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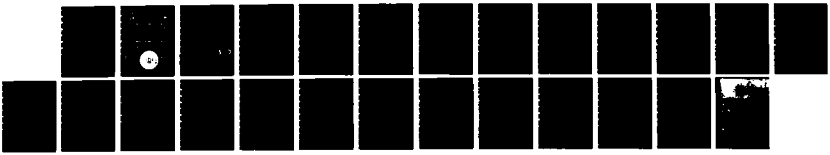

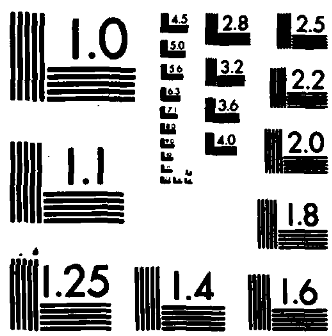

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NAVY EXPERIMENTAL DIVING UNIT
REPORT NO. 5-84

PURGING PROCEDURES FOR THE DRAEGER LAR V UNDERWATER BREATHING APPARATUS

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and

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NAVY EXPERIMENTAL DIVING UNIT

DEPARTMENT OF THE NAVY
NAVY EXPERIMENTAL DIVING UNIT
PANAMA CITY, FLORIDA 32407

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MARCH 1984

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The U.S. Navy SEAL teams currently utilize the Draeger LAR V closed-circuit oxygen Underwater Breathing Apparatus (UBA) for clandestine combat swimmer operations. Prior to beginning a dive with a closed-circuit oxygen UBA, a purge procedure is carried out to remove inert gas (nitrogen) from the breathing mixture. This study seeks to establish an optimal purging procedure for the Draeger LAR V. Twenty-four purges were conducted using the current

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Standard three fill/empty cycle purge procedure; the average oxygen percentage obtained in the breathing mix was 85% with a high of 96% and a low of 73%. Fifty-four Single Fill/Empty Cycle (SFE) purge procedures resulted in an average oxygen percentage of 74% with a high of 89% and a low of 50%. Forty No Fill/Empty Cycle (NFE) purge procedures resulted in an average oxygen percentage of 55% with a high of 82% and a low of 20%. Eighteen 2-hour dives using the two experimental purge procedures showed no significant inert gas buildup during the course of the dive. Conclusions from this study are: (1) The NFE purge procedure was not found to reliably produce adequate oxygen levels in the Draeger LAR V UBA and should not be used operationally; (2) The SFE purge procedure did reliably produce oxygen levels adequate to prevent hypoxia; (3) The Standard purge procedure produced higher levels of oxygen than the SFE procedure but is considered less desirable than the latter procedure because: (a) these higher oxygen levels are not required to prevent hypoxia; (b) higher oxygen levels increase the probability of encountering Central Nervous System (CNS) oxygen toxicity; (c) the extra fill/empty cycles consume additional oxygen, thus depleting the gas supply in the UBA; (4) Inert gas buildup was not observed to be present during the 2-hour dives, thus eliminating the need for additional purging during the conduct of the dive. It is recommended that these additional purges not be performed, for the reasons enumerated in paragraph (3) above, and to minimize the possibility of the diver being detected because of escaping bubbles; (5) the SFE purge procedure without any additional purging during the dive is felt to be the optimum purge procedure for the Draeger LAR V.

ABSTRACT

The U.S. Navy SEAL teams currently utilize the Draeger LAR V closed-circuit oxygen Underwater Breathing Apparatus (UBA) for clandestine combat swimmer operations. Prior to beginning a dive with a closed-circuit oxygen UBA, a purge procedure is carried out to remove inert gas (nitrogen) from the breathing mixture. This study seeks to establish an optimal purging procedure for the Draeger LAR V. Twenty-four purges were conducted using the current Standard three fill/empty cycle purge procedure; the average oxygen percentage obtained in the breathing mix was 85% with a high of 96% and a low of 73%. Fifty-four Single Fill/Empty Cycle (SFE) purge procedures resulted in an average oxygen percentage of 74% with a high of 89% and a low of 50%. Forty No Fill/Empty Cycle (NFE) purge procedures resulted in an average oxygen percentage of 55% with a high of 82% and a low of 20%. Eighteen 2-hour dives using the two experimental purge procedures showed no significant inert gas buildup during the course of the dive. Conclusions from this study are: (1) The NFE purge procedure was not found to reliably produce adequate oxygen levels in the Draeger LAR V UBA and should not be used operationally; (2) The SFE purge procedure did reliably produce oxygen levels adequate to prevent hypoxia; (3) The Standard purge procedure produced higher levels of oxygen than the SFE procedure but is considered less desirable than the latter procedure because: (a) these higher oxygen levels are not required to prevent hypoxia; (b) higher oxygen levels increase the probability of encountering Central Nervous System (CNS) oxygen toxicity; (c) the extra fill/empty cycles consume additional oxygen, thus depleting the gas supply in the UBA; (4) Inert gas buildup was not observed to be present during the 2-hour dives, thus eliminating the need for additional purging during the conduct of the dive. It is recommended that these additional purges not be performed, for the reasons enumerated in paragraph (3) above, and to minimize the possibility of the diver being detected because of escaping bubbles; (5) the SFE purge procedure without any additional purging during the dive is felt to be the optimum purge procedure for the Draeger LAR V.

KEY WORDS:

Draeger LAR V
Purge Procedures
UBA

GLOSSARY OF ABBREVIATIONS

cc	cubic centimeter
C	Centigrade
CNS	Central Nervous System
CO_2	Carbon Dioxide
F	Farenheit
FRC	Functional Residual Capacity
FSW	Feet of Sea Water
mmHg	millimeters of mercury
N_2	Nitrogen
NEDU	Navy Experimental Diving Unit
NFE	No Fill/Empty Cycle
OSF	Ocean Simulation Facility
O_2	Oxygen
SEAL	Sea/Air/Land
SFE	Single Fill/Empty Cycle
UBA	Underwater Breathing Apparatus

INTRODUCTION

Closed-circuit oxygen Underwater Breathing Apparatuses (UBA's) have been utilized for clandestine combat swimmer operations since the Second World War. Advantages inherent in this type of UBA over open circuit and semi-closed circuit UBA's include a lack of bubbles escaping from the UBA by which a diver might be detected, compact size, and conservation of gas supply, with resultant longer operating times. The U.S. Navy SEAL Teams currently use the Draeger LAR V for combat swimmer operations; the Draeger replaces the Emerson UBA, which was the mainstay of United States clandestine diving operations for many years.

Prior to beginning a dive with a closed-circuit oxygen UBA, the diver is required to carry out a "purge" procedure, consisting of filling the breathing bag with oxygen and then emptying it by inhaling from the bag and exhaling to the atmosphere (i.e. through the nose) a specified number of times. The purpose of this procedure is to remove the nitrogen, which is metabolically inert, from the diver's breathing mixture. This eliminates the possibility of becoming hypoxic as a result of breathing too high a percentage of inert gas (and therefore too low a percentage of oxygen) from the UBA.

The U.S. Navy Diving Manual (1), in describing the purge procedure for the Emerson UBA, requires that the breathing bags be emptied initially, then refilled and emptied three times. After the last purge, the breathing bag is inflated with 100% oxygen to a comfortable breathing volume and the dive is begun. No additional purges are required during the dive. The current edition of the Diving Manual does not include procedures to be used with the Draeger LAR V. The Draeger LAR V Technical Manual (2) specifies a single initial fill/empty cycle followed by an additional purge every 30 minutes during the dive. Navy SEAL teams currently use a hybrid procedure in which they perform three fill-empty cycles prior to the dive and then a single fill/empty cycle every 30 minutes while underwater. The reason for the additional purges every 30 minutes is to prevent inert gas buildup which could theoretically result from nitrogen offgassing from the body tissues and accumulating in the breathing loop. A review of the literature revealed no experimental data documenting this nitrogen buildup or the necessity of performing additional purges.

This study was done to examine in detail purging procedures for the Draeger LAR V and to quantitate the effects of various purge procedures on UBA oxygen percentage and gas supply depletion. In particular, the goals of this study were:

(1) To determine the amount of oxygen used in accomplishing the purge procedure.

(2) To ascertain the percentage of oxygen obtained in the Draeger LAR V with the purge procedure currently in use in the SEAL community.

(3) To investigate the effectiveness of two experimental purge procedures.

(4) To determine how the UBA oxygen percentage changes during the course of a 2-hour dive.

(5) To use the information in items (1) through (4) in determining an optimum purge procedure for the Draeger LAR V.

METHODS

Purge Procedures

Reference will be made to three purge procedures as described below:

(1) The Standard Purge Procedure - as described in the Introduction, this procedure consists of emptying the breathing bag, then refilling it with oxygen and emptying it three times. After the last fill/empty cycle, the bag is inflated with oxygen to a comfortable breathing volume and the diver begins breathing from the UBA. This is the purge procedure currently in use.

(2) The Single Fill/Empty Cycle (SFE) Purge Procedure -consists of emptying the breathing bag, filling it with oxygen and emptying it a single time, then re-inflating the bag with oxygen to a comfortable breathing volume. This procedure is described in detail in Figure 1.

(3) The No Fill/Empty Cycle (NFE) Purge Procedure -consists solely of emptying the air from the breathing bag and refilling it with oxygen as described in Figure 2.

For both experimental purge procedures, an initial classroom session was held during which the divers were taught the procedures and given a chance to practice the technique. For the actual experiment, the divers received a preliminary briefing in which the purge procedures were quickly reviewed. After proceeding to the area where the purges were actually carried out, no further coaching was allowed and no corrections were made when procedural variation was noted. This was felt to provide a reasonable opportunity for diver error which must be considered in developing a purge procedure.

DIVE SUBJECTS

All experimental divers in this series were active duty U.S. Navy divers. Forty-four divers took part in the study; 26 from NEDU and 18 from the U.S. Navy SEAL community. All were in good physical condition and familiar with the use of the Draeger LAR V UBA.

OXYGEN USAGE (Standard Purge Only)

To determine the amount of oxygen used for purging, each diver was instructed to perform the Standard Purge Procedure with its three fill/empty cycles. No attempt was made to control the amount of oxygen used to "fill" the breathing bag; each diver stopped the filling process when he subjectively perceived his bag to be full. After each filling, the diver emptied his breathing bag by inhaling from the bag and exhaling into an over-water bell spirometer. The volume was measured at the actual temperature and pressure (temperature 37°C; pressure 700 mmHg) and recorded by hand. Only the Standard Purge Procedure was evaluated in this manner, since the fill/empty cycle in the SFE procedure is conducted in an identical manner.

FIGURE 1

EXPERIMENTAL SINGLE FILL/EMPTY CYCLE (SFE) PURGE PROCEDURE

1. Blow all the air out of your lungs and insert mouthpiece.

2. Empty the air out of the breathing bag by inhaling from the mouthpiece and exhaling to atmosphere.

3. Activate the oxygen supply valve.

4. Refill the breathing bag completely with oxygen.

5. Empty the bag once more as in Step #2.

6. Refill the breathing bag to a comfortable volume.

7. Start normal breathing.

FIGURE 2

EXPERIMENTAL NO FILL/EMPTY CYCLE (NFE) PURGE PROCEDURE

1. Blow all the air out of your lungs and insert mouthpiece.

2. Empty the air out of the breathing bag by inhaling from the mouthpiece and exhaling to atmosphere.

3. Activate the oxygen supply valve.

4. Refill the breathing bag to a comfortable volume.

5. Start normal breathing.

PURGE EFFICIENCY (Standard, SFE, NFE)

The efficiency of each particular purge procedure was determined by measuring the percentage of oxygen present in the UBA's of divers who had purged according to that procedure. Upon completion of the Standard purge procedure, a gas sample was drawn from the UBA canister effluent coupling into three 50cc syringes through a 1/8" nylon sample tube. The first syringe thus obtained was discarded to ensure that the sample line was adequately purged. The other two syringes were analyzed by a Chemetron Medspect II (Chemetron Medical Products, St. Louis, MO) mass spectrometer for oxygen and nitrogen percentages.

The next area of interest was to determine what percentage of oxygen was present in the divers' breathing mixture after the two experimental purge procedures (SFE and NFE) were performed. After the appropriate purge procedure was completed, the diver breathed his UBA for a period of 1 minute to allow complete equilibration of the gases throughout the breathing loop. The percentages of oxygen and nitrogen were then measured by a mass spectrometer, either a Perkin Elmer MGA 1100 (Perkin Elmer Aerospace Division, Pomona, CA) or Chemetron Medspect 2 (Chemetron Medical Products, St. Louis, MO). Gas samples were obtained from the CO_2 adsorbent canister effluent coupling of the UBA and conducted to the mass spectrometer through a 1/8" nylon sampling line. Gas sampling was also carried out prior to beginning the experimental purge procedures to ensure that the breathing mixture present in the UBA contained a percentage of oxygen which approximated that of air (20-22%).

OXYGEN PERCENTAGE CHANGES DURING A DIVE (SFE, NFE)

For the final portion of the study, the changes in the breathing mixture that occur during the course of a dive were examined in order to determine whether or not nitrogen buildup occurs in the UBA. The length of the dive was two hours; 17 divers were used in this part of the study. The purge procedure consisted of either the SFE or the NFE procedure as described above. No dives were done using the Standard purge procedure since this procedure resulted in higher oxygen levels than the SFE and NFE procedures; if a diver did not encounter a potentially hypoxic situation using these latter procedures, he would not be expected to do so using the Standard procedure. After the divers had performed the SFE or NFE purge procedure and had their UBA oxygen percentages measured as described above, they entered the NEDU Ocean Simulation Facility (OSF) where the remainder of the study was done. They descended into the wet chamber of the OSF and took a position on one of the four bicycle ergometers (3) present in the 46 foot long by 15 foot diameter wet chamber.

The dives were conducted by pressurizing the OSF with compressed air to a depth of 19 FSW. This pressure combined with the 1 foot water column over the diver provided a 20 FSW dive depth. Twenty FSW was chosen as the dive depth for two reasons: (1) 20 FSW is the normal transit depth for combat swimmers; (2) 20 FSW was the shallowest depth from which adequate gas flow for analysis was obtained. The divers pedalled the ergometers at a work rate of 50 watts for 6 minutes, followed by 4 minutes of rest and continued this alternating work/rest cycle throughout the dive.

The UBA's used in this portion of the study were equipped with a gas sample line from the canister effluent coupling. The sample lines were 70 ft. long by 0.078 in. internal diameter unbroken lines which were routed through a penetrator in the chamber wall to one of the mass spectrometers described above. Samples were taken at five separate times during the dive; immediately after reaching a depth of 20 FSW and every 30 minutes thereafter. The diver's gas was again analyzed to determine the percentages of oxygen and nitrogen present in his breathing mixture. Gas sample rate was set at 100 cc/min; the length of sample time was 1 to 2 minutes. Except for these periods, the sample lines were secured to prevent gas from escaping from the UBA's. This sampling procedure was used to minimize gas loss from the UBA and prevent an increase in the oxygen percentage resulting from continuous gas sampling. After the 120 minute sample was complete, the divers were instructed to stand up, turn off their oxygen supply valves, and breathe from the breathing bag until they felt that there was not enough gas in the bag to allow a normal inspiration. As each diver reached this point, he closed his mouthpiece valve, isolating the UBA from the chamber atmosphere, and a "last gas" sample was taken. This sample was included to simulate the conditions that would be present should a diver exhaust his oxygen supply and begin to decrease the oxygen percentage in his breathing mix. The point at which the diver becomes aware of an insufficient volume of gas in his breathing bag for a normal inspiration should therefore represent a minimum figure for oxygen percentage in the UBA. Once all divers had their last sample taken, the experiment was concluded and the OSF brought to the surface.

RESULTS

The results of the volume analysis studies are shown in Table 1. The four divers performed a total of 16 Standard purge procedures, each consisting of three fill/empty cycles. The mean volume that was emptied from the breathing bag for one fill/empty cycle was 3.9 liters (at actual temperature and pressure). The mean volumes for each diver ranged from a low of 3.1 liters for Diver A to a high of 4.4 liters for Diver C, a difference of 1.3 liters. The mean volume of oxygen used for the Standard purge procedure was 11.7 liters, with a low value of 9.2 liters (Diver A) and a high value of 13.2 liters (Diver C).

The results of the experiments done to determine the oxygen percentages present in the divers breathing mixture after the three different purge procedures are shown in Table 2. As expected, the Standard purge procedure resulted in the highest percentage of oxygen, achieving a mean level of 85%. The SFE procedure resulted in a mean oxygen percentage of 74%, while the NFE procedure yielded a mean oxygen percentage of 55%.

TABLE 1

VOLUME OF OXYGEN USED

FOR STANDARD PURGE PROCEDURE

	Number of Purge Procedures*	Mean Gas Volume Per Fill/Empty Cycle	Mean Gas Volume Per Purge Procedure
DIVER A	4	3.1 ± 0.4 liters	9.2 ± 0.7 liters
DIVER B	3	4.0 ± 0.8 liters	12.0 ± 0.7 liters
DIVER C	5	4.4 ± 0.4 liters	13.2 ± 0.8 liters
DIVER D	4	4.2 ± 1.0 liters	12.5 ± 1.1 liters
Total	16	3.9 ± 0.6 liters	11.7 ± 1.8 liters

*NOTE: Each purge procedure represents 3 fill/empty cycles.

TABLE 2

OXYGEN PERCENTAGES PRESENT

AFTER PURGING

Purge Procedure	Number of Trials	Mean Oxygen Percentage	RANGE	
STANDARD	24	85 ± 6%	HIGH	96%
			LOW	73%
SFE	54	74 ± 6%	HIGH	89%
			LOW	50%
NFE	40	55 ± 14%	HIGH	82%
			LOW	20%

The results from the SFE and NFE purge procedures followed by two hour dives to observe the changes in oxygen percentage during the dive are shown in Figures 3 and 4. Figure 3 depicts the oxygen percentages for a SFE purge procedure followed by a 2 hour dive. Immediately after completing the purge on the surface, the mean oxygen percentage was 71%. When the divers reached 20 FSW, the percentage had increased to 82%. This increase is a result of the divers adding additional oxygen to their breathing bag to maintain volume as the pressure on the bag increases with depth. At 30, 60, 90, and 120 minutes, the mean oxygen percentages were 80%, 81%, 81%, and 82% respectively. On the "last gas" samples as described above, the mean oxygen percentage dropped slightly to 80% with a minimum value of 71%. An NFE purge procedure followed by a 2 hour dive produced the values shown in Figure 4. Eight dives were done on this protocol. The mean percentage of oxygen in the UBA's on the surface following the purge procedure was 57%. Compression to 20 FSW raised this value to 75%. The 30, 60, 90, and 120 minute samples showed mean oxygen percentages of 76%, 77%, 77%, and 78% respectively. The "last gas" sample mean was 77% with the lowest single value noted to be 63%.

DISCUSSION

It has long been considered essential by Navy closed-circuit divers to purge their UBA's in such a manner that they start their dive with essentially 100% oxygen in their rigs to avoid the possibility of hypoxia. Hypoxia is truly a dangerous condition when encountered in diving because the diver is often unable to identify its subtle early symptoms and there may be no warning of impending unconsciousness. However, if one could safely lower the oxygen percentage below 100% by allowing some nitrogen to remain in the breathing bags, one would lessen the chance of Central Nervous System (CNS) oxygen toxicity. The question to be addressed is what minimum percentage of oxygen must be present in the Draeger LAR V to prevent the development of hypoxia.

To begin to answer this question, one must first examine the gas volumes contained in the breathing loop formed by the diver and his UBA. These volumes are shown in Figure 5 and approximate values are represented. The average value for pulmonary Functional Residual Capacity (FRC) is obtained from West (4). FRC represents two pulmonary gas volumes: (1) Residual Volume-the air remaining in the lungs after a complete (forced) exhalation; (2) Expiratory Reserve-the air which can be forcibly exhaled from the lungs after a normal exhalation. The Expiratory Reserve is thus equal to the difference between the volume of gas in the lungs at End Expiration and the Residual Volume. The "dead space" in the UBA consists of the non-collapsible components of the Draeger LAR V breathing loop (i.e. the canister and the hoses). This volume was obtained by measuring the volume of water required to fill the hoses and a packed canister. The value for the gas contained in the breathing bag may vary somewhat from diver to diver. The capacity of the bag is over 8 liters, but in practice, the bag is not filled to this volume. The mean figure of 3.9 liters obtained for each fill/empty cycle during the purging procedure represents a more accurate maximum figure for the bag capacity upon completion of a purge procedure. Beyond this volume, the breathing bag exerts an uncomfortable pressure on the diver's chest and

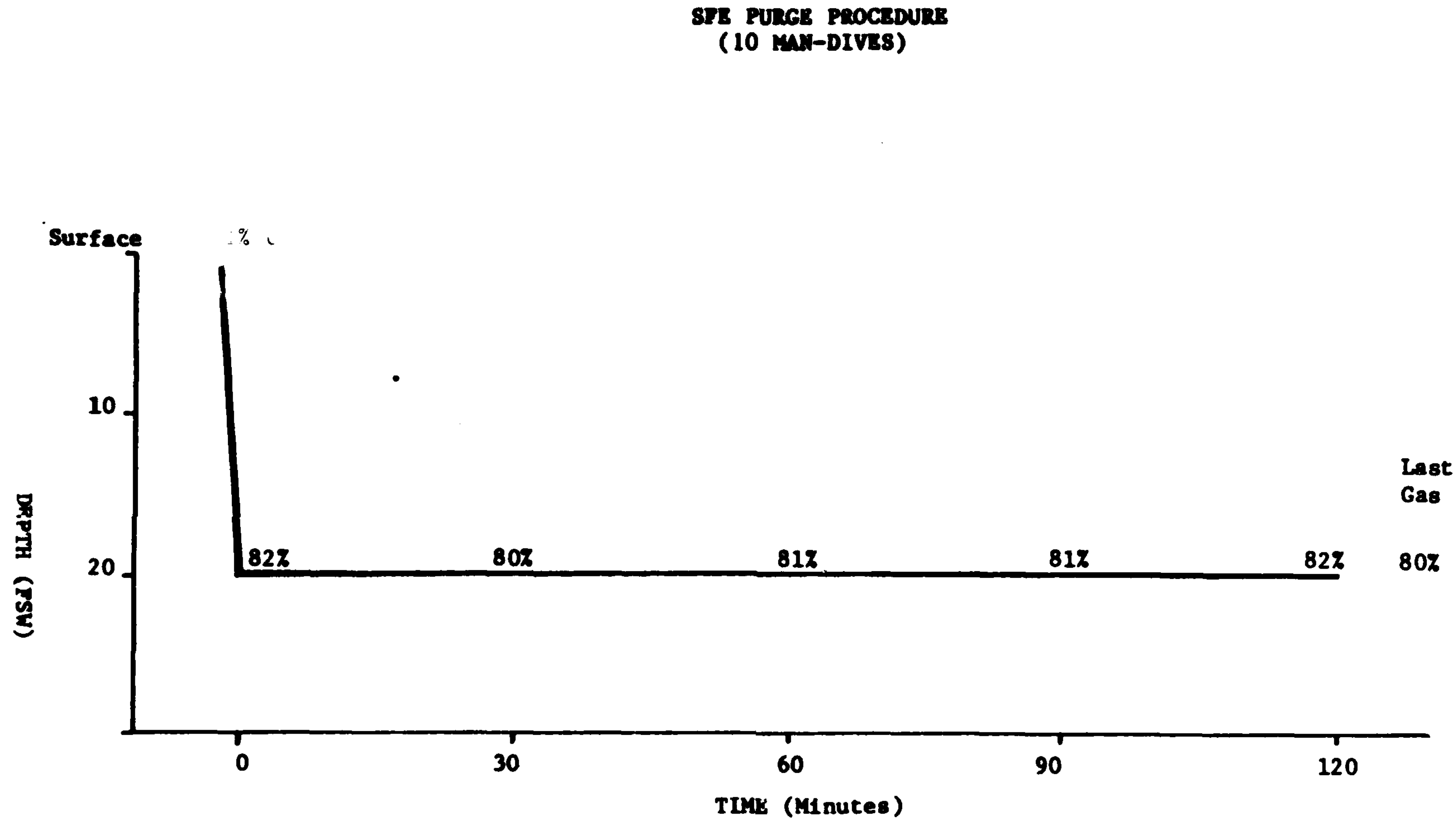


FIGURE 3. Mean UBA Oxygen Percentage Changes During a Two-Hour Dive. Solid Line Represents Dive Depth. Values For Oxygen Percentage Represent Percent By Volume.

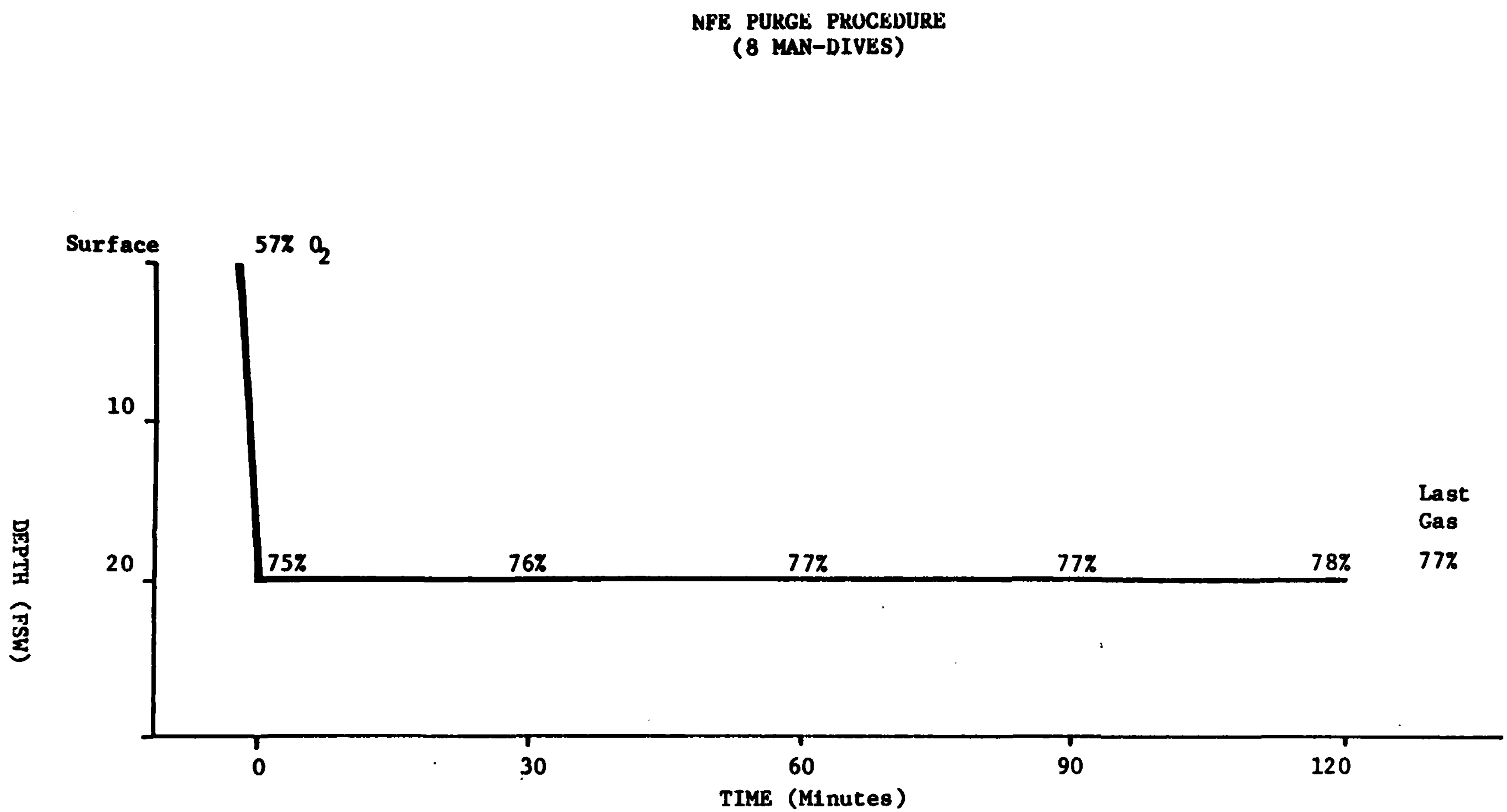
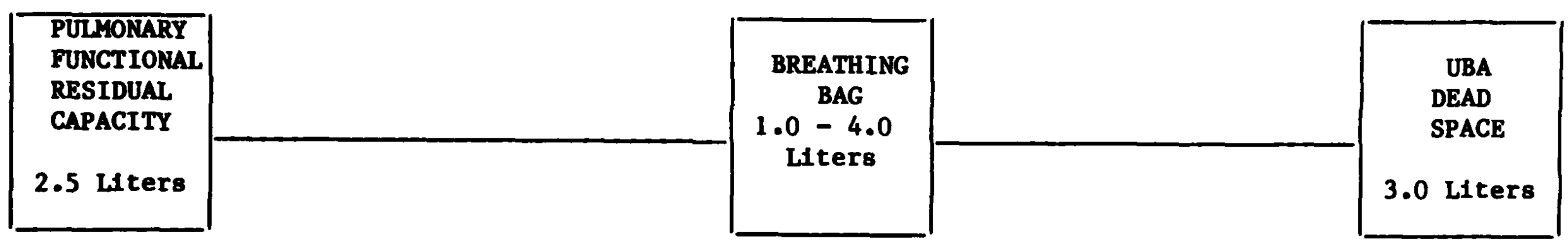


FIGURE 4. Mean UBA Oxygen Percentage Changes During a Two-Hour Dive. Solid Line Represents Dive Depth. Values For Oxygen Percentage Represent Percent By Volume.

FIGURE 5

GAS VOLUMES OF THE COMPONENTS OF

THE RESPIRATION LOOP OF A DIVER USING A DRAEGER LAR V



abdomen. Note that the purge procedures call for the diver to inflate his bag to a "comfortable volume" as opposed to refilling it following the required fill/empty cycles. The volume contained in the breathing bag during an underwater swim should be considerably less than 4 liters (measured at ambient pressure). The second stage of the LAR V regulator is constructed to provide additional oxygen on a demand basis at end-inhalation since the bag must be emptied before the demand valve is activated. Thus, in a well-adjusted UBA, the bag volume would be expected to approximate the diver's respiratory tidal volume. A diver doing mild to moderate work (swimming) would be expected to have a tidal volume of approximately 1.5 liters, while a diver at rest on the surface would have a smaller tidal volume (1.0 liters).

The presence of the two "dead space" volumes (pulmonary FRC and UBA dead space) has a great deal of significance to the diver using the Draeger UBA. Although he may reduce the volume present in his breathing bag, he cannot reduce the gas volume in the dead space in his UBA and the residual volume in his lungs. The oxygen present in these spaces will be in equilibrium with that in the gas remaining in his breathing bag and thus act as a buffer against the development of a hypoxic breathing mixture. (It must be emphasized that the breathing bag and UBA dead space figures apply only to the Draeger LAR V and not ncessarily to any other UBA).

With an understanding of the gas volumes involved in the diver-UBA breathing loop when using the Draeger LAR V, it is possible to approach the question of what is the minimum acceptable level of oxygen following the purge procedure. The first situation which must be considered is that of a diver who has completed his purge procedure and is breathing from his UBA while waiting on the surface for the dive to begin. All three purge procedures call for the diver to fill his breathing bag to a volume comfortable for normal breathing at the completion of the procedure. If the breathing bag is inflated to a volume equal to the tidal volume (the volume of air moved in and out of the lungs with each respiration), the second stage will begin to add pure oxygen as soon as oxygen is consumed from the breathing bag and the volume decreases. In this case, the oxygen percentage in the breathing mix will not drop at all as the diver breathes from his UBA on the surface. If, however, the diver fills his breathing bag at the end of the purge procedure to a volume which exceeds the tidal volume, the second stage of the Draeger will not add more oxygen until the volume of the breathing bag at end inspiration approaches zero. In this case, oxygen will be removed from the breathing mix while the inert gas (nitrogen) volume remains unchanged, which will result in a decrease in the oxygen percentage as the diver breathes his bag down. This potential for a decrease in oxygen percentage during such a surface "breathedown" prior to commencing the dive must be considered in establishing minimum acceptable oxygen percentages for the purge procedure.

Tables 3 and 4 describe the derivation of the minimum acceptable oxygen percentage in light of the preceding paragraph. Table 3 describes how the gas volumes in the breathing loop would change during a surface breathedown. Note that the volume for the breathing bag is assumed to be 4.0 liters. This is done in order to arrive at a "worst case" figure in which the diver has filled his bag all the way up to the average volume noted in Table 1 for a "full" bag rather than a comfortable breathing volume. In addition, the tidal volume has been assumed to be 1.0 liters. This, again, is done to arrive at a worst case

TABLE 3

Breathing Loop Compartment	Before Breathedown	Oxygen Consumed	After Breathedown
UBA Dead Space	3.0 liters		3.0 liters
Pulmonary Functional Residual Capacity	2.5 liters		2.5 liters
Breathing Bag	4.0 liters	3.0 liters	1.0 liters
TOTAL	9.5 liters	3.0 liters	6.5 liters

NOTES: (1) Pulmonary Functional Residual Capacity =

Residual Volume + Expiratory Reserve.
2.5 liters is an average figure taken from West (4).

(2) Values shown assume that the diver is at end expiration.

TABLE 4

A.	STARTING TOTAL VOLUME	9.5 liters
B.	MINIMUM OXYGEN PERCENTAGE ALLOWED	20%
C.	ENDING TOTAL VOLUME	6.5 liters
D.	MINIMUM ALLOWABLE ENDING OXYGEN VOLUME (B x C)	1.3 liters
E.	OXYGEN CONSUMED DURING BREATHEDOWN	3.0 liters
F.	MINIMUM STARTING OXYGEN VOLUME (C + D)	4.3 liters
G.	MINIMUM STARTING OXYGEN PERCENTAGE (F ÷ A)	45%

figure and reflects the fact that the diver may have a smaller tidal volume during the breathedown period since he has not begun to exercise. These two adjustments have the effect of maximizing the oxygen volume which may be consumed before the second stage begins to add more oxygen and, therefore, to show the greatest decrease in oxygen percentage which may be experienced during breathedown. Note that the pulmonary Functional Residual Capacity and UBA dead space do not change during breathedown. The breathing bag volume may drop as much as 3.0 liters as oxygen is consumed.

The effect of this decrease in oxygen is shown in Table 4. Assuming a minimum acceptable oxygen level of 20% after breathedown, we see that the minimum oxygen percentage acceptable immediately after completion of the purge procedure is 45% assuming the worst case condition of a completely full breathing bag at the start. Table 2 shows the oxygen percentages present after the three purge procedures. The breathing bag volumes at which these are measured would usually be considerably less than a full, 4 liters. Thus, if the oxygen percentages are above 45% after purging, one can be very confident that the minimum oxygen level obtained in the UBA will never be below 20%. Table 2 reveals that simply emptying the breathing bag and refilling it with oxygen (NFE purge procedure) resulted in an average of 55% oxygen. Occasional oxygen levels as low as 20% were obtained, however, making this procedure unacceptable. The SFE purge procedure resulted in an average of 74% oxygen with a minimum value of 50%. This procedure, therefore, is seen to have provided safe oxygen levels in the UBA for every one of the 54 experimental purges done in this manner. The Standard purge procedure resulted in the highest mean oxygen percentage (85%) and also provided safe oxygen levels in every case.

The next question to be addressed is how the breathing mix in the UBA changes during the course of the dive. First of all, an initial increase in the percentage of oxygen present in the UBA would be expected because the diver will have to add additional oxygen to his UBA as the depth increases. It has been assumed that nitrogen offgassing from the body tissues into the lungs and the breathing mixture during the course of the dive would increase the amount of inert gas present and require additional purges to prevent hypoxia. This was not observed in our dives as shown in Figures 3 and 4. The oxygen percentage at depth remained at 82% for the SFE purge dives and rose from 75% to 78% during the NFE purge dives. A significant increase in the percentage of nitrogen was probably not seen for 2 reasons: (1) the amount of nitrogen dissolved in the body at 1 atmosphere is only about 1 liter (1); (2) any gas lost from the diver's face mask during the dive acts as a de facto purge, resulting in the replacement of a volume of mixed N_2/O_2 with pure oxygen.

The minimal drop in the diver's oxygen percentage at the end of the dive after his oxygen supply was turned off provides evidence that (1) the diver's breathing bags contained a volume of gas not significantly larger than his tidal volume, and (2) the diver became aware of the breathing bag containing insufficient gas volume for a normal inspiration well before the bag volume was totally depleted. Therefore, the minimum acceptable oxygen level of 45% required to ensure that hypoxia will not result from a surface breathedown is also adequate for the submerged portion of the dive. There is no indication from this study that additional purging is required during a dive after the initial purge has been completed. Purging during the dive also has the undesirable effect of potentially giving away the diver's presence as a result of the escaping bubbles.

Several additional considerations must be considered in selecting an optimal purge procedure. Certainly a breathing mixture of 100% oxygen would be consistent with adequate oxygen supplies for the body's metabolic needs. Unfortunately, it is also consistent with maximizing the likelihood of a diver encountering CNS oxygen toxicity. In addition, the voluminous purging required to achieve very high levels of oxygen in the breathing mixture rapidly depletes the UBA's oxygen supply and thus potentially shortens its operating time. The SFE purge procedure has been demonstrated to provide adequate oxygen levels for Draeger LAR V dives, both on the surface and during the course of the dive, without any additional fill/empty cycles being done during the submerged portion of the dive. Additional fill/empty cycles in the initial purge or while submerged are not necessary. The Standard purge procedure, therefore, is considered less desirable than the SFE because: (1) the higher oxygen levels it provides are not required; (2) the risk of CNS oxygen toxicity is increased with higher oxygen levels; and (3) the UBA's gas supply is depleted more than necessary. For these reasons, the SFE purge procedure, without any additional fill/empty cycles during the dive, is felt to be the optimum method of purging the Draeger LAR V.

SUMMARY

(1) The NFE (No Fill/Empty Cycle) purge procedure was not found to reliably produce adequate oxygen levels in the Draeger LAR V UBA and should not be used operationally.

(2) The SFE (Single Fill/Empty Cycle) purge procedure did reliably produce oxygen levels adequate to prevent hypoxia.

(3) The Standard Purge Procedure (3 Fill/Empty Cycles) produced higher levels of oxygen than the SFE but is considered less desirable than the SFE procedure because:

a. these higher oxygen levels are not required to prevent hypoxia;

b. higher oxygen levels increase the probability of encountering CNS oxygen toxicity;

c. the extra fill/empty cycles consume additional oxygen, thus decreasing the gas supply in the UBA.

(4) Inert gas build-up was not observed to occur during the 2-hour dives, thus eliminating the need for additional purging during the conduct of the dive. It is recommended that these additional purges not be performed, for the reasons enumerated in paragraph (3) above and to minimize the possibility of the diver being detected because of escaping bubbles.

(5) The SFE purge procedure without any additional purging during the dive was found to be the optimum purge procedure for the Draeger LAR V.

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