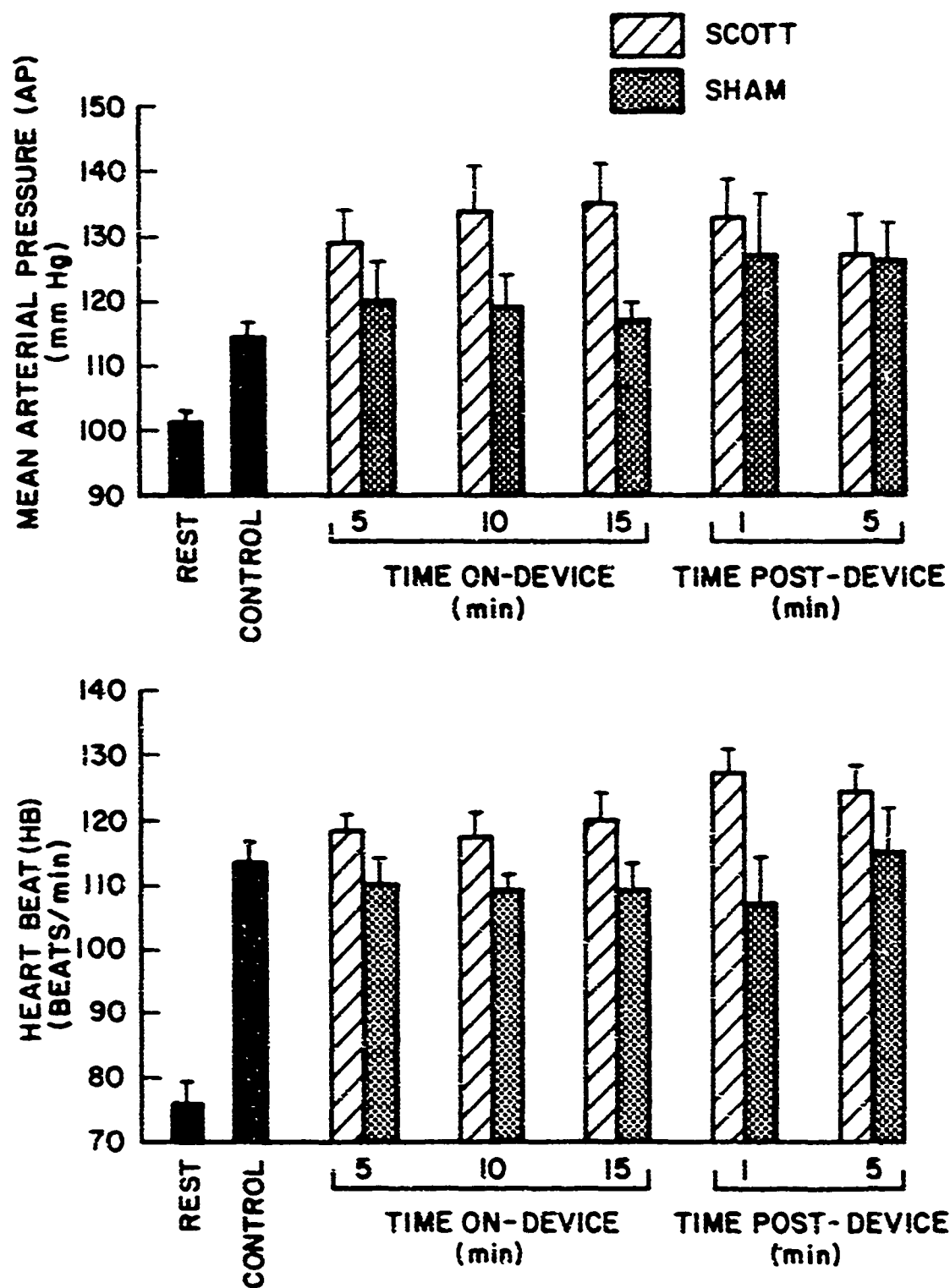


FIGURE 2
MEAN HEART RATE AND ARTERIAL PRESSURE DURING REST, CONTROL
AND TIME ON-DEVICE PERIODS

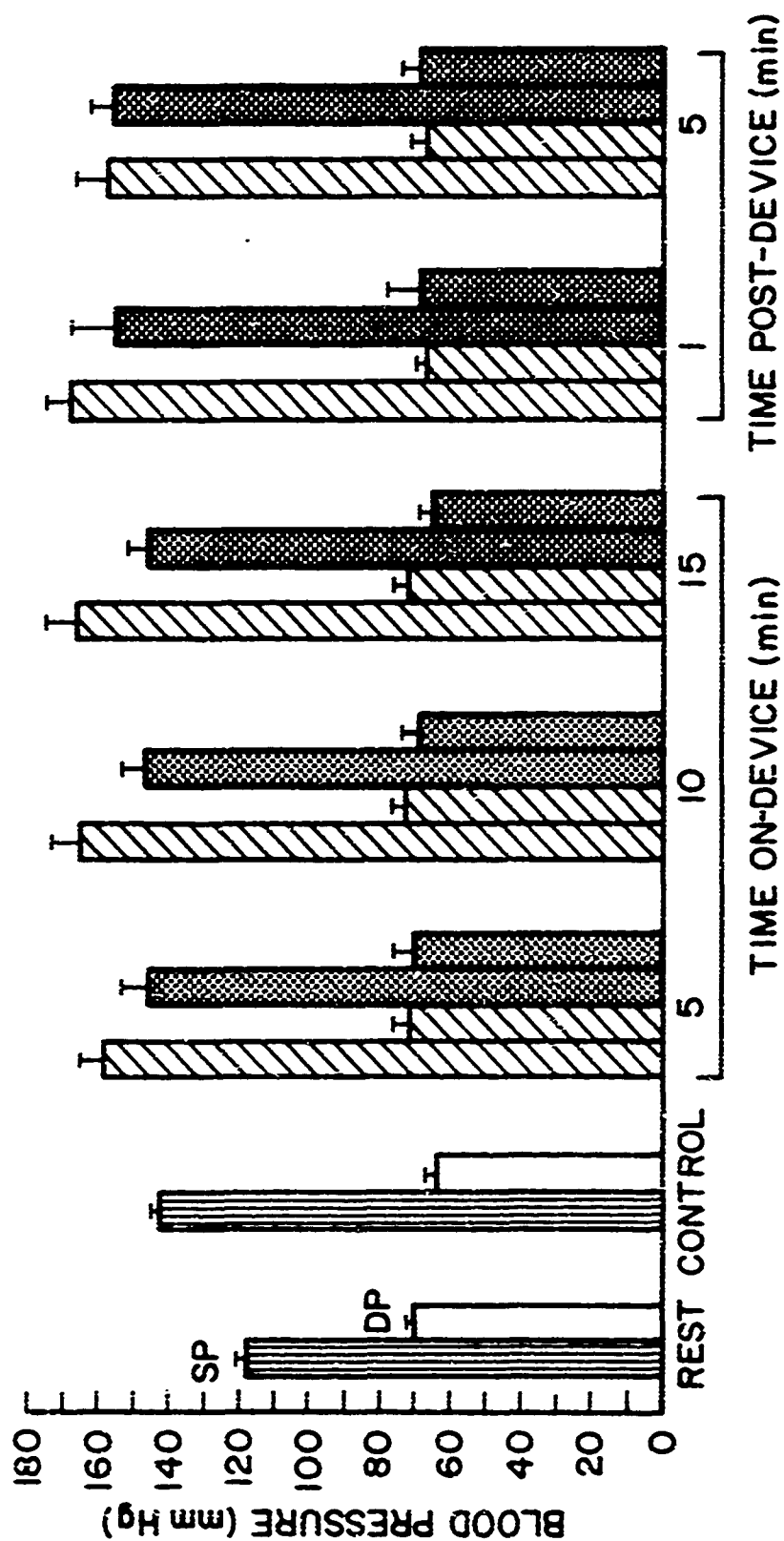


FIGURE 3

MEAN SYSTOLIC (SP) AND DIASTOLIC PRESSURE (DP) DURING REST, CONTROL, TIME ON-DEVICE AND TIME POST-DEVICE PERIODS

TABLE 3

RESULTS FROM MANNED IN-LEAKAGE TESTS¹

SUBJECT	AVERAGE PENETRATION (%)	PROTECTION FACTOR
Unbearded	0.015	6,666
Unbearded	0.008	12,500
Bearded	0.07	1,422
Bearded	0.02	5,000
Long-haired ²	0.038	2,632
Long-haired ³	0.018	5,556
Long-haired ⁴	0.36	275

1. The minimum protection factor allowed is 133.
2. The subject was assisted in placing his hair into the device.
3. The subject was told to take a reasonable amount of time to place his hair into the device, but to consider that he was in a "fire situation". The subject took approximately 15 seconds.
4. The subject was told to don the device without attempting to place his hair into the device.

REFERENCES

1. NIOSH "Criteria for a Recommended Standard: Occupational Exposure to Carbon Dioxide" HEW Publication No. (NIOSH) 76-194 (1976)
2. NIOSH/OSHA Pocket Guide to Hazardous Chemicals, DHEW (NIOSH) Publication No. 78-210 (1978)

APPENDIX A

EMERGENCY BREATHING DEVICE SPECIFICATIONS

The purpose of this Appendix is to provide the reader with an overall understanding of the requirements and characteristics of the Navy EEBD, therefore the Appendix is not complete and will not reflect subsequent changes.

1. REQUIREMENTS

A. ITEM DEFINITION

The device shall consist of a hood with a transparent visor and an elastomeric neck seal; a chlorate candle-based O₂ generator; an air purification filter or scrubber; and a venturi arrangement to recirculate the breathing gas through the scrubber. The hood shall be designed to allow voice communication, to provide the user with unobstructed vision and to permit the user to wear eyeglasses. The major components of the EEBD device are:

1. a flexible double hood with a neck seal to encapsulate the user's head
2. a component mounted on the back of the hood to provide a safe breathing environment within the hood for 15 minutes
3. a carrying case to house and protect the device during transportation and storage.

B. DIMENSIONS AND WEIGHT

The dimensions of the device packaged in the carrying case shall not exceed 4.3 in x 8.3 in x 9.3 in, and, as worn, the weight of the device shall not exceed 4 lbs.

C. SHELF LIFE

Storing the EEBD for a minimum of 5 years shall not significantly degrade the performance of the device. The hood shall remain flexible, without cracking or brittleness.

D. MAINTAINABILITY

The maintenance for the device shall consist of a periodic inspection to assure that the device is ready to be used. A humidity indicator will be sealed inside the plastic evacuated bag and located so that it can be easily seen when the device is stored.

2. PERFORMANCE CHARACTERISTICS

The device shall have the ability to provide respiratory support and eye protection to allow the wearer to escape from a lighted or darkened compartment along a toxic gas and smoke-filled escape route.

For the purpose of defining the nominal performance, the design condition shall be based on a work rate equivalent to an O_2 consumption of 1.7 lpm, measured at standard temperature and pressure (STP), for an average 160 lb man doing moderate to heavy work.

3. OXYGEN GENERATOR PERFORMANCE

A. GENERATOR OUTPUT

The O_2 flow, averaged over the life-time of the device, shall not average less than 4.8 lpm, at normal temperature and pressure (NTP). Averaged over any 2 minute period during the first 15 minutes of operation, the flow shall not be less than 4.0 lpm at NTP. The flow shall not be below 3.0 lpm (NTP) at any time during the life-time of the device.

B. GENERATOR DURATION

Under normal conditions, the generator shall produce O_2 for a minimum of 15 minutes.

C. GENERATOR PRESSURE

The maximum internal pressure within the generator shall not exceed 60 pounds per square inch.

D. EFFECT OF TEMPERATURE ON PERFORMANCE

After stabilizing the device at 140°F or -20°F, the device shall be activated and have a minimum life-time of 15 minutes. Based on a 2 minute average sample taken at an O_2 consumption rate of 1.7 lpm (NTP), the CO_2 level shall not exceed 4.0%.

E. OXYGEN PURITY

The breathing gas formed by the device shall not contain more than:

Carbon dioxide	5,000 ppm (0.5%)
Carbon monoxide	15 ppm
Chlorine	0.2 ppm

averaged over the duration of the device. The device shall not form any noxious odors nor shall the Cl_2 level exceed 1.0 ppm for any 2 minute period.

F. BREATHABLE GAS TEMPERATURE

The peak breathable dry gas temperature shall not exceed 160°F (71.1°C).

4. SCRUBBER EFFICIENCY

A. CO₂ LEVELS

During the first 15 minutes of operation and with a rate of O₂ consumption of 1.7 lpm or less, the CO₂ level averaged over any 2 minute segment shall not exceed 4.0%.

B. GAS PURITY

Except for odorous gases trapped inside the hood during donning, the gas circulated within the hood shall be free of harmful gases, dust, smoke and noxious odors.

5. BREATHING RESISTANCE

During inhalation, the breathing resistance or pressure drop shall not exceed 40 mm of water. During exhalation, the breathing resistance shall not exceed 35 mm of water.

6. HOOD IN-LEAKAGE

In-leakage is defined as the leakage of the ambient air into the face mask, hood, or neck seal. While the device is in use, an in-leakage greater than 0.75% atmospheric gases will not be allowed.

7. MATERIALS

A. COMPATIBILITY OF MATERIALS

Over the range of operating conditions specified, the materials that are in contact with the breathing gases must be compatible with O₂, and not emit noxious or toxic fumes. To ensure that the characteristics and operation of the device is not compromised by deformed parts, the materials of construction also must be compatible with the temperatures formed while the device is operating. When exposed to a "below deck" shipboard environment, the materials shall not degrade or corrode.

B. HOOD MATERIAL

With a 100% O₂ environment within the hood and ambient air outside, the hood shall not ignite or support self-sustained burning when exposed to an open flame. This protection shall also be provided when the interior of the hood is sprayed with marine diesel fuel.

8. DONNING

The operation of the device shall be such that individuals who have been properly trained will be able to remove the device from the carrying case, activate and don the device in a dimly lit area in less than 30 seconds.