Closed-circuit oxygen diving in the U.S. Navy.

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The pioneers of modern closed-circuit oxygen attack swimming were the Italians. In the early days of World War Two, the Italian Navy found itself lacking the surface warfare power of other nations. In an effort to overcome this deficiency, they developed a cadre of intrepid naval commandos who attacked ships riding on torpedoes and using closed-circuit oxygen underwater breathing apparatuses (UBAs). The Italians had been evaluating these methods of underwater sabotage as early as 1918 (1). Operating against overwhelming odds, these commandos damaged 2 British battleships in Alexandria Harbor in 1941, the HMS Queen Elizabeth and HMS Valiant (2, 3). Later, operating from an Italian tanker, the Olterra, that had been scuttled in 1940 but was later floated and moored in Algeciras harbor, Italian frogmen attacked allied shipping in Gibraltar in 1942/43 and damaged a number of ships (1).

British frogmen had a measure of success in this area as well, sinking six Italian ships in Sicily in 1943 and the Japanese cruiser Takao in the Johore Straights (Clark Presswood – personal communication). The biggest British success was the operation against the Tirpitz on 22 Sept 1943 (1). The Tirpitz was one of the most powerful vessels in the German fleet. It was anchored at the innermost end of the 20-mile Alten Fjord in Norway – a harbor protected by nets, mines, and listening posts. Three British mini-subs launched an attack on the harbor– two of the submersibles successfully penetrated the defenses and launched torpedoes. The Tirpitz was not sunk, but was incapacitated for six months. The crews of the midgets were captured.

At the start of World War II, the United States Navy had no combat swimmer capability. Diving was performed using the deep-sea hard-hat rig in which the divers were confined to the immediate vicinity of the support vessel. Combat swimming for the purpose of clearing obstacles for an amphibious landing was not a recognized need. At this time, a medical student at the University of Pennsylvania named Chris Lambertsen was designing and building the United States' first closed-circuit oxygen SCUBA rig. Dr. Lambertsen was a first-year medical student in 1939 when he completed the initial prototype of his Lambertsen Amphibious Respiratory Unit (LARU) (4). He first dove in his LARU prototype in 1940 in Lake Nokomis, near Minneapolis, Minnesota (5) to test the functioning of his new UBA. These were the first closed-circuit oxygen SCUBA dives in U.S. history. About 12 dives were accomplished, including one on which Dr. Lambertsen suffered an oxygen toxicity episode consisting of extremity and diaphragmatic twitching. Although he was tended from the surface, the line was improperly rigged and was dropped by the tender. Dr. Lambertsen managed to return to the surface under his own power (Chris Lambertsen – personal communication). Dr. Lambertsen had a reasonably finished product by the end of 1940. He demonstrated the LARU to the U.S. Navy Experimental Diving

Unit (NEDU) in October of 1940 (Chris Lambertsen – personal communication), but there was little interest in this new type of diving apparatus.

Undaunted, in November of 1942, Dr. Lambertsen demonstrated the LARU MK II to individuals who were in the process of forming a maritime unit for the Office of Strategic Services. This classified demonstration took place in the swimming pool at the Shoreham Hotel in Washington DC. The LARU was a distinct improvement over the British and Italian UBAs used at the time in that it had a one-way, recirculating gas flow design that provided much more efficient carbon dioxide removal than the pendulum (or "counterlung") design used by the Italian and British UBAs. The Browne UBA was also evaluated, but the LARU was judged the best UBA for use by the Maritime Unit (5). Lambertsen's UBA was called simply the "Lambertsen Lung" by the OSS swimmers who used it during the war, (Tom Hawkins – personal communication) with the LARU MK III being the UBA used early in OSS operations and the MK 10 replacing it shortly thereafter. On 17 May 1943, Dr. Lambertsen conducted the first closed-circuit oxygen dive training in this country in the pool of the U.S. Naval Academy(5). The characteristics of the LARU used by these early OSS oxygen divers are shown in Table 1 (1).

Table 1.The LARU Closed-Circuit Oxygen UBA (1)

Closed-circuit rebreathing system
28 pounds
Full Face Mask
Oxygen cylinder - 2000 psi operating limit
Manual oxygen bypass
Over-the-shoulder breathing bag
Underwater gauge for oxygen bottle
Oxygen flow adjustable by needle valve

Fig. 1. The Lambertsen Amphibious Respiratory Unit LARU.

(Photo Courtesy CJLambertsen)

The LARU is shown in Figure 1. Dr. Lambertsen graduated from medical school in 1943 and was commissioned as a second lieutenant in the Army Medical Corps. Also in May of 1943, the Chief of Naval Operations ordered the establishment of Naval Combat Demolition Units (NCDUs) made up of men trained as assault demolitioneers to blow up obstacles placed on enemy beaches to prevent boats from coming ashore (6). The Marine landing on Tarawa, where the landing boats were grounded on an offshore reef, resulted in a heavy loss of life and demonstrated the need for combat demolition swimmers in amphibious warfare(6). LCDR Draper Kauffman, who was the Commanding Officer of the Navy Bomb Disposal School, was chosen to lead this new enterprise and he set up training for the NCDUs in Fort Pierce, Florida. LCDR Kauffman had originally been denied entry into the Navy because he failed the entrance eye exam. He then volunteered to serve in the war, first with the French Army ambulance service, where he won the Croix de Guerre, and then with the British bomb disposal units. Training at Fort Pierce started in June 1943. Lambertsen demonstrated the LARU to LCDR Kauffman in October 1943, but was again informed that there was no place in combat beach reconnaissance and demolition operations for this radically new device (5).

Closed-circuit oxygen diving and combat swimming evolution in the United States continued, then, under the auspices of the OSS with Dr. Lambertsen leading the way. One of the major factors that divers using 100% oxygen UBAs must contend with is central nervous system (CNS) oxygen toxicity. The French physiologist Paul Bert had demonstrated that breathing oxygen at increased pressure could lead to convulsions and death (7). Significant research had been done in this area by Dr. A.R. Behnke and his colleagues at NEDU as they explored the use of oxygen to accelerate decompression from long, deep dives and to treat decompression sickness. Following a series of chamber dives, Behnke and his colleagues published the first set of hyperbaric oxygen exposure guidelines in the U.S. military (2,8). (See Table 2.)

As we will see later on, had they been used as operational limits for OSS divers, the results might have been disastrous. Dr. Lambertsen displayed great insight in making the limits for OSS oxygen diving much more conservative than Behnke's chamber limits. Lambertsen's OSS oxygen exposure limits are shown in Table 3 (9). The increased conservatism in his tables at the deeper depths was not based on any personal observation that immersion and exercise increased the likelihood of oxygen toxicity, but from Lambertsen's realization that there would be a high probability of injury or death should a convulsion occur in a free-swimming diver (Chris Lambertsen – personal communication).

Table 2. Behnke Dry Chamber Oxygen Exposure Limits (2,8)

Sea Level	4 hours
33 FSW	3 hours
66 FSW	3 hours
99 FSW	45 min

Dr. Lambertsen also realized that more definitive limits needed to be established and requested additional guidance from the Navy Experimental Diving Unit after the war (Chris Lambertsen – personal communication). This was a prescient action, because the OSS limits are still far less conservative than modern limits. The assertions made in the History of the OSS Maritime Unit (1) would find few subscribers today, "Diving with the Lambertsen Unit is possible to depths as great as 100 feet. No diver should remain at that depth longer than 15 minutes at one time, however…. A more workable depth is from 50 to 60 feet at which the unit functions perfectly and permits submergence for 45 minutes without danger" (1).

Table 3. Lambertsen OSS Closed-Circuit Oxygen Exposure Limits (9)

Sea level	24 hours
40 FSW	2 hours
60 FSW	45 minutes
100 FSW	10 minutes

Despite these permissive deeper limits, the OSS had an excellent safety record using oxygen during World War II, with very few toxicity episodes and no fatalities (Chris Lambertsen – personal communication). This is probably due to Dr. Lambertsen's emphasis in training that the swimmers swim no deeper than required by the mission. Most of the diving was conducted between 20 and 25 feet. This chapter of U.S. closed-circuit oxygen diving history ended when the OSS was dissolved by President Truman on 1 October 1945 (10).

After the war, Dr. Lambertsen corresponded with CAPT O.K. O'Daniel to ask if NEDU had any guidance to provide on the subject of oxygen exposure limits for closed-circuit oxygen divers. CAPT O'Daniel responded on 30 September 1946 with the limits shown in Table 4 (11).

Table 4. 1946 NEDU Oxygen Exposure Limits (11)

Sea level	17 hours
30 FSW	2 hours
60 FSW	30 minutes

" The 60 FSW limit has been set by both the United States and British navies."

The pioneering work of Professor Ken Donald in the area of CNS oxygen toxicity in divers was done in the United Kingdom during World War II, but this work was not completed until the latter part of the war and was not published until after the war (12). Donald decided that the risk of CNS oxygen toxicity mandated a maximum depth of 25 feet for closed-circuit oxygen divers. He was also the first to describe the role of water temperature, immersion, and exercise in reducing a diver's tolerance to hyperbaric oxygen.

In 1946 and 1947, perhaps inspired by the work of Donald and the experiences of the OSS Maritime Unit, Yarborough and Behnke at NEDU undertook the first tests of oxygen tolerance using immersed, working divers done in the U.S. (3,13). They attempted 71 exposures to 2 hours at 40 feet. 19 of the 71 exposures were stopped because of toxicity episodes. The UBAs used for this study were the LARU and the Browne units and the water temperature was 90 degrees F. At 50 feet, 3 of the 5 divers developed signs or symptoms of CNS oxygen toxicity. At 30 feet, they found that there were no toxicity episodes in 35 one-hour exposures, but two divers had symptoms at 87 and 111 minutes(3,13). As a result of these investigations, the 1947 NEDU report stated that "For underwater work the safe inhalation of pure oxygen is limited to a depth of 30 feet." No time limit was imposed.

In an effort to preserve the diving capability developed in the OSS Maritime Unit, Dr. Lambertsen had arranged to have custody of an inventory of LARUs transferred to him so that he could introduce OSS diving techniques to other groups. During the post-war period, Dr. Lambertsen introduced his diving apparatus to U.S. Army Engineers, the U.S. Coast Guard, and U.S. Navy Underwater Demolition Team (UDT) personnel. In 1947, the UDTs, under the leadership of LCDR Doug Fane, saw the advantages of having their members trained in the use of SCUBA gear for combat operations. This decision may have been hastened by receipt of the now-famous letter that Fane received addressed to "Underground Demolition Unit Two." LCDR Fane proposed this training in 1947, but was informed by NEDU and the Navy Dive School that this type of diving gear was too dangerous(6). Undaunted, LCDR Fane invited Dr. Lambertsen to come to the Naval Amphibious Base in Little Creek, Virginia, in January 1948 to demonstrate the LARU to the UDT operators and conduct the first-ever training for Navy divers in SCUBA ("self-contained underwater breathing apparatus" - a term coined by Dr. Lambertsen)(4, 6,14).

Following this successful training, it was time to demonstrate for the Navy how closed-circuit oxygen diving might be employed by safely inserting combat swimmers using a submarine. On 22 February 1948, Fane and Lambertsen accomplished the first free-swimming, closed-circuit oxygen SCUBA lock-out and re-entry from an underway submarine (USS Grouper) operating off Saint Thomas, U.S. Virgin Islands. The sub was operating at periscope depth, so the lockout depth would have been approximately 30 feet. Although this would have been within the guidelines of the 1947 NEDU oxygen exposure limits, this was not a conscious factor in planning the dive, which lasted approximately 30 minutes (Chris Lambertsen – personal communication).

After the success of the USS Grouper closed-circuit oxygen SCUBA operations, Fane returned to the UDT base in Little Creek and established a "Submersible Operations" or SUBOPS platoon with men drawn from UDT 2 and 4(4). The activities of this group were extremely classified, even within their own organization. LTJG Bruce Dunning was the officer-in-charge of the SUBOPS platoon, which was the first unit with a SCUBA diving capability in the U.S. Navy.

Fane and Lambertsen next determined to do a study to better define the limits of safe oxygen exposures in free-swimming divers. They arranged a study at the Naval Submarine

Medical Research Laboratory escape training tower later that year. This study was conducted by Schaefer and Willmon and was the first time that fin-swimming, LARU oxygen divers were observed in a study under controlled conditions. The divers swam a circular path in the tower at a speed of 0.9 knots in 90-degree water temperature. They did fifty dives with a maximum exposure time of 90 minutes at various depths and had 14 toxicity episodes(4,6,15). This study also developed the Oxygen Tolerance Test, a 60 FSW for 30 minutes resting exposure in a dry chamber that was designed to test an individual's tolerance for hyperbaric oxygen. No specific new Navy-approved oxygen exposure limits were established after the trials, however, leaving the 1947 NEDU limit of 30 FSW for an unlimited time as the most authoritative Navy oxygen diving limit at this time.

In October of 1948, Lambertsen and Fane conducted the second operational demonstration of closed-circuit oxygen diving capabilities operating from the USS Quillback. The UDT divers were first trained to operate on the deck of the underway submarine. The dives were approximately 30 minutes in duration at a lockout depth of 30 FSW. Finally, the underway recovery of the British submersible canoe "Sleeping Beauty" aboard the Quillback was performed. Lambertsen positioned himself in the Sleeping Beauty ahead of the submarine on its course. He had a short bow line rigged from the bow to the cockpit of the Sleeping Beauty. After intercepting the submarine, which was towing a buoy, he threaded the Sleeping Beauty's bow line through a metal loop on the towed buoy and then drove the craft down the line with the submersible's power to the deck of the submarine. Losing only a stern plane to the sail of the sub, he maneuvered the Sleeping Beauty onto a cradle with the aid of the deck crew. The deck crew was out 30-40 minutes during the operation, at a depth of approximately 30 FSW. (Chris Lambertsen – personal communication) These operations demonstrated the feasibility of launching and recovering a free-flooding combatant submersible aboard an underway submarine and paved the way for modern-day SEAL Delivery Vehicle (SDV) and Dry Deck Shelter (DDS) operations. Figure 2 shows UDT members with their LARUs.

After the successful Quillback combat swimmer operations and training, Fane briefed VADM Jerraud Wright at Amphibious Forces, Atlantic Fleet. He was stunned to receive official correspondence directing UDT to confine itself to conventional hydrographic reconnaissance and beach clearance (4). Interpreting these orders somewhat creatively, Fane and Dunning continued to develop a submersible operations capability in the SUBOPS platoon. Perhaps appropriately, this training was headquartered in a building that had served recently as the base brig. The four UDTs on the East and West Coast used the LARU for submersible operations and training from 1948 into the early fifties. (Chris Lambertsen – personal communication)

Fig. 2. Underwater Demolition Team members with their LARUs. (Photo coutesy C.J. Lambertsen)

The next event in the evolution of SCUBA diving operations in the U.S. Navy was the introduction of the new French "aqualung" in (Jacques Cousteau and Emile Gagnan). The gas cylinders contained not oxygen, but compressed air. This apparatus was an open-circuit UBA, which meant that the diver's exhaled gas did not re-enter the UBA so that carbon dioxide could be removed and the unused oxygen rebreathed, but rather escaped to sea. The key bit of technology needed to make this breakthrough was Gagnan's redesign of a car regulator such that it could sense the ambient pressure the diver was exposed to and provide him with inhaled gas at a pressure that was slightly higher than ambient. Cousteau and others in the French Navy had made many dives with this new apparatus in the years that followed. Fane met with Gagnan and arranged for him to come to Little Creek in the spring of 1949 to teach the UDTs how to dive with the aqualung(4). The aqualung had some advantages over closed-circuit oxygen UBAs: it was less complex, easier to set up, had a greater depth range, and reduced the possibility of diving accidents. These advantages led many UDT divers to have a strong preference for the new UBA in spite of the tactical advantages of the LARU. In one of the least distinguished chapters of UDT diving history, many of the remaining OSS World War II LARUs were consigned to a bonfire at a team beach party in 1953(4,5,16).

The early fifties saw the UDT thus introduce open-circuit SCUBA into use in the U.S. Navy. Fane allegedly made the first dive by an American using the new UBA, diving to 100 feet on his first dive(6). The aqualung was subsequently used by Fane to demolish a wreck in the Chesapeake Bay that was posing a hazard to navigation in December 1949. It was used by UDT in 1950 in Sleeping Beauty and other submersible trials. In 1952, a research program headed by Dr. Lambertsen conducted open-water trials in the waters off of Coronado, California with the aqualung and the LARU to study physiological limiting factors in underwater swimming (4). This series of research dives was also notable in that it was the first use of the newly developed wet suits by the U.S. Navy.

Another factor that contributed to the unfortunate but temporary demise of closed-circuit oxygen diving in UDT was the July 1952 publication of the first closed-circuit oxygen diving limits in the U.S. Navy Diving Manual, which stated:

"When diving with a mask, oxygen should not be used at depths greater than 30 feet. The time of dive should not exceed 30 minutes" (17). The 30-minute time limit was very restrictive and effectively put attack swimmers out of business, since most combat operations would entail much longer swims than this. This extremely restrictive limit was short-lived, however. Further research done at NEDU by Lanphier and his colleagues resulted in this overly conservative limit being changed(3,18). Lanphier did 51 dives using 19 immersed, working divers at a variety of depths. The divers were breathing oxygen (averaging 99.5% purity) from an open-circuit source and the water temperature was 80 degrees F. The limits recommended by Lanphier in Table 8-2 of NEDU report 11-54 are shown in Table 5 (18).

Table 5. Third NEDU Closed-Circuit Oxygen Limits - Lanphier 1954 (18)

10 ft for 120 minutes
15 ft for 90 minutes
20 ft for 65 minutes
25 ft for 45 minutes
30 ft for 30 minutes
35 ft for 20 minutes
40 ft for 15 minutes

After several years, the UDTs began to reconsider their infatuation with open-circuit SCUBA. Closed-circuit SCUBA offered the advantages of being much smaller and lighter than open-circuit UBAs that would last for equivalent dive depths and times. Another important advantage was that there is no stream of tell-tale bubbles cascading to the surface as the diver approached a hostile ship or pier, a decided tactical plus. Since the LARUs were no longer serviceable, the UDTs acquired the World War II-vintage Italian Pirelli UBA in the years after the Korean War (Norm Olson – personal communication).

The foremost individual credited with bringing closed-circuit tactical diving back to the teams was LCDR Frank Kaine during the time that he was Commanding Officer of UDT 21 in Little Creek, Virginia but the West Coast UDTs also acquired and used the Pirelli (Layton Bassett – personal communication).

Fig. 3. UDT diver with Italian Pirelli closed-circuit oxygen rebreather. (Photo courtesy C.J. Lambertsen)

As shown in Figure 3, the Pirelli was a pendulum-type rebreather, in which a single hose was used both to inhale from and exhale to the CO_2 scrubber and the breathing bag. The characteristics of the Pirelli are listed in Table 6(19). Pendulum rebreathers have an inherent design flaw. The gas flows to and from the scrubber and the breathing bag via the same hose, creating a "dead space" in the loop that contributes to CO_2 buildup. While this may not be a problem for divers at rest, it quickly becomes a problem for free-swimming divers. The Pirelli was given the nickname "The Black Death" because of the numerous CO_2 and oxygen toxicity episodes suffered by team members while diving with this rig. (Layton Bassett – personal communication) After a near-fatal accident with the Pirelli in 1956, UDT operator Harold Nething recalled, "…after some investigation, it was discovered that in the breathing bag where the scrubber canister attached to the breathing hose, there's a fitting that's sweat soldered on….it had parted and failed. Later, after testing all the Pirellis, about 85% failed." (Harold Nething –Internet site)

Table 6. Description of the Italian Pirelli (19)
LS-901
Pendulum system
Two 1.6 liter bottles of oxygen
Each oxygen bottle charged to 3000 psi
Constant flow regulator adjustable from 0.5 to 2 L/M flow
Lasted for up to 4 hours under normal working conditions
CO_2 absorbent canister inside the breathing bag

These problems were reported to the Bureau of Ships(20). Further investigation by NEDU resulted in a recommendation that no more Pirellis be procured (21). Use of the Pirelli decreased in 1956 and 1957 and this UBA was soon replaced by the initial German Draeger. The Draeger UBA is shown in Figure 4 and its characteristics in Table 7 (19).

Table 7. Description of Draeger LT Lund II (19)
Draegerwork, Lubeck, Germany
Two oxygen cylinders – 0.8 liters each
Charged to 2800 psi
Total gas supply of 320 liters (11.2 cu ft)
Constant flow regulator set to provide 0.9 L/min O_2
Also had manual oxygen bypass
CO_2 absorbent canister was inside breathing bag
Operating limit 90 minutes

The Draeger LT Lund II UBA had an excellent reputation in the UDTs (N. Olsen, and L. Bassett personal communications). Weber stated that "Most of our divers prefer the Draeger to other rebreathers due to simplicity of design and reliability of operation" (19). The Draeger was used only for several years (approximately 1957-1958) due to lack of replacement parts and subsequent maintenance problems. Subsequently, Scott Aviation reverse engineered and built a U.S. version of the Draeger. While externally, it looked the same, it did not achieve the quality of the German version and was shelved shortly thereafter (N. Olson – personal communication).

Fig. 4. UDT diver with early German Draeger closed-circuit oxyen rebreather. (Photo courtesy T. Hawkins).

In the early 1950s, Dr. Lambertsen worked with the J.H. Emerson Company to develop the LARU MK 20 UBA. They introduced this updated UBA first to the Army. (Chris Lambertsen – personal communication) The LARU MK 20 was eventually modified and introduced into the Navy as the Emerson-Lambertsen UBA in about 1963(19). One major difference between this UBA, which came to be called simply the Emerson in the teams, and the LARU series was that the Emerson was typically used with a T-bit mouthpiece and a partial facemask that was isolated from the breathing loop. The LARU had been used with a full facemask by the OSS swimmers and the initial Army and Navy trainees. There are two primary advantages to using a full facemask with closed-circuit SCUBA: the airway is better protected in the event that the diver should become unconscious from oxygen toxicity or other diving disorder and the diver is better able to use underwater communication devices for operational or emergency communications. The Emerson-Lambertsen was also a recirculating system and had over-the-shoulder breathing bags, which have the advantage of being comfortable to breathe in both prone and sitting positions. One aspect of the rig that was not ideal was the 4-setting metered oxygen supply valve design. If the diver's oxygen consumption changed underwater, he might find himself with insufficient oxygen to breathe and would have to use the manual bypass valve. Conversely, if his oxygen consumption was lower than the add rate, his bags would overfill with oxygen and he would experience an undesired increase in buoyancy. (Don Crawford – personal communication) A description of the Emerson-Lambertsen UBA is provided in Table 8 (19) and a picture in Figure 5.

Fig. 5. The Emerson-Lambertsen UBA. (Photo courtesy U.S. Navy).

Table 8. The Emerson-Lambertsen Closed-Circuit Oxygen UBA (19)

Metered oxygen flow valve – 0.5, 0.9, 2.0, or 3.0 L/min
Cylinder charged to 2000 psi
Capacity 360 L (12.7 cu ft)
Normal duration of operation 120 min

The Emerson-Lambertsen served the teams well for almost 20 years, from 1963 until approximately 1981. By that time, replacement parts for the UBA had become very hard to obtain. Rigs were cannibalized for spare parts, maintenance was difficult, and increasing numbers of the rigs began to malfunction. By 1980, the problem had become severe and the Emerson was declared no longer usable by Naval

Special Warfare (Don Crawford – personal communication).

The demise of the Emerson meant that the UDT and now the SEA/Air/Land (SEAL) teams were in need of new closed-circuit oxygen UBA. NEDU evaluated both the German Draeger LAR III ("LAR" is an acronym for "Lung Automatic Regenerator") (22) and the LAR V (23) closed-circuit rebreathers as potential replacements for the Emerson-Lambertsen. The rig selected after NEDU testing was a modified version of the LAR V introduced into the Naval Special Warfare community in 1981, with the first 10 units going to SEAL Team Six (D. Crawford and R. Woolard – personal communications)

Fig. 6. SEAL diver with the Draeger LAR V/MK 25 closed-circuit oxygen rebreather. (Photo courtesy U.S. Navy).

The LAR V has several advantages over the Emerson-Lambertsen. At 25 pounds, it is significantly lighter. It is also smaller, simpler in design, and has (as did the LARU MK 20) a well-designed oxygen add system in which a second stage demand regulator opens any time that the diver empties all the air from his breathing bag. A description of the Draeger LAR V is provided in Table 9 (24) and a picture of this UBA is shown in Figure 6. This UBA is still the primary UBA used by Naval Special Warfare in 2002. Renamed the MK 25, it has been recently modified to include a larger oxygen bottle and a larger, better insulated CO_2 absorbent canister (MK 25 MOD 2) (24).

Table 9. The Draeger LAR V/MK 25 MOD 2 UBA (24)

Length:	18 inches
Width:	13 inches
Height:	7 inches
Weight:	27 pounds
Buoyancy:	Neutral
O2 Cylinder:	1.9 L at 3000 psig
Chest-mounted fiberglass housing	
Bypass add rate:	60 liters/min
Oxygen addition by demand	
No constant addition of oxygen	

Although the Teams got their new UBA from the Germans, they took many of their combat swimming tactics from the French via SEAL Team TWO. Combat swimming had become an area of decreased emphasis during the Vietnam War, where the SEALs and UDT became jungle warriors. Many SEALs, including then-CDR Bob Gormly at SEAL Team Two, recognized the need to re-establish the SEAL's expertise in the water. LT Ryan McCombie, recently returned from Vietnam, was sent to France for an exchange tour with the French Commando Hubert in St Mandrier. There he was exposed to a totally different diving culture. During this period, the Commando Hubert were arguably the best combat swimmers in the world. Their training typically entailed 5-7 dives per week. The dives were complex, multi-dogleg and long duration. During the 6 month French basic training, Lt McCombie with Lt. Jean Francois Tardiveau as a swim buddy, completed a 7000 meter, 4hour 10 minute closed-circuit oxygen dive. This particular dive was remarkable, even for the Commando Hubert, and demonstrated what could be accomplished with the proper training and equipment. Now-LCDR McCombie returned from France with a clear vision of how Naval Special Warfare could enhance its combat swimming skills.

He was to have an opportunity to act on this vision. Several years later, CDR Rick Woolard assumed command of SEAL TeamTwo2 and LCDR McCombie was his Executive

Officer. CDR Woolard had been embarrassed by a poor showing of SEAL attack swimming abilities during a "Flintlock" combat exercise with German and Dutch counterparts in 1981. He also had great respect for French oxygen diving capabilities. While Executive Officer of SEAL Team TWO, McCombie had arranged for a Hubert officer to be assigned there. LT Francois d'Avout reported to SEAL Team TWO shortly after Woolard assumed command in 1982, and Woolard immediately directed McCombie and d'Avout to develop and conduct a course in attack swimming to correct the SEAL operational deficiency. The resulting eight-week Combat Swimmer Course stressed accurate underwater navigation, precise buoyancy control, long-distance underwater and surface swimming ("turtlebacking"), and full-mission profiles that realistically integrated the attack swim into stealthy air/land/water target approach and withdrawal scenarios. The instructors and students were carefully selected, and all graduates had to show they could approach, attack, and withdraw from targets miles from their dive point without surfacing despite multiple underwater course changes. In 1983, Woolard's efforts were rewarded when his SEALs successfully completed a long and very arduous attack swim during a major exercise in Germany...and their German counterparts did not. From then on, Combat Swimmer Course graduates routinely outperformed their European counterparts, and by the late 1980s they were teaching attack swimming to others. The course was eventually accepted by the Naval Special Warfare community as a major improvement in SEAL capabilities, and its primary lessons are still part of both the Basic Underwater Demolition/SEAL and SEAL Qualification Training courses that every SEAL must complete." (R. McCombie and R. Woolard – personal communications) Figure 7 shows SEAL team members using the LAR V.

Fig. 7. SEALs with Draeger LAR V/MK25 closed-circuit oxygen rebreathers . (Photo courtesy U.S. Navy).

No experimental basis was identified for these changes. By 1981, the USN oxygen exposure limits had been modified further (Table 11).

Table 11. 1981 U.S. Navy Diving Manual Oxygen Exposure Limits (26)

20 ft for 110 minutes
25 ft for 75 minutes
30 ft for 45 minutes
35 ft for 25 minutes
40 ft for 10 minutes

The Navy oxygen exposure limits also evolved over time. New limits appeared in the 1959 Diving Manual (Table 10) that were modified from those proposed by Lanphier in 1954 (25).

Table 10. 1959 U.S. Navy Diving Manual Oxygen Exposure Limits (25)

10 ft for 240 minutes
15 ft for 150 minutes
20 ft for 110 minutes
25 ft for 75 minutes
30 ft for 45 minutes
35 ft for 25 minutes
40 ft for 10 minutes

Note that the 240-minute limit for dives 10 feet and shallower as well as the 150 minute limit for dives 15 feet and shallower had both been dropped. Again, the reasons for these changes from previous limits were not documented in the Diving Manual (26).

For the SEALs to utilize their new Draeger Vs and newfound combat swimming skills, the advance in oxygen diving required next was the establishment of less restrictive closed-circuit oxygen exposure limits. Increasing contact with combat swimmers in allied countries revealed that their oxygen exposure limits were less restrictive in those in the U.S. Navy. In 1981, Naval Special Warfare requested that NEDU re-evaluate the oxygen exposure limits to see if longer exposures might be safely accomplished. NSW also requested that NEDU evaluate the feasibility of making a brief downward excursion after a lengthy exposure at a shallow "transit" depth. This request resulted in 3 major dive series conducted by Butler and Thalmann at NEDU between 1982 and 1984 (27,28,29). Divers were immersed, exercising, and subjected to moderate cold stress in an attempt to create reasonable "worst-case" conditions for operational combat swimmers. Experimental divers used the same Draeger LAR V UBAs then in use by the SEAL teams. The UBA was purged to achieve a minimum oxygen fraction of 95% before the exposure was started and CO_2 levels were constantly monitored to ensure that there was no CO_2 build-up, which would make the divers more susceptible to oxygen toxicity. limit. The trials began by re-evaluating the 40-foot exposure. A 20-minute exposure at this depth produced 2 convulsions in 17 dives while a 15-minute exposure produced no convulsions or definite symptoms of CNS oxygen toxicity in 41 exposures (27). A 15-minute excursion was then attempted following a two- hour "transit" period at 25 feet. This profile produced 2 definite hits on the previously safe 40-foot excursion and one convulsion at 25 feet. After consultation with operational SEAL units, the transit depth was reduced to 20 feet and the testing resumed (28).

The second set of dive trials finished re-evaluating the single-depth oxygen exposure limits. The new single-depth oxygen exposure limits proposed after this series (28) and displayed in Table 12 were approved for use in Naval Special Warfare in 1983 and are still in effect in 2002 (30). The second set of dive trials also found that a 20-foot oxygen exposure for periods of up to 4 hours did not adversely affect the diver's ability to make a brief downward excursion (28). The current U.S. Navy Transit with Excursion limits are shown in Table 13; they were also approved for use in 1983 and are still in use in 2002 (30).

Table 12. Current USN Single Depth Oxygen Exposure Limits (30)

25 FSW or shallower	240 minutes
30 FSW	80 minutes
35 FSW	25 minutes
40 FSW	15 minutes
50 FSW	10 minutes

Table 13. Current USN Transit with Excursion Limits (30)

Transit portion of dive 20 FSW or shallower	
Single excursion allowed	
21-40 FSW	15 minutes
41-50 FSW	5 minutes
Total dive time 240 minutes or less	

A third NEDU oxygen dive series was conducted in November and December 1985 and was designed to evaluate the feasibility of making multiple downward excursions from 20 feet on a 4-hour dive(29). This series encountered an increased incidence of toxicity episodes in attempting multiple excursions on a single dive and no modification to the single-excursion rule was proposed(29). A total of 686 dives were accomplished during the three series with 67 episodes of in-water CNS oxygen toxicity, including 8 convulsions.

On the protocols above, a single toxicity episode was seen on the 25 and 30-foot depths within an exposure time that was completed by many other divers without incident. Both divers suffered multiple oxygen toxicity episodes during the dive series and were considered to be more sensitive to the effects of hyperbaric oxygen than their fellow experimental divers. Since both divers had passed the oxygen tolerance test (OTT) as part of their screening for diver training, the sensitivity of this test in identifying individuals who are unusually susceptible to oxygen and its usefulness as a screening tool was questioned. This issue was addressed by Butler and Knafelc following the NEDU oxygen dive trials(31). They identified three divers that had had multiple episodes of oxygen toxicity on profiles other divers had performed without difficulty. They then performed multiple OTTs on these individuals to see if the test was sensitive enough to identify any of the divers as sensitive on multiple exposures. None of the divers had symptoms on any of the OTTs, leading the investigators to conclude that the failure of the OTT to elicit symptoms of CNS oxygen toxicity in these divers was reproducible. The next question addressed was how many individuals fail the OTT (have signs or symptoms of CNS toxicity within the 30 minutes at 60 feet). A review of the records from the Naval Safety Center revealed a 1.9% failure rate among diving candidates undergoing the OTT. Since the individuals identified as sensitive to oxygen during the NEDU dive trials had repeatedly passed the OTT, the 1.9% of individuals who failed the OTT on the first trial were considered to be perhaps even more sensitive to oxygen. The authors therefore recommended that the OTT be retained for any divers who would be using closed-circuit oxygen SCUBA because of the high probability of a fatality resulting from a convulsion that occurred while engaged in untethered diving (31).

The issue of approving oxygen exposure limits that had been shown to produce CNS oxygen toxicity was contentious, especially in light of one convulsion that occurred at 25 feet after only 72 minutes, when many other divers were able to tolerate 4 hours at this depth without incident. Professor Donald commented some years later, “The present author would strongly oppose the acceptance of the possibility of acute oxygen poisoning in the oxygen exposure time limits recommended for routine diving operations. Such an acceptance could impair the traditional and essential trust between divers and those responsible for their safety” (3).

The safety of the new limits was greatly enhanced by a SEAL corpsman who inquired in 1983 about the rationale for the purge procedure used at the time. (Master Chief Johnny Johnson – personal communication) The Draeger LAR V purge procedure in use in 1983 was to manually fill the breathing bag with oxygen and then empty it by inhaling through the mouth and exhaling through the nose three times on the surface before the dive. The UBA was also purged every 30 minutes during the dive to protect against dilutional hypoxia occurring as the tissues of the body off-gassed nitrogen. A review of NEDU reports and the Navy Diving Manual revealed no explanation of why that particular volume of purging had been chosen nor any measurement of the oxygen fraction produced in the UBA by the procedure. (32) The procedure used by Lambertsen in the OSS and in the initial training of Navy UDT and Army cadres prior to diving the LARU was as follows: “….sucking the bag completely flat and closing the mask shut-off valve. O_2 could be added to the bag or not. Then, when ready to dive (could be an hour or more later), a full exhalation of air from lungs, and switch to O_2 rebreathing. No O_2 flushing of the unit was done. Any later gas venting supplemented this by accident and not intent.“ (Chris Lambertsen – personal communication) This procedure was used throughout World War II and apparently served well. The origins of the three-cycle fill and empty and the every-30 minute purge during the dive procedure that came into Navy use later remain obscure.

In rethinking the purge procedure at NEDU following Master Chief Johnson’s question, Butler and Thalmann determined that the purge should seek to achieve a level of oxygen in the UBA only high enough to prevent hypoxia. This level was determined to be 45% for a purge being done on the surface (32) and 55% for a purge being done at depth (33). A single fill/empty cycle of purging prior to the dive was found to be sufficient to ensure this level of oxygen in the UBA and to produce a mean value of 71% FIO_2 (fraction of inspired oxygen) on the surface. Purging nitrogen out of the rig beyond this level serves only to increase the risk of CNS oxygen toxicity and consume gas from the UBA cylinder, thereby shortening the gas supply available for the mission. The mean oxygen percentage in the UBA was found to increase to a mean of 82% as the diver descends to a depth of 20 FSW to begin his swim. Additional purging conducted during the dive was found to be unnecessary for hypoxia prevention, to consume additional gas, and to potentially compromise the diver's position if his bubbles are observed by hostile forces on the surface(32).

This seemingly modest decrease in FIO_2 may be of great importance to the safety of the diver. Using a probabilistic model, Harabin and her colleagues at NMRI showed that the risk of developing CNS oxygen toxicity from breathing "nearly pure" oxygen at 30 feet for 80 minutes is about 4 %. If the recommended new purge procedure is followed, however, resulting in a lower FIO_2 of 0.74, the probability of toxicity after 80 minutes is less than 0.1% (34). How safe have the 1983 oxygen exposure limits proven in practice? Walters et al addressed this issue in their 2000 paper(35). A review of the records from the Naval Safety Center found 157,930 LAR V dives with only one reported episode of oxygen toxicity.

Many SEAL operations, including ones that entail closed-circuit oxygen diving, are carried out in secret and never become public knowledge. One exception to this rule is the ship attack that was carried out during Operation Just Cause in Panama in 1989 (16).

CDR Norm Carley, Commanding Officer of SEAL Team Two, was directed to attack three Panamanian Defense Force (PDF) gunboats prior to the larger assault. The planners for Just Cause wanted to avoid major damage to the vessels so that they could be used by the new Panamanian government, but CDR Carley convinced them that this would entail unacceptable risks to the SEAL operators involved. The operation was complicated by several additional factors. The patrol boats were made of aluminum, so limpet mines would not stick to the hulls. The attack was instead carried out with haversacks of C-4 plastic explosives.

Cutting across the Panama Canal, the two SEAL combat rubber raiding crafts (CRRCs) ran into unanticipated boat traffic north of Balboa Harbor, including some boats with spotlights. The CRRCs, running at low speeds so not to leave a wake, avoided detection. Arriving at the far shore early, the CRRCs hid in a mangrove tree line north of Balboa Harbor while waiting to insert the SEALs. Two boats left Balboa Harbor, but the Presidente Porres remained at the pier. After 15 minutes, CRRC #1 started its motor and began creeping out of the mangrove. CRRC #2's outboard motor had quit, and it was thus unable to follow. Carley, aboard CRRC #1, decided to proceed to the insertion point alone. The CRRC advanced out of the mangrove, headed a few hundred yards in a southeasterly direction, and quietly approached a position 150 yards north of Balboa Harbor's Pier 18. With a backdrop of the darkened mangrove, the CRRC approached without being detected. A pair of SEALs, LT Edward Coughlin and EN3 Timothy Eppley, slipped over the CRRC's side at 2330, went underwater, and started toward their target. CRRC #1 withdrew, returned to the hideout, slipped a tow line to its disabled sister, and headed out of the mangrove. Together they proceeded to the insertion point off pier 18, where the second swimmer pair, ET1 Randy Beausoleil and PH2 Christopher Dye, quietly left CRRC #2. Swimming underwater, the second pair was five minutes behind the other two swimmers. To destroy the target, each swimmer pair was equipped with a 20-pound Mark 138 Haversack explosive package with a MCS-1 clock, a Mark 39 Safety and Arming Device, and a Mark 96 detonator.

After the SEALs were inserted, Carley ordered that CRRC #2 be towed back to NS-Rodman so that its outboard motor could be changed. Although the CRRC had a spare outboard motor on board, Carley felt that it was too risky to attempt an engine change out on the water, given the CRRCs' proximity to the target and the level of activity around Balboa Harbor. Besides, the starting process of the outboard motor was loud and sure to alert the PDF. Avoiding a compromise of the SEALs swimming to the target was uppermost in Carley's mind. On the return to NS-Rodman, the CRRCs evaded two more craft going across Balboa Harbor. The remainder of the assault force arrived at NS-Rodman and began changing CRRC #2's outboard motor. Carley observed the target area for indications that the PDF might be alerted. Balboa Harbor appeared quiet. The pairs of SEALs, swimming underwater on a compass bearing, approached pier 18. It became apparent to the swimmers that the marine effect of bioluminescence was playing havoc with their ability to read watches, depth gauges, and compasses. Underwater navigation was difficult. Surfacing under the pier, the swimmer pairs used it as overhead cover as they alternated between surface and underwater swimming to reach the inner part of Balboa Harbor. As the SEALs reached toward the shore end of the pier, they saw the PDF patrol boat was moored by its stern to a nearby floating dock adjacent to a quay wall and its bow pointed out into Balboa Harbor. The SEALs dove and approached the target underwater. Swim pair #2, ET1 Beausoleil and PH2 Dye, swam underneath the target at 0011, 20 December. It took them two minutes to attach the haversack of explosives to the port propeller shaft just forward of where the "V" strut held the shaft. They then began swimming south to pier 17. The other pair of SEALs, LT Coughlin and EN3 Eppley, arrived on target a minute later and attached a haversack to the starboard propeller shaft near the "V" strut. These SEALs finished the arming sequence of the demolition charges--the detonator cord leads between the two charges were tied to ensure dual priming--and set the charges to explode at 0100. The SEALs had 45 minutes to exfiltrate a safe distance from the target.

Just as Coughlin and Eppley swam away, the patrol boat's engines started. The propellers were not engaged and the boat remained stationary. Tonight, unlike previous nights, some PDF crew were aboard the patrol boat. The second pair of SEALs also swam underwater to pier 17. Following the contour of the pier for concealment, the SEALs swam away from the target. With the advancing of H-Hour, battles had started in Panama City with the attack on the Comandancia. Shortly afterwards, the SEALs were subjected to two intense underwater explosions. The SEALs, afraid they were compromised and under an anti-swimmer grenade attack from PDF soldiers patrolling pier 17, surfaced and hid behind pilings to escape injury. Continuing to move under the pier, the SEALs alternated between surface and underwater swimming to conserve oxygen in their Draeger systems. A couple of hundred yards further, four more underwater explosions forced the SEALs to surface again and take refuge behind the pilings. Although firing was heard overhead and tracers were seen arcing toward the Panama Canal, it did not appear to be directed at the SEALs.

Both pairs of SEALs were behind pilings under pier 17 when at precisely 0100 the charges underneath the Presidente Porres detonated. "The boat reared up forward . . . it went straight up--the bow went up," recalled LT Michael Argo, who observed the explosion through high powered binoculars from Naval Station Rodman. The explosion blew a hole ten feet wide through the hull and deck, destroying the stern of the boat. The engine room was a complete loss. The boat flooded and sank within two minutes. The floating dock next to the patrol boat, its steel floats punctured, swamped with water the next day.

Shortly after the explosion, most boats in Balboa Harbor started their engines and turned their propellers as an anti-swimmer attack measure. The SEALs were behind schedule to make the extraction point and rendezvous with the CRRCs to be taken back to NS-Rodman. The extraction point was located at the south end of pier six, a structure 500 yards south of Balboa Harbor, and a distance that the swimmer pairs could not arrive at by the previously planned time of a few minutes after H-Hour. Prior to H-Hour, the swimmers had tried to establish communications with TU-WHISKEY to say they were behind schedule. But the radios were malfunctioning. After the explosion, the SEALs pairs started moving again, heading to the end of pier 17, on a course toward the extraction point. Swimming a course to reach pier 6 took the SEALs near the main shipping channel of the Panama Channel. As the SEALs swam into the Panama Canal, a strong current of six knots running in the direction of the Pacific Ocean nearly swept them off course. Just then a deep-draft ship was making its way through the Panama Canal shipping channel. As Coughlin recalled, "You can't tell under the water exactly where a vessel is; you just hear it getting louder, and louder--it sounds like a freight train coming." With the ship approaching, the SEALs descended to 45 feet to avoid being drawn into the propellers. The increased toxicity of the pure oxygen in the Draeger system in deeper water was risky. Alternatives, however, were lacking. The SEALs remained at this depth for 10 to 15 minutes until the ship passed overhead. They then ascended to 20 feet, executed a turn, and swam on a bearing for pier 6. Reaching the pier separately, the swimmer pairs surfaced, used the pier as overhead cover to swim on the surface, and reached the extraction point at its southern end.

Meanwhile, as the swimmer pairs were making their way under pier 17, the CRRC crews replaced CRRC #2's outboard motor. The engine change took just a few minutes. At 0045, both CRRCs departed NS-Rodman and arrived at the extraction point ten minutes later. They hid under the pier, eight to nine feet above their heads, as firefights erupted in the vicinity between PDF and American forces. A few minutes later the harbor shook from the explosion under the patrol boat. The CRRCs waited but the swimmers did not appear at the designated time. CDR Carley sent CRRC #2 to search for the SEALs in case they had missed the extraction point. CRRC #2 returned reporting no sign of the SEALs. The CRRCs continued their vigil at the extraction point. An hour passed before the first SEAL pair, Coughlin and Eppley, arrived at 0200. The other pair, Beausoleil and Dye, made it to the extraction point five minutes later. The SEALs were recovered and the CRRCs headed back to NS-Rodman. As the assault force cleared the far shore and went across the Panama Canal to NS-Rodman, infrared strobes onboard the CRRCs were turned on to help U.S. forces recognize the CRRCs as a friendly unit. A message was transmitted to TF White stating that the SEALs had been recovered and Task Unit-WHISKEY had executed its mission without causalities. (Norm Carley – personal communication)

Butler and Knafelc suggested in their 1986 paper (31) that the reported incidence of OTT failures was suspicious based on a smaller than expected number of OTTs reported. Walters *et al* reviewed records from the primary chambers administering the OTT to Navy SEAL candidates and found that the incidence of failure of the OTT was only 0.096%, much lower than previously reported (35). The conclusions and recommendations of this paper were:

1) The failure rate for the OTT as it is currently administered in Naval Special Warfare is 0.096%. This number is approximately 5% of the previously reported incidence of 1.9%, which was based on data from the Naval Safety Center.
2) The logistic burden of administering the OTT had caused testing to be currently conducted after the SEAL students have completed the most rigorous 9 weeks of SEAL

training. Disqualification of a SEAL candidate at that point in training should be based on clear and compelling evidence that he is unfit to continue training. The OTT does not meet that standard.

3) Even if a more severe OTT were to be developed, intra-individual variability prevents any single screening test from being a reliable indicator of increased oxygen sensitivity.

4) Factors other than individual oxygen tolerance such as a high exercise rate, diver hypoventilation, canister failure, inadvertent depth excursions, inadequate thermal protection, or excessive purging of the UBA may contribute more to the risk of operational oxygen toxicity than individual sensitivity (36).

5) Naval Safety Center dive reporting procedures should be modified to document all suspected episodes of oxygen toxicity which occur on closed-circuit oxygen dives. This should include a reporting format that provides for the maximum capture of pertinent data to facilitate accurate and reliable determinations of the CNS oxygen toxicity incidence in operational diving.

6) In light of items 1 through 4 above, the authors recommend discontinuation of the OTT as a screening test for Navy Seal candidates. The OTT was discontinued as a screening test for NSW candidates in 1999 (37).

Another significant advance in oxygen diving in the Navy was the establishment of UBA and oxygen exposure limits for resting as opposed to swimming divers. This physiological situation applies primarily to SEALs who are piloting or riding in SDVs. These free-flooding submersibles, whose operating characteristics are classified, are capable of transporting SEALs over long distances underwater. Since these divers have a much lower rate of oxygen consumption and CO_2 production, their gas supply and canisters should both last longer and the risk of CNS oxygen toxicity should be lower. This realization in 1996 resulted in the Naval Special Warfare Command initiating tasking for NEDU to re-evaluate limits for both the Draeger LAR V and the SEAL operator at 20 feet in a mostly-resting scenario. Marino and Maurer tested 8-hour dives in 76-81 degree F. degree water and found that all canisters were still adequately removing CO_2 after 8 hours (38). Approximately 25% of the UBAs had to have oxygen bottles replaced before the end of this period. There were no episodes of CNS oxygen toxicity although a number of divers displayed early symptoms of pulmonary oxygen toxicity. New limits were subsequently established by NAVSEA for this UBA which remain classified, but are significantly longer than allowed by the previous limit (39). At shallow depths, pulmonary oxygen toxicity or UBA limits may be the limiting factor for exposures rather than CNS oxygen toxicity (38,39,40).

Current research in oxygen diving in the U.S. Navy has focused on the development of deep water Draeger LAR V lockout procedures for the Advanced SEAL Delivery System (ASDS). The ASDS is a new submersible that transports SEALs close to their intended target in a dry, one-atmosphere environment. At their lockout point, the SEALs exit the ASDS and begin a combat swim for their final approach. Operational units using this craft requested that a procedure be developed whereby missions requiring deep-water lockout could be accomplished using a Draeger LAR V rather than a bulkier and more complex closed-circuit mixed-gas UBA. A proposed procedure has been developed in which the divers breathe chamber air and vent the UBA rig to equalize pressure during compression. They then exit the lockout hatch breathing from the submersible's built-in hookah rigs until they reach the ascent line. Once ready to ascend, the divers swim toward the surface inhaling through the mouth and exhaling through the nose. This serves both to vent the expanding gas from the UBA and to provide the diver with compressed air to breathe during the ascent. The oxygen valve is closed until the diver reaches 15 feet and carries out an underwater purge. He then begins his swim with a purged UBA. This procedure was proposed by the Naval Special Warfare Command in 2001 (41) and has been successfully tested by NEDU in controlled conditions. (42) Additional testing of these techniques is ongoing at NEDU.

It is a noteworthy observation that Dr. Lambertsen was a member of the ASDS Medical Advisory Panel that developed the procedure described above, thus resulting in his contributions to closed-circuit oxygen diving spanning the entire history of the U.S. Navy experience in this area. Another important observation is that the Naval Special Warfare community was responsible not only for the introduction of closed-circuit SCUBA diving to the Navy, but for the first employment of open-circuit air SCUBA as well.

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