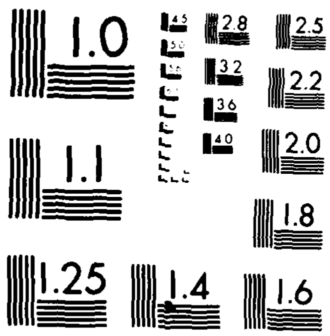
AD-A170 822 UNDERWATER PURGING PROCEDURES FOR THE DRAEGER LAR V UBA 1/1
(UNDERWATER BREATHING APPARATUS)(U) NAVY EXPERIMENTAL
DIVING UNIT PANAMA CITY FL F K BUTLER MAY 86 NEDU-6-86

UNCLASSIFIED F/G 6/11 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

(6)

AD-A170 822

NAVY EXPERIMENTAL DIVING UNIT
REPORT NO. 6-86

UNDERWATER PURGING PROCEDURES FOR THE DRAEGER LAR V UBA

By

LCDR F. K. BUTLER, Jr., MC, USN

NAVY EXPERIMENTAL DIVING UNIT

86 8 12 0[illegible]

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

(6)

IN REPLY REFER TO:

NAVY EXPERIMENTAL DIVING UNIT
REPORT NO. 6-86

UNDERWATER PURGING PROCEDURES FOR THE DRAEGER LAR V UBA

By

LCDR F. K. BUTLER, Jr., MC, USN

Submitted:	Reviewed:	Approved:
F. K. Butler, Jr.	J. L. Zumrick	J D M Hamilton
F. K. BUTLER, Jr.	J.L. ZUMRICK	J.D.M. HAMILTON
LCDR, MC, USN	CDR, MC, USN	CDR, USN
Medical Research Officer	Senior Medical Officer	Commanding Officer

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: NEDU REPORT NO. 6-86

2. GOVT ACCESSION NO.: ADA1708[illegible]2

3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): UNDERWATER PURGING PROCEDURES FOR THE DRAEGER LAR V UBA

5. TYPE OF REPORT & PERIOD COVERED: FINAL

6. PERFORMING ORG. REPORT NUMBER:

7. AUTHOR(s): LCDR F. K. BUTLER, Jr., MC,USN

8. CONTRACT OR GRANT NUMBER(s):

9. PERFORMING ORGANIZATION NAME AND ADDRESS: NAVY EXPERIMENTAL DIVING UNIT, PANAMA CITY, FL 32407-5001

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:

11. CONTROLLING OFFICE NAME AND ADDRESS:

12. REPORT DATE: MAY 1986

13. NUMBER OF PAGES: 20

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office):

15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

PURGE PROCEDURES
NEDU TEST PLAN #85/32
OXYGEN DIVING
DRAEGER LAR V
CLOSED-CIRCUIT UBAs

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The U.S. Navy has identified a need to switch to the Draeger LAR V closed-circuit oxygen Underwater Breathing Apparatus from open-circuit air while underwater. The revised purge procedure described in NEDU Report 5-84 and subsequently approved for Fleet use was tested only at 1 ATA. This study was carried out to develop a purge procedure suitable for use underwater. Three different purge procedures were tested. The incluence of diver possition in the water during the procedure and the type of open circuit air facemask/ regulator configuration used prior to switching to the LAR V were also

(CONTINUED)

20. (Continued)

examined. Conclusions from this study were as follows:

1. Purge Procedure C was found to provide oxygen fractions well above the minimum required when tested at 30 FSW. This procedure is recommended for purging the Draeger LAR V UBA at depths of 30 FSW and shallower.

2. Diver body position and type of open circuit air facemask/regulator configuration used prior to switching to the Draeger LAR V were not found to significantly affect the efficacy of the purge procedure. Purge Procedure C is, therefore, considered adequate for a diver in either an upright or prone position and for a full facemask as well as standard facemask/mouthpiece configuration.

3. The Draeger LAR V was noted to have an uncomfortable static pressure and exhalation resistance when breathed in the sitting position.

4. Subjecting the Draeger LAR V closed circuit UBA to pressure changes when not in use by a diver may result in rig damage unless it is protected from under or over pressurization.

ABSTRACT

The U.S. Navy has identified a need to switch to the Draeger LAR V closed-circuit oxygen Underwater Breathing Apparatus from open-circuit air while underwater. The revised purge procedure described in NEDU Report 5-84 and subsequently approved for Fleet use was tested only at 1 ATA. This study was carried out to develop a purge procedure suitable for use underwater. Three different purge procedures were tested. The influence of diver position in the water during the procedure and the type of open circuit air facemask/regulator configuration used prior to switching to the LAR V were also examined. Conclusions from this study were as follows:

1. Purge Procedure C was found to provide oxygen fractions well above the minimum required when tested at 30 FSW. This procedure is recommended for purging the Draeger LAR V UBA at depths of 30 FSW and shallower.

2. Diver body position and type of open circuit air facemask/regulator configuration used prior to switching to the Draeger LAR V were not found to significantly affect the efficacy of the purge procedure. Purge Procedure C is, therefore, considered adequate for a diver in either an upright or prone position and for a full facemask as well as standard facemask/mouthpiece configuration.

3. The Draeger LAR V was noted to have an uncomfortable static pressure and exhalation resistance when breathed in the sitting position.

4. Subjecting the Draeger LAR V closed circuit UBA to pressure changes when not in use by a diver may result in rig damage unless it is protected from under or over pressurization.

KEY WORDS:

PURGE PROCEDURES
OXYGEN DIVING
DRAEGER LAR V
CLOSED-CIRCUIT UBAs

INTRODUCTION

The U.S. Navy Special Warfare community currently uses the Draeger LAR V for closed-circuit oxygen diving operations. Prior to beginning a dive with a closed-circuit oxygen Underwater Breathing Apparatus (UBA), the diver is required to carry out a "purge" procedure to remove nitrogen from the breathing mixture. This procedure, if done correctly, eliminates the possibility of the diver becoming hypoxic as a result of breathing too high a percentage of nitrogen from the UBA. NEDU Report 5-84 described the experimental work done at NEDU to establish the most efficient purge procedure for the Draeger LAR V. As a result of these studies, the currently used purge procedure was recommended to NAVSEA and subsequently approved. This procedure is shown in Figure 1 and basically consists of emptying the breathing bag, refilling it with oxygen, emptying it again, and refilling the bag to a volume comfortable for swimming. No additional purging later in the dive is required. This procedure has been used successfully for over a year, but it has been tested and used only for purging the UBA at the surface. Under certain circumstances, it may be necessary to switch from air SCUBA to closed-circuit oxygen SCUBA while underwater or at pressures in excess of 1 ATA. The underwater environment introduces several additional factors such as increased volume of nitrogen to be purged and changes in the diver's breathing pattern which may require modifications to the purge procedure. The purpose of this study was to establish a safe and effective underwater purge procedure for the Draeger LAR V.

METHODS

Experimental Conditions

The first segment of the testing was carried out in the NEDU test pool, a rectangular tank with a depth of 15 feet. This portion of the study will be referred to as the Test Pool Phase. Dives conducted in this phase of testing were designed to evaluate the initial experimental purge procedure and to test the effect of diver position and type of open-circuit breathing apparatus on the efficacy of the purge procedure. Although this phase of testing produced a purge procedure which worked effectively at 15 feet, additional testing was required to ensure that the proposed procedure worked at the maximum desired depth of 30 FSW, since the increased depth would result in a greater standard volume of nitrogen to be purged from the breathing loop. The second phase of the purge study was therefore carried out in the NEDU Ocean Simulation Facility (OSF). This portion of the study will be referred to as the OSF Phase. Apparatus, instrumentation, and procedures will be discussed separately for the two phases of testing. Water temperature for both phases was maintained at 75-80°.

Dive Subjects

All experimental diver-subjects in this study were trained military divers. A total of 40 divers participated; 14 in the pool phase and 28 in the OSF phase (2 divers participated in both phases). All divers were trained in the use of the Draeger LAR V before the study began. All divers received an initial classroom brief on the purge procedure and had a chance to practice it at least once prior to doing it in the study.

FIGURE 1

DRAEGER LAR V
PRE-DIVE PURGE PROCEDURES

1. Don the apparatus by attaching the neck and waist straps. The upper surface of the UBA should be approximately at the level of the diver's lower chest.

NOTE

The waist strap should fit loosely to permit complete filling of the breathing bag.

2. Ensure that the oxygen supply valve is closed. Blow all air out of lungs and insert mouthpiece. Open the dive/surface valve. (The dive/surface valve is left open for the remainder of the procedure.)

3. Empty air out of the breathing bag by inhaling from the mouthpiece and exhaling into the atmosphere (through the nose). Continue until the bag is completely empty.

NOTE

Be sure <u>not</u> to exhale into the mouthpiece (breathing bag) during the emptying process in step 3 or 5.

4. Open the oxygen supply valve and fill the breathing bag by depressing the bypass valve completely for approximately 6 seconds or until the bag begins to press against your chest. (The oxygen supply valve is left open for the remainder of the procedure.)

5. Empty the breathing bag once more as in step 3.

6. Fill the breathing bag to a comfortable volume for swimming by depressing the bypass valve completely for approximately 4 seconds. Begin normal breathing.

7. The Draeger LAR V UBA is now ready for diving.

8. If the purge procedure is interrupted at any point, the procedure should be repeated starting with step 2. It should also be repeated any time the mouthpiece is removed and air is breathed.

NOTE

Additional purging during the dive is not necessary and <u>should not</u> be performed.

UBA Modification

The Draeger LAR V is a very simple closed-circuit oxygen UBA whose gas flow path is shown in Figure 2. The gas is exhaled by the diver and directed by one-way valves into the exhalation hose. From there it then enters the CO_2 absorbent canister where the carbon dioxide is removed. Upon leaving the canister the gas enters the breathing bag from which it travels via the inhalation hose to the diver's lungs when he inhales. The gas flow described above is powered entirely by the diver's breathing efforts. As the diver exhales, the gas in the UBA is pushed forward by the exhaled gas; upon inhalation, the one-way valves in the hoses cause gas to be pulled into the diver's lungs from the breathing bag.

The UBAs used in this study were modified slightly for experimental purposes. A penetration was made in the canister inlet coupling to which a one foot gas sample line was connected. A quick disconnect fitting was used on the free end of the sample line. A penetration was also made in the canister outlet coupling and a one foot sample line with similar fittings attached. The inlet fitting was used for flushing the UBA with a nitrogen-oxygen (N_2O_2) gas mixture between purges and the outlet fitting was used to obtain gas samples for analysis.

Diver Dress

Diver-Subjects taking part in this study were dressed as follows:

a. Wet suit top
b. SECUMAR Life Jacket
c. Face mask
d. Wet suit booties or tennis shoes
e. Weight belt
f. 3/8" neoprene wet suit gloves

The wet suit top and SECUMAR life jacket were worn to approximate the upper body dress of a combat swimmer on an operational dive; the 3/8" wet suit gloves were worn to ensure that the purge could be accomplished despite the decrease in manual dexterity resulting from their use.

Instrumentation and Procedures - Test Pool Phase

During the Test Pool Phase, the purges were carried out on the bottom of the NEDU test pool. Pool depth was 15 feet with the diver depth (midline of lungs) from one to three feet shallower, depending on the diver's position in the pool. Gas samples were obtained by connecting the canister outlet sample whip on the UBA to a 50 foot sample line which ran directly to a mass spectrometer (a Perkin Elmer MGA 1100, Perkin Elmer Aerospace Division, Pomona, CA) where the gas was analyzed for nitrogen, oxygen, and argon fractions. Gas flow was controlled by a ball valve located at the mass spectrometer. The time for gas to travel from the UBA to the mass spectrometer was measured and found to be approximately 40 seconds. This time

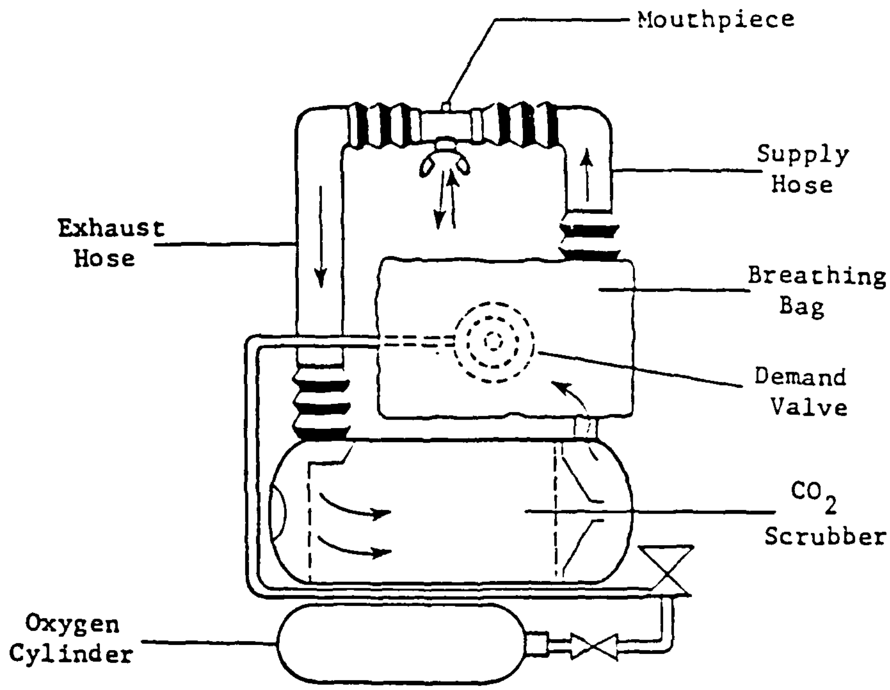


FIGURE 2. GAS FLOW PATH OF THE DRAEGER LAR V.

was determined by flushing the sample line with 100% N_2 and having a diver with a known percentage of oxygen in his UBA descend to the bottom of the pool.The ball valve was then opened and the elapsed time required for the mass spectrometer to stabilize at the new oxygen fraction measured. Time for gas equilibration in the diver's breathing loop (lungs and UBA) following an underwater purge was determined by having a diver perform an underwater purge procedure after starting the dive on open-circuit air. Following completion of the purge procedure, the ball valve was opened and the time to achieve a stable reading was noted. This time was found to be approximately 90 seconds, of which 40 seconds was delay time as noted before.

The UBAs were checked prior to each experimental run to ensure that the oxygen fraction prior to starting the purge procedure was less than 22%; this fraction, which approximates that of air, was felt to represent a worst case condition for the LAR V prior to the purge procedure. If the oxygen fraction exceeded 22%, as was the case in UBAs which had been previously purged, an 80/20 N_2O_2 mix was flushed through the UBA using the canister inlet fitting. The flushing process was continued until the oxygen fraction was below 22%.

The procedure for the pool phase of the testing was as follows:

(1) The Draeger LAR V UBA to be used was checked for an acceptable oxygen fraction and flushed with 80/20 N_2O_2 as necessary. The breathing bag was left partially inflated following this procedure.

(2) The diver-subject donned the UBA and received a dive supervisor check.

(3) When directed by the dive supervisor, the diver began breathing from open circuit SCUBA and entered the pool.

(4) The diver descended to the bottom of the pool and assumed either a sitting or a prone position as directed. He remained on the bottom breathing open circuit air for a period of two minutes. After two minutes, he was directed to carry out the prescribed purge procedure. Four different trials were conducted. Each trial used a different combination of open-circuit SCUBA equipment, diver position, and purge procedure. These combinations are in shown in Table 1. The two purge procedures (A and B) are shown in Figures 3 and 4.

(5) Upon signal from the diver that the purge was completed, the ball valve was opened and gas was allowed to flow for two minutes before the sample was recorded. All gas samples showed stable readings by the end of this two minute period.

(6) After the sample was complete, the ball valve was closed and the diver was signalled to return to the surface, completing that trial.

TABLE 1

Purge Procedure Conditions

Test Pool Phase

	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4
Beginning Oxygen Fraction	<22%	<22%	<22%	<22%
Initial Breathing Media	Air	Air	Air	Air
Face Mask/Regulator Configuration	Face Mask/T Bit Mouth-piece	Face Mask/T Bit Mouthpiece	U.S. Divers Full Face Mask	Face Mask With T Bit Mouth piece
Diver Position	Sitting	Prone	Sitting	Sitting
Purge Procedure	A	A	A	B

FIGURE 3

PURGE PROCEDURE A

1. Open the oxygen supply valve. (The oxygen supply valve is left open for the rest of the procedure).

2. Take a breath and hold it.

3. Remove the open-circuit SCUBA.

4. Don face mask if necessary.

5. Put the Draeger LAR V mouthpiece in your mouth. With the dive/surface valve still on surface, exhale briefly into the mouthpiece to clear water from the mouthpiece through the the vent hole. Put the dive/surface valve on "dive".

6. Exhale into the Draeger mouthpiece.

7. Empty the air out of the breathing bag by inhaling from the mouthpiece and exhaling through the nose. The face mask should be cleared during this process, if necessary. Continue until the oxygen demand valve begins to add gas to the bag.

8. Completely fill the breathing bag by depressing the bypass valve all the way for approximately 9 seconds or until it is tight against the chest.

9. Empty the breathing bag once more as in step 7.

10. Fill the breathing bag to a comfortable volume for diving by depressing the bypass valve all the way for approximately 6 seconds. Begin normal breathing.

*NOTE: Purge Procedure A was done underwater. No surface purge was used.

FIGURE 4

PURGE PROCEDURE B
Surface Phase

1. Don the apparatus by attaching the neck and waist straps. The upper surface of the UBA should be approximately at the level of the diver's lower chest.

2. Ensure that the oxygen supply valve is closed. Blow all air out of lungs and insert mouthpiece. Open the dive/surface valve. (The dive/surface valve is left open for the remainder of the procedure).

3. Empty air out of the breathing bag by inhaling from the mouthpiece and exhaling into the atmosphere (through the nose). Continue until the bag is completely empty.

4. Open the oxygen supply valve and fill the breathing bag completely by depressing the bypass valve all the way for approximately 6 seconds or until it begins to press against your chest. (The oxygen supply valve is left open for the remainder of the procedure).

5. Empty the breathing bag once more as in step 3.

6. Fill the breathing bag to approximately 1/2 full by depressing the bypass valve all the way for approximately 4 seconds. Place mouthpiece valve on "surface".

7. Close oxygen supply valve.

Underwater Phase

1. Open the oxygen supply valve. (The oxygen supply valve is left open for the rest of the procedure).

2. Take a breath and hold it.

3. Remove the open circuit SCUBA.

4. Put the Draeger LAR V mouthpiece in your mouth. With the dive/surface valve still on surface, exhale briefly into the mouthpiece to clear water from the mouthpiece through the vent hole. Put the dive/surface valve on "Dive".

5. Exhale into the Draeger mouthpiece.

6. Empty the air out of the breathing bag by inhaling from the mouthpiece and exhaling to the atmosphere (through the nose). Continue until the oxygen demand valve begins to add gas to the bag.

7. Fill the breathing bag to a comfortable volume for diving by depressing the bypass valve until the bag contains enough gas to take a full breath.

Instrumentation and Procedures - OSF Phase

In the OSF Phase of testing, the purge procedure was performed with the diver seated in the wet chamber of the OSF. The complex was pressurized to 29 FSW with the diver 1-2 FSW below the surface in a seated position. The UBA canister outlet sample whip was connected to a gas nylon sample line as before; in this case the sample line (approximately 100 ft in length) was routed through a chamber penetrator to a Perkin-Elmer MGA 1100 mass spectrometer. Sample line flush time from 30 FSW using a gas flow of 300 cc/min was determined to be approximately 30 seconds.

In this phase, the experimental procedure was as follows:

(1) Each UBA to be used was checked to ensure that oxygen fraction was less than 22% and flushed with 80/20 N_2O_2 if necessary.

(2) Five diver-subjects at a time were compressed in the dry chamber (Bravo) of the OSF. Each diver-subject had his own Draeger LAR V. All divers donned their rigs, received a dive supervisor check and brief, and performed the surface phase of purge procedure C (Figure 5) before being compressed to depth in the dry chamber. The dive supervisor brief included a review of the experimental purge procedure.

(3) When directed by the dive supervisor, the diver-subjects entered the wet chamber one at a time and took a sitting position. Divers were breathing compressed air from an umbilical with a second stage regulator. Standard face masks were used. The divers breathed compressed air for two minutes before starting the purge. When directed, the diver performed the underwater phase of Purge Procedure C.

(4) Upon completing the purge procedure, the diver breathed from the the UBA for one minute to allow gas equilibration between his lungs and the UBA. Following that, the flowmeter was opened to 300 cc/min and gas allowed to flow at this rate for two minutes. The oxygen, nitrogen, and argon fractions were recorded, and the flowmeter was then closed to prevent gas loss from the UBA during the work cycle as described below.

(5) The diver was then directed to mount a specially modified bicycle ergometer and perform 6 minutes of continuous work pedalling at a work rate of 50 watts[2]. This was done to ensure that the diver had consumed enough oxygen in his UBA breathing bag to cause it to reach a minimum level; at this point the UBA begins to add oxygen via the demand valve.

(6) At the completion of the work cycle, the flowmeter was again opened to 300 cc and a sample recorded after two minutes of gas flow. This concluded the experiment for that diver.

FIGURE 5

PURGE PROCEDURE C
Surface Phase

1. Don the apparatus by attaching the neck and waist straps. The upper surface of the UBA should be approximately at the level of the diver's lower chest.

2. Ensure that the oxygen supply valve is closed. Blow all air out of lungs and insert mouthpiece. Open the dive/surface valve. (The dive/surface valve is left open for the remainder of the procedure).

3. Empty air out of the breathing bag by inhaling from the mouthpiece and exhaling into the atmosphere (through the nose). Continue until the bag is completely empty.

4. Open the oxygen supply valve and fill the breathing bag completely by depressing the bypass valve all the way for approximately 6 seconds or until it begins to press against your chest. (The oxygen supply valve is left open for the remainder of the procedure).

5. Empty the breathing bag once more as in step 3.

6. Fill the breathing bag to approximately 1/2 full by depressing the bypass valve all the way for approximately 4 seconds. Place mouthpiece valve on "surface".

7. Close oxygen supply valve.

Underwater Phase

1. Open the oxygen supply valve. (The oxygen supply valve is left open for the rest of the procedure).

2. Take a breath and hold it.

3. Remove the open circuit SCUBA.

4. Put the Draeger LAR V mouthpiece in your mouth. With the dive/surface valve still on surface, exhale briefly into the mouthpiece to clear water from the mouthpiece through the vent hole. Put the dive/surface valve on "dive".

5. Exhale into the Draeger mouthpiece.

6. Empty the air out of the breathing bag by inhaling from the mouthpiece and exhaling to the atmosphere (through the nose). Continue until the oxygen demand valve begins to add gas to the bag.

7. Completely fill the breathing bag by depressing the bypass valve all the way for approximately 9 seconds or until it begins to press against the chest.

8. Empty the breathing bag once more as in step 6.

9. Fill the breathing bag to a comfortable volume for diving by depressing the bypass valve until the bag contains enough gas to take a full breath.

RESULTS

Table 2 shows the results of the Pool Phase testing. Although the prone position might theoretically decrease the efficacy of the purge procedure by preventing full expansion of the breathing bag during the procedure, little difference in mean O_2 percentage was noted between the sitting and prone positions. A significant difference was noted in the breathing performance of the rig, however. In the sitting position, the hydrostatic pressure differential resulting from the breathing bag on the LAR V being 12-18 inches below the diver's mouth caused marked exhalation resistance and an uncomfortable fullness in the upper airway at rest.

Use of a full face mask in lieu of the face mask/mouthpiece combination in Trial 3 required the divers to discard the full face mask, don a standard face mask, and clear the standard face mask during the purge procedure. Despite the increased complexity of this procedure, an oxygen percent of 75.5 was obtained, the highest of all trials conducted in the pool phase.

Trials 1-3 were conducted using Purge Procedure A, which had only an underwater phase; no surface purging was done. Trial 4 was conducted using Purge Procedure B, which combines a surface purge with an abbreviated underwater purge phase (the diver simply emptied his bag and refilled it to a comfortable volume for swimming without the intervening fill/empty cycle used previously and on the surface phase of this procedure.)

Although the results using this procedure were adequate (oxygen percentage of 70.2), it was felt that the difference between the surface phase and the underwater phase was a source of confusion to the divers. Therefore, when the OSF phase of the study was done, Purge Procedure B was modified such that the underwater phase of the procedure used the same Empty/Fill/Empty/Fill sequence as the surface phase. This resulted in Purge Procedure C, which was used during the OSF testing. When performed in the OSF at 30 FSW, Purge Procedure C resulted in a mean oxygen level of 84.3% prior to the work cycle and 85.0% following the work cycle as seen in Table 3.

DISCUSSION

A thorough understanding of the design and function of the Draeger LAR V is necessary prior to reviewing the results of this study. The diver inhales gas from a breathing bag. Oxygen is added to the breathing bag from the compressed gas cylinder <u>only</u> if the bag contains insufficient gas for the diver's tidal volume (inhalation volume). In this event, the efforts of the diver's respiratory muscles create a slightly negative pressure in the bag which opens the oxygen demand valve and allows gas to enter. If the gas

TABLE 2

Pool Phase Results

TRIAL	VARIABLES	NUMBER OF RUNS	MEAN 02%	STANDARD DEVIATION	MAXIMUM VALUE	MINIMUM VALUE
1	A)Sitting B)Face Mask w/T-Bit Mouthpiece C)Purge A	14	68.8	13.1	95.9	45.0
2	A)Prone B)Face Mask w/T-Bit Mouthpiece C)Purge A	12	70.2	6.5	80.7	56.0
3	A)Sitting B)Full Face Mask C)Purge A	10	75.5	7.2	85.3	62.2
4	A)Sitting B)Face Mask w/T-Bit Mouthpiece C)Purge B	13	70.2	5.9	84.4	62.9

TABLE 3

PURGE STUDY RESULTS
OSF PHASE

	MEAN	HIGH	LOW
Starting Oxygen % in UBA	20.2 ± 0.28%	---	---
Oxygen % in UBA After Purge	84.3 ± 8.5%	98.9	62.5
Oxygen % in UBA After Work Cycle	85.0 ± 7.2%	96.7	69.9

NOTE: Number of Divers = 29

Number of Runs = 38

volume in the bag is adequate to take a breath without emptying the bag, the demand valve will not be activated and no gas will be added. If a large amount of nitrogen is present in the rig, this gas may provide sufficient volume such that the breathing bag may not be collapsed even though the oxygen level has become dangerously low through metabolic consumption of the oxygen present in the system. Hypoxia and sudden unconsciousness, which are often fatal in the underwater environment, may result. Since there is no oxygen sensor or constant gas flow into the rig, the only protection against hypoxia is to ensure that the rig is purged of inert gas.

The purge procedure, therefore, is designed to eliminate most of the nitrogen in the diver's lungs and UBA. The minimum safe oxygen percentage following a surface purge procedure was calculated to be 45%[1]. This figure results in an oxygen partial pressure of 0.45 at one atmosphere, which is obviously greater than the 0.21 partial pressure experienced when breathing air at one atmosphere. As NEDU Report 5-84 describes, this seemingly high figure is required because of the possibility for bag "breathedown" following the purge. That is, when the purge is complete, the bag may contain more gas than the diver requires for a tidal volume. If the breathing loop (UBA and diver's lungs) were to contain a level of 21% oxygen and only enough gas for a tidal volume, the diver would be in no danger because oxygen would be replaced as it is consumed. Should his bag contain significantly more than a tidal volume, however, the nitrogen present in the system would prevent the bag from being emptied as oxygen is consumed. The process of reducing the bag volume through metabolic consumption of the oxygen it contains will be referred to as "breathedown". The oxygen fraction could fall to dangerously low levels as the volume of the breathing bag is being reduced to its minimum volume. This minimum volume will be referred to as the oxygen add volume (OAV)and its value is equal to the diver's respiratory tidal volume (the volume of gas inhaled with each breath). The 45% oxygen level was derived as shown in Tables 3 and 4 of reference one assuming an OAV of 1.0 liter, a minimum safe oxygen level of 20% in the bag at OAV, and a maximum bag volume of 4.0 liters before breathedown.

Another consideration is the changes in oxygen fraction brought about by pressure changes during the dive. For a diver breathing from his UBA, as he leaves the surface and descends to depth, extra volume must be added to the breathing loop. This gas must be sufficient to allow both the UBA and his lungs to compensate for the increased pressure. The gas added to provide this extra volume is pure oxygen; the nitrogen volume (in surface liters) remains the same. Therefore, the deeper the diver descends, the larger his oxygen fraction becomes.

Once at depth, the change in oxygen fraction depends on two opposing factors--offgassing of nitrogen from the tissues of the body into the breathing loop, which would tend to decrease the oxygen fraction, and loss of gas from the breathing loop, which would tend to increase the oxygen fraction. Little change was noted in the oxygen fraction during a two-hour dive in the previous study[1], even though gas loss from the rig was minimized, demonstrating that the amount of tissue off-gassing which occurs is relatively insignificant.

Upon ascent, one of two situations will occur--either the diver will make a relatively fast ascent and lose gas from his breathing loop or he may make a slow, staged ascent to prevent loss of bubbles from the rig as may be required in a tactical situation. The divers oxygen fraction therefore may stay essentially the same or decrease. Minimum decrease in oxygen fraction would occur with a diver who makes a rapid ascent, offgasses continuously during the ascents to get rid of the extra gas volume, and arrives at the surface with his bag volume at the OAV, so that no subsequent breathedown will occur before the demand regulator begins to add oxygen. Maximum decrease in oxygen fraction would occur during the slow, staged ascent when the amount of nitrogen in the loop remains the same as the amount of oxygen is steadily reduced through metabolic consumption. In a worst case situation, all of the nitrogen present in the loop at the start of ascent will still be present at the surface. This presents no problem for the diver who began breathing from the Draeger LAR V at the surface; assuming that his oxygen fraction was 45% or greater following the surface purge procedure, any subsequent depth increase would result only in additional oxygen being added to the UBA with no increase in the nitrogen volume.

For a diver who has purged at depth, the situation is slightly different. Arrival back at the surface is the point at which the risk of hypoxia is greatest because here the absolute pressure has been reduced to 1 ATA and the volume of the bag has been maximally increased by gas expansion with the attendant possibility of lowering the oxygen fraction in the UBA during breathedown before the bag again reaches its OAV.

The minimum oxygen fraction that must be present in the Draeger LAR V to prevent such breathedown hypoxia can be calculated. The bag volume at the surface will be assumed to be no more than 4.0 liters, since at this point the bag will be perceived as full and further increases in volume resulting from ascent will be off-gassed[1] by the diver. This represents essentially the same situation as presented in Tables 3 and 4 of NEDU Report 5-84. Therefore, 1.3 liters of the 6.5 liter volume of the breathing loop after breathedown must be oxygen to provide an oxygen fraction of 20% when the bag volume reaches OAV. The remaining 5.2 liters of nitrogen then constitutes a maximum safe nitrogen volume for the UBA. Since the total volume of the breathing loop in standard liters varies with depth, the minimum oxygen fraction for the UBA at any depth just prior to beginning ascent is then calculated as follows:

$$\text{Minimum Oxygen Fraction} = \frac{TV - 5.2\ L}{TV}$$

Where:

TV is the total volume in standard liters of the breathing loop (= 6.5 liters x pressure in ATA).

The pool phase of the purge testing was done to examine the effect of several different parameters on the efficacy of the purge procedure. Although theoretically a diver in the prone position might have a decreased breathing bag volume and therefore smaller purge volumes as a result of compression of the bag between his abdomen and the canister as he rests in the prone position, this did not result in a decreased oxygen fraction as seen in Table 2. The sitting position resulted in a slightly lower oxygen fraction than the prone position using the same purge procedure; this may be partly the result of a training effect since the sitting purge was done first. In any event, the oxygen fractions obtained were very close and there was no evidence to suggest that the position of the diver has a significant effect on the efficacy of the purge procedure. Similarly, although the difficulty entailed in switching from a full face mask to a standard face mask/T-bit mouthpiece underwater might be expected to affect the purge procedure adversely, this was not observed to be the case. This portion of the study resulted in our choosing the sitting position and a standard face mask with t-bit mouthpiece for the definitive OSF testing. Although the mean oxygen percentages obtained using Purge A were satisfactory, several individuals had oxygen levels much lower than this, as noted in Table 2. Additionally, on the single practice purge performed by the divers, one diver was found to have an oxygen fraction of 14% which was caused by his mistakenly exhaling back into the bag during the bag-emptying portion of the procedure. This resulted in the incorporation of a surface phase to the purge procedure. Trial 4 utilized Purge B, which had an Empty/Fill/Empty/Fill surface phase and an Empty/Fill underwater phase. This resulted in the same mean oxygen percentage as obtained in Trial 1 but the standard deviation was reduced from 13.1% to 5.9% and the minimum oxygen percentage obtained was 62.9%. Purge B, therefore, produced adequate oxygen percentages; however, it also produced some dissatisfaction among the experimental subjects who noted that the purge would be easier to remember if both the surface and the underwater phase contained the same Empty/Fill/Empty/Fill sequence. These changes were incorporated into Purge C which was subsequently used for the OSF study.

The OSF purges were performed at 30 FSW diver depth. Using the formula derived previously, a minimum safe oxygen percentage of 58% was calculated. The 6 minute work cycle was incorporated into the study to ensure that the divers had consumed any extra oxygen over the OAV in their breathing bags prior to measuring the oxygen fraction. This measurement of the oxygen fraction at the OAV (minimum volume of the breathing bag) obviated the need to compensate for breathedown as was required in the previous study. The mean oxygen fraction obtained was 85.0% with a low value of 69.9%. Both figures are well above the minimum safe level of 58% at 30 FSW.

Several additional points related to switching to and from the Draeger LAR V at depth must be mentioned. When the LAR V is not being used by the diver, pressure changes encountered during the dive may result in mechanical trauma to the UBA. For example, if the rig is stored with the bag empty and the oxygen supply valve off, as the depth increases, a relative negative pressure develops in the UBA canister. This may result in canister cracking or leaking with subsequent UBA floodout. On the other hand, if the oxygen supply valve is left on and the rig adds gas to compensate for a pressure increase (or if the diver discontinues breathing from the rig at depth), subsequent ascent will result in gas expansion in the UBA and may over-pressurize the breathing bag. Venting of the UBA is required to prevent breathing bag rupture in this situation. These considerations resulted in the partial filling of the breathing bag as described in Purge C prior to starting the dive. UBAs were vented on ascent to prevent rupture.

A final point should be made regarding the specificity of this purge procedure. Differences in UBA design and function might result in significantly different purge requirements from one UBA to the next. The purge procedure described here should not be considered adequate for any other closed circuit oxygen UBA without appropriate testing.

CONCLUSIONS

1. Purge Procedure C was found to provide oxygen fractions well above the minimum required when tested at 30 FSW. This procedure is recommended for purging the Draeger LAR V UBA at depths of 30 FSW and shallower.

2. Diver body position and type of open circuit air facemask/regulator configuration used prior to switching to the Draeger LAR V were not found to significantly affect the efficacy of the purge procedure. Purge Procedure C is, therefore, considered adequate for a diver in either an upright or prone position and for a full facemask as well as standard facemask/mouthpiece configuration.

3. The Draeger LAR V was noted to have an uncomfortable static pressure and exhalation resistance when breathed in the sitting position.

4. Subjecting the Draeger LAR V closed circuit UBA to pressure changes when not in use by a diver may result in rig damage unless it is protected from under or over pressurization.

REFERENCES

1. Butler FK, Thalmann ED: Purge Procedures For the Draeger LAR V Underwater Breathing Apparatus. NEDU Report 5-84; March 1984.

2. Thalmann ED, Sponholtz DK, Lundgren CEG: Chamber-Based System for Physiological Monitoring of Submerged Exercising Subjects. Undersea Biomedical Research 5(3):293-300; 1978.

END
DTIC
9 — 86