DIVER EDUCATION SERIES

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BUOYANCY AND THE SCUBA DIVER

Lee H. Somers, PhD

INTRODUCTION

It all began many years ago when man first ventured into the sea as a **diver.** He discovered that any object, such as himself, placed in a liquid, such as the sea, will either float or sink depending upon the density and the volume of the object relative to the density of the liquid. Long before the scuba diver discovered this relationship, the scholar Archimedes observes that "any object wholly or partially immersed in a liquid is buoyed up by a force equal to the weight of the liquid displaced by the object." The buoyant force of the fluid depends upon its density or weight per unit volume.

Pure water, with a density of 62.4 pounds per cubic foot (or, 1 gram per cubic centimeter), has slightly less buoyant force than an equal volume of sea water which has a density of 64 pounds per cubic foot (or, 1.025 grams per cubic centimeter). Thus, this slight difference in density accounts for the fact that the diver has to add more weight in order to submerge in the ocean as compared to a fresh water lake or pool. In fact, sea water increases the diver's buoyancy by approximately 1/30th the body weight over what it would be in fresh water.

If a diver floats, he is considered to be "positive" buoyant and if he sinks, he is "negative" buoyant. Since that first scuba dive, the diver has strived to be in a **state of hydrostatic balance** or "neutral" buoyant. This state is achieved when the weight of the diver and his equipment when totally submerged is exactly equal to the weight of the water displaced.

Throughout the history of scuba diving the diver has had to cope with variations in buoyancy. First of all, since the diving man is naturally a bit portly (Navy divers are brawny) he tends to float on the surface. This natural buoyancy is overcome by strapping a weighted belt around his waist. Nearly all early scuba diving textbooks discuss the selection of a proper amount of weight. In 1954 Cross [1] stated:

> To overcome this [buoyancy] it is necessary to add weights to the diver. As he submerges, water compresses the air in the suit reducing the buoyancy. A relatively safe method is to add a few pounds of weights, then submerge to twenty or thirty feet and check to determine if an excess positive buoyancy still

exists. More or less weights can be added as needed to obtain neutral buoyancy at the desired depth.

This was my first formal "diving manual." The next year David Owen published his exceptional diving manual "A Manual for Free-Divers Using Compressed Air" [2]. I've included his explanation of buoyancy control since this manual only exists on the book shelves of a few old timers:

> One pleasant characteristic of free diving is the weightlessness in water, which enables the swimmer to proceed in any direction with surprisingly little effort. The same neutral buoyancy allows various submarine acrobatics and maneuvers, to the beginner's delight.
>
> A standard 70 cubic foot Aqua-Lung tank charged to 1800 pounds per square inch and with the regulator attached - selected at random by the author - weighed 36 pounds in air and 2.1 pounds in water. The same tank, when effectively exhausted, had a positive buoyancy of about 4 ounces in sea water.
>
> In addition to the weight of the 70 cubic foot Aqua-Lung (2.1 pounds) the author requires another 3 pounds ballast for approximately neutral buoyancy in sea water while using swim trunks. In fresh water, however, the author is slightly heavy (negatively buoyant) with no ballast. A cold water exposure suit will require much more ballast, perhaps 15 pounds, for neutral buoyancy in sea water, because of the diver's changed displacement.
>
> It must be kept in mind that the individual buoyancy and ballast requirements will vary greatly, depending on the body build (or specific gravity) of the diver. Some people even tend to sink in salt water, without a suit, and with lungs full of air. Negatively buoyant swimmers, perhaps 3% of individuals, should be aware of their peculiarity.
>
> Ballast adjustment may depend on the type of activity planned. If much stationary or heavy work on the bottom is anticipated, the diver may prefer to be quite heavy. For most underwater activities, however, the free diver will prefer approximately neutral buoyancy and the following adjustment procedure is recommended:
>
> With the cylinder(s) about 50% exhausted and wearing full equipment, the diver should enter water about 9 feet deep. While upright in the water, with arms and legs motionless, the diver exhales as much as possible. If neutral, he will sink slowly to the bottom, only to begin rising at the same rate as a full

breath is taken. If this is not the case, he adds one pound at a time until this balance is achieved. Often, a beginner will find his buoyancy apparently "changing" after diving for a time. This will happen if he did not completely exhale or inhale, as described, during the buoyancy test.

Adjustment to neutral buoyancy enables a free diver to make small depth corrections simply by breathing control. Otherwise, much cylinder air is needlessly wasted through constant maneuvering to maintain a desired depth level. If the above procedure is used, the diver will find himself slightly heavy at the beginning of the dive with a full tank, and slightly positive when the tank is exhausted. This results in the most effortless dive.

Well, that is the way it was three decades ago for an earlier generation of diver. Take note of two considerations: (1) the very careful adjustment of ballast (to the pound), and (2) breath control. Today, after thirty years of scuba diving evolution and equipping the diver with nearly $400 worth of power-inflated buoyancy control equipment, one of the pleasant characteristics of free diving is the weightlessness in water which enables the swimmer to proceed in any direction with surprisingly little effort.

To quote a line from a TV commercial, "You've come a long way, Baby!" So true! Scuba diving has come a long way in these 30 years. Easy breathing single-hose regulators, pressure gauges, "octopus" regulators, decompression microprocessors, thin fabric dry suits, and buoyancy compensators (BC) are all common items for the scuba diver of the 80's. It's great to be a scuba diver today!

For nostalgia let's turn back the pages of time and think about that pre-BC scuba diver. There were some great divers 30 years ago. Names like Cross, Owen, Stewart, Tillman, Morgan, Limbaugh, Fane, Bonin, Pedersen, Erickson, and Brown, to name only a few, bring memories of good days and good diving to many readers (and I do apologize for the many equally great divers that I did not mention). Do you realize that all of these diver's survived and enjoyed scuba diving without the buoyancy compensator? Amazing! Let's go back to the beginning of modern scuba diving during WW II (that's the big one) on the Mediterranean coast in the south of France. Cousteau, Dumas, Tailliez and their colleagues slipped silently beneath the surface of the sea with this breathing device called the aqualung -- and modern "manfish" was born. Enough historical daydreaming! Just keep in mind that they also did it without a BC.

Have you ever seen a Frenchman dive? Have you ever seen a Cousteau dive? Sure you have. Each year 1000s of feet of Cousteau film are shown on TV and in theaters throughout the world. How many BCs have you seen on the Cousteau team? Not many! I once had the rare honor of diving with Phillipe Cousteau. I watched Phillipe prepare for the dive. He donned borrowed equipment and slipped into the water to adjust his ballast. And, believe it or not, he came up and asked for a one pound lead weight. For a few great moments in my life as a diver I was privileged to observe the most graceful and skillful movements underwater that I had ever seen. And it was all accomplished without the use of a BC - just ballast adjustment and breathing control. Some years later I was to observe a similar diving technique at a NAUI instructor course when I swam with a young diver named Craig Barshinger. He had learned to dive "the French way"!

If all of these early divers did so well without BC's, why does every diver use a BC today? How and why did the BC evolve? To be perfectly honest, I do not know all of the hows and whys or the whos. To me there appear to be two evolutionary paths. Many divers wanted some sort of emergency personal flotation device that could be carried on their person. Cross [1] describes the **Res-Q-Pak** as follows:

> The Res-Q-Pak is a small, inflatable, water wing type float, folded into a plastic packet measuring about 1 x 2 x 3 inches. By squeezing, a CO_2 cartridge is punctured inflating the unit. It can be clipped to the swimmer's trunks or tied to a belt if he is wearing a suit. When inflated, it will support a 200 lb. man. However, when used in an emergency, all weights, such as weight belt, should be released to obtain maximum safety.

Several similar "emergency floats" were marketed in the early years.

In the 1950's the U. S. Navy underwater swimmers were using a "life preserver." In an old copy of a booklet titled "Underwater Swimmers School Class Notes" the following is stated [3]:

> The **UDT Yoke Type Life Preserver** is most efficient in that it is lightweight, reasonably small, and may be quickly inflated either by a single non-magnetic CO_2 cylinder or orally. This preserver is worn on all water operations for safety precautions. A small light may be attached for night operations. This is one item that will deteriorate rapidly unless cared for. Another section of this book contains full maintenance and repair of the life preserver. **KNOW IT AND ABIDE BY IT.**

This booklet and subsequent UDT and UDT/SEAL handbooks made similar reference to the **yoke-type life presever** and contained fairly detailed instructions on how to patch the unit and maintain the CO_2 cylinder inflator [4,5]. The U. S. Navy Diving Manuals of 1963 and 1970 [6,7] designated the yoke-type inflatable life jacket as **mandatory** for underwater swimmers and scuba divers. It is interesting to note that no reference is made to buoyancy compensation in any of these early manuals. The unit was apparently designated for safety and emergency flotation.

The influence of the U. S. Navy's diving program is obvious in the earlier years of recreational scuba diving and instruction. In the 1960's most scuba diving instructors had a copy of the U. S. Navy Diving Manual in their personal libraries. Today, I doubt if that is the case. As you will see later, the U. S. Navy's opinions are often inconsistent with modern trends in recreational scuba diving equipment and procedures.

When and why did the trend toward modern "buoyancy compensation" begin. Buoyancy compensation of one form or another has always been a part of scuba diving. Some early divers blew air into their dry suits by placing the mask skirt under the hood. This compensated, to some degree, for suit and hood squeeze; it also compensated for loss of buoyancy as air was squeezed from the suit during descent.

The modern wet suit diver is truly a free diver. He does not want to be concerned with descent-ascent lines, adjusting weights for various dive depths, or the "limitations" that might be imposed on multi-level diving by a "fixed" buoyancy adjustment. In some respects this modern breed of scuba diver might be considered too lazy to deal with weight belt adjustments on a "per dive" basis. On the other hand, he may be considered a more "intelligent" diver who takes advantage of modern technology.

There is also concern among some instructors and "old timers" that many individuals with "poor" watermanship are training as scuba divers. In such cases, the BC may become a substitute for swimming ability and physical fitness.

The advent of foamed-neoprene wet suit diving played a major role in the evolution of buoyancy compensation. Compression of a 1/4-inch foamed-neoprene wet suit results in the loss of about 5 pounds of buoyancy between the surface and 30 feet; 9 pounds loss at 120 feet.

Air consumption also plays a role in buoyancy variation. Eighty cubic feet of air weighs about 6 pounds. This means that the diver will be between 5 and 6 pounds heavier at the beginning of the dive than at the end. And since many divers plan to dive to their greatest depth at the beginning of the dive and spend time "in shallow water" at the end of the dive, the implications are obvious.

If we combine the compression of the wet suit and the weight of a full cylinder of air, the diver will be about 8 to 9 pounds "heavier" at the beginning of his 120 foot dive than he will be at the end of the dive when he is "playing around" at 30 feet.

If he plans to "decompress" at 10 feet, then he will be about 3 pounds more buoyant than at 30 feet. In the final analysis, the diver experiences a 14 to 15 pound buoyancy variation over the course of the dive.

Buoyancy, ballast adjustment, and buoyancy compensation values depend upon a number of variables. First of all, each diver is an individual. The buoyancy of that individual will depend primarily on size (displacement), weight, body composition, tidal volume, vital capacity, psychological condition (relaxation vs. anxiety), and respiratory minute volume (or RMV; minimal exertion vs. exercise). A larger person generally will be able to compensate for a greater degree of buoyancy compensation through adjustment of the breathing pattern than a smaller individual.

The diver's equipment will also make a difference. The diver wearing a full 1/4-inch foamed-neoprene wet suit will no doubt have to make some artificial or equipment assisted (in otherwords, put some air in the BC at some point in the dive) buoyancy adjustment. Whereas, the diver wearing a 1/8-inch wet suit may be able to compensate for all buoyancy variations through breathing adjustments alone. Keep in mind that air in the BC also compresses during descent and that you also have to compensate for this compression factor. It is desirable to be able to start the dive with no air in the BC.

Another thing that divers tend to forget is that buoyancy changes when equipment changes. The buoyancy characteristics of a steel 70 cylinder are different than those of an aluminum 80. A large knife is heavier than a small knife. Add a 1/8-inch vest or take off your gloves and there is a slight change. Some wet suits lose a slight bit of their buoyancy with age. Remember, good divers adjust the ballast "to the pound!"

Experience is a great "changer of buoyancy." I have seen divers remove as much as 8 pounds of weight from their weight belt over a year or so of diving. They simply become more relaxed, their breathing pattern evens out (reduced tidal volume and RMV), and they gain skill in handling themselves in the water.

HISTORICAL NOTES ON BUOYANCY COMPENSATION

How did the early scuba diver survive without the advantages of the modern buoyancy compenstor (BC)? First of all, these scuba divers simply adjusted their weight belts for the dive depth, equipment worn, and diving conditions. A diver might plan to begin a dive "slightly heavy," compensate for the negative buoyancy by taking slightly deeper breaths on each breathing cycle, and end the dive "slightly light." It worked! For deep dives, especially where suit compression became more of a factor, the diver would begin the dive "slighty light," descend to a depth where he would be approximately neutral about half way through the dive, and ascend in a "positive buoyant" state. One key to making this system work comfortably was the use of a shot line (or weighted descent-ascent line). At the beginning of the dive the diver would "pull" himself down the line and breath relatively shallowly until the suit compressed. At the end of the dive he would control his ascent by holding on to the weighted line. If he planned to decompress, he simply wrapped his leg around the line to maintain position.

Some divers made up special weights with snap hooks. The weight was "snapped" to a ring on the diver's weight belt to assist during descent. The descent line was also fitted with rings or loops at various depths. As the diver descended and his suit compressed, he simply snapped the "extra weight" on to the descent line. The weight would be retrieved on the way back to the surface in order to maintain a comfortable, controlled ascent and facilitate decompression. I remember scores of very pleasant deeper "sink hole" dives using this technique.

As divers went deeper, carried more equipment, and developed less appreciation for the descent-ascent line, they began to experiment with self-contained buoyancy control systems. My first BC was a plastic Clorox bottle attached to a D-ring on scuba harness. Air was placed into the bottle from the regulator exhaust. Some divers carried the bottles in their hands. By proper positioning of the bottle, a good swimming position could be achieved with minimum effort. Ascent could be controlled by dumping small amounts of the expanding air from the bottle throughout ascent. The bottle did increase drag and, if hand-carried, required the continuous use of one of the diver's hands.

Somewhere around 1960 the "fixed-volume, open end" BC appeared. Both single and double chamber models were used. This unit consisted of a small metal or plastic cylinder closed at the top and open at the bottom; at least one model had the bottom of the unit "partially" closed with only a small opening on the bottom side. When the diver entered the water, he would invert and fill the cylinder(s) with water. When buoyancy compensation was necessary, air was injected into the top of the chamber via a hose from the first stage in order to displace the water in the cylinder. During ascent the air in the cylinder would expand and the diver would periodically invert to discharge some or all of the air; controlled "dumping" of air by inversion was not an easy task. Some divers fitted a second "discharge" hose and valve to the top of the cylinder thus enabling them to easily control the amount of air in the cylinder during ascent. The cylinder(s) retained air as long as the diver was swimming in a position with the head slightly higher than the feet (some considered a 30° position to be acceptable); however, if the diver changed to a slightly head down position, the air would "dump" and the diver would lose his buoyancy control.

Recreational divers began experimenting with using inflatable life preservers as BCs in the 1950s. Earlier units were acquired through military surplus (Mae West lifejackets) or "borrowed(?)" from commercial airlines. The size and position of the oral inflation hose made the units slightly awkward to inflate underwater and required some interesting maneuvers to deflate. The "UDT vest" was available to the recreational diving community on a limited basis, but it did not achieve high popularity. I remember purchasing the UDTs for less than $25, and I still consider it to be one of the most comfortable units that I ever used, though I seldom used it as a BC. It was simply there in the event that I got into trouble on the surface or had to assist another diver on the surface.

Probably the first true BC to be introduced to the American market was the Fenzy which was imported from France somewhere around 1968. This was one of three "air bottle" BCs marketed in the United States. Instead of the more traditional CO_2 cylinder, this BC was equipped with a small compressed air cylinder that could be refilled from a diver's scuba cylinder. The air was used for buoyancy compensation as well as surface inflation. This was one of the most rugged and well-constructed units to ever appear on the American market; however, it was expensive (by 1968 standards) and never achieved wide popularity. The "air bottle" BC is still used in the United Kingdom and throughout Europe. The British used this type of BC for an emergency breathing/ascent apparatus.

By the early 1970's every major manufacturer was selling at least one, if not several, BCs. Twenty to 30 models were available. Buoyancy compensator design begins to evolve in two different directions. The more conventional collar-type (front-mounted) BC that fit around the diver's neck had undergone numerous refinements. Large inflation-deflation hoses had been added and positioned near the top of the BC so that the diver could easily discharge air from the BC. Air hoses had been attached to the regulator first-stage and inflation valves to the BC thus enabling the diver to add air (adjust buoyancy) with the simple push of a button. Air could be discharged similarly. New "buzz words" such as life capacity, filling rate, and exhaust rate fueled the competitive scene.

In about 1970 the At-Pac appeared on the scene. This unit consisted of a horseshoe-shaped bag fitted to a scuba backpack. The backpack was hollow and could be filled with lead pellets for ballast (to replace the weight belt). A quick-release "door" on the bottom of the back pack enabled the diver to jettison his ballast in an emergency. This was a significant departure from the conventional BC design and developed as a second evolutionary path. In fact, the entire diving community started dividing into two "camps," the At-Pacers and "otherwise." A segment of the recreational diving community accepted and **aggressively** promoted the "At-Pac" training and diving philosophy. At least seven diving equipment companies marketed the "back-mounted" or "buoyancy compensating pack" (BCP), generic names for this design, by the mid-70s.

In the search for the "ideal" buoyancy compensator several excellent designs were developed but, for one reason or another, never gained popularity in the diving community. In my opinion, Rory Dickens, a Florida cave diver, published the best paper ever written on buoyancy control "theory" in 1973 [8]. Based on an analysis of such factors as the diver's center of buoyancy, center of gravity, longitudinal axis, lateral axis, stability, and so on, he suggested that the "ideal" BC would be a "bag mounted on straps so that it could be moved back and forth during the dive." This bag would be positioned on the diver's front (chest-stomach area).

At least one major manufacturer did market this type of BC, and several smaller firms made them on a custom basis. One major manufacturer took this concept one step further and designed/marketed a "dual bladder" front-mounted combination BC and "lifejacket." This unit "tested well" in an evaluation of BCs conducted by the U. S. Navy [9]. The lower bladder, located over the diver's stomach, provided "precise and comfortable" buoyancy control. And, by inflating the upper bladder which encircled the diver's neck, the diver's head was held out of the water in an emergency. This design concept was "lost" a few years later and this excellent BC never achieved popularity.

Another innovative BC design, and probably the most radical departure from conventional design, was the back-mounted constant-volume automatic buoyancy control system which also appeared in the late 1970s. A rigid buoyancy chamber, instead of the conventional flexible bag, was integral with the backpack and also contained the diver's weights. The system operated on a principle similar to that of a submarine ballast system. The chamber was fitted with valving to discharge air and admit water. Air also fed directly from the scuba cylinder.

To dive, you first opened the valves at the surface to allow air to escape and water to enter until you started to sink. At about 30 feet, the point at which the major effect of suit compression had been experienced, the diver adjusted buoyancy by admitting air into the chamber from the scuba. The volume of air in the rigid container was fixed. A demand system injected more air into the system as the diver descended and vented air as the diver ascended. Total buoyancy capacity was about 60 pounds.

The system also allowed the diver to preset the rate of ascent, and ascent was then automatically controlled by discharging expanding air through an overpressure relief valve. In the event of buoyancy loss, the weights could be manually released.

The system was relatively complex to use properly and much more bulky than conventional units. The unit never received a high level of diver or instructor acceptance, and its manufacture was discontinued several years after it was introduced.

Throughout the 1970s the divers, instructors, and manufacturers debated the merits (and demerits) of different BCs. Lift capacity seemed to be important to some debater-divers and ranged from 15 to 57 pounds. One scholar suggested that 18 to 20 pounds of lift would be adequate to hold a diver's head out of the water. A noted national training director felt that it should be at least twice that figure and another expert gave a range of 25 to 50 pounds. Lift capacity is still with us today. At least one BC currently available has a "rated buoyancy lift" of 80 pounds.

Other divers seemed more concerned about how fast they could inflate and deflate their BC; full inflation times ranged from "about" 3 to 15 seconds while deflation times ranged from 3 to 22 seconds. Both lift capacity and fill rate were important factors in the use of the BC for "emergency flotation" on the surface as well as "emergency" buoyant ascents. I remember watching in amazement as divers trained in "emergency buoyant ascent procedures" at Salisbury Quarry. A diver would depress the power inflation button at a depth of about 40 feet and shoot to the surface. Some divers cleared the water surface to their weight belts. I was operating a hyperbaric chamber facility at that time, and one of our few "less than successful" treatments was a young man who experienced a severe embolism during such a training ascent.

Many divers and instructors were concerned about "surface flotation position." Would the inflated BC hold the diver's head "out-of-the-water" or "under water" at the surface? What if the diver was panicked? What if the diver were unconscious? Generally, what if? This debate raged through the 70s and into the 80s. All of this seems rather elementary now. My new "Super Duper Mark XIII Mod 4" BC purchased in 1985 includes the following "disclaimer" printed directly on it, "EMERGENCY FACE UP FLOTATION MAY NOT BE PROVIDED FOR ALL WEARERS AND CONDITIONS." A quick review of the manufacturer's instruction manual that came with my other BC revealed (1) "The XXX YYY ZZZ is not an emergency life vest, but is a means of compensating buoyancy." and (2) "Be aware that the XXX YYY ZZZ may not float a diver on his back with his head and mouth out of the water." Well, there it is, in print, "the BC is a BC, not a life saving device."

Now that that little issue has been resolved, let's get back to 1977. That was the year Scubapro "revolutionized" buoyancy compensation with the introduction of the "Stabilizing Jacket." In some ways it was the beginning of the end for "front-mounts" and "back-mounts." The "jacket-style" BC combined the best of both worlds into a single unit. The diver was now literally surrounded by a bouyancy bladder. Radical in design, aggressively promoted, widely accepted, and expensive -- all the key ingredients to success if you add one more. Highly copied! Today, the "jacket-style" BC probably represents 80% or more of the BC sales in the United States. Some dive stores only sell "front-mounts" and "back-mounts" by special order; they don't even stock samples.

The "jacket-style" BC is now available in a number of "design variations." Some units are "adjustable" and others are sold by "size" (x-small to x-large). The original "wrap around" stablizer jacket was basically a single air bag attached to the scuba backpack and encased the diver's entire upper body like a "vest." The BC was also the scuba "harness." Air moved freely throughout the entire BC to seek the highest point depending upon the diver's attitude (position) in the water. Consequently, no large pocket of air was formed behind the diver's neck as in the "collar-type" (front-mount) units, and the diver could more easily maintain a "horizontal" swimming position. In essence, the scuba floated slightly off of the diver's back, thus suspending the diver in the BC and increasing diver comfort. As the diver changed to a vertical position for ascent, the air shifted to the shoulder area for better vertical ascent control. At the surface, the fully inflated BC floated the diver in a vertical position high in the water with air in front, under the arms, behind the neck, over the shoulders, and in the back.

Several manufacturers later eliminated the under arm portion of the bladder and replaced it with a fixed or adjustable fabric panel. This eliminated the under arm bulkiness and allowed for greater freedom of movement at the surface. The popularity of the jacket-style BC grew from the diver's desire for a unit that facilitated a "horizontal" swimming position underwater, reduced the number of straps to adjust and items of equipment to put on when preparing for a dive, and left the chest unencumbered.

BUOYANCY COMPENSATION VS. LIFESAVING FLOTATION

Most manufacturers clearly define that they build and market "buoyancy compensators" not "life preservers." However, most diver rescue procedures, either self-rescue or second party rescue, involve use of the BC at some point in the rescue procedure. Are we, the divers and instructors, "misusing" a piece of equipment? Unfortunately, the American diver lives in a "law suit society" where nearly anyone can be sued at any time for anything. Diving instructors and the diving equipment manufacturers are especially vulnerable. Regretfully, the manufacturers have been forced into this position. I will spare you my "dissertation" on our society and its legal system. However, in a way this whole attitude places us all "between a rock and a hard spot."

It becomes paramount that we understand both the capabilities and the **limitations** of the equipment that we use and teach others to use. Unfortunately, very few organizations are in the diving equipment evaluation business. If we review equipment evaluation information published in popular dive magazines, we might conclude that "everything is wonderful." The U.S. Navy evaluates diving equipment periodically and publishes its findings. Unfortunately, many instructors and most divers never see these publications. And, many recreational diving community "authorities" are quick to point out the fact the "the U.S. Navy's criteria are not intended for or consistent with the standard of practice in recreational diving!" This is especially true if the U.S. Navy does not "agree" with the recreational diving viewpoint.

In 1980 the U.S. Navy published a report on the evaluation of 14 commercially available buoyancy compensators [9]. One of the conclusions stated in that report was:

> Back-mounted and jacket-style BCs are functional and have application in specific diving situations. However, training and operational requirements preclude Navy use of these type compensators.

The report further stated:

> Since it is imperative that a Navy diver be able to ditch his scuba gear on the surface <u>without</u> losing his flotation, any jacket style BC whose harness is integral with the BC is unsatisfactory.

Modern "trends" in recreational diving seem to dismiss the possibility that a **scuba** diver will ever encounter a situation in which he will be required to "discard his scuba on the surface and desire to retain his flotation system." Numerous salespersons and instructors have supported this fact when asked the question, "What happens if I have to ditch my scuba and I need emergency flotation?" Some claim that that situation will never arise in the real world of diving. Maybe? Maybe not?

Several of my instructor friends and former students responded to the question by saying that "they could reach back and release the cylinder from the backpack and, thus, retain their BC." I tried and it worked. However, the Navy also included this option in their evaluation and reached the following conclusion [9]:

> Once the scuba tanks are disconnected from the [brand name], the BC floated the diver face down. The weight of the tanks kept the diver's center of gravity and center of buoyancy in the right relationship to float a diver face up. Without the tank weight, this relationship no longer existed.

In the final analysis, it appears that diver surface floating attitudes (positions) **without** scuba have not been considered as an important factor by most divers and instructors if one considers the "dominance" of the jacket-type BC in the recreational diving community today. Over the past years I have observed numerous training dives where the jacket-type and back-mounted BCs were used for "skin diving" exercises. I do encourage all instructors to make their students aware of the possibility that some BCs do not float you in a face-up position under all conditions.

Although it is only academic to most recreational divers and diving instructors at this point, I will present one more of the Navy's conclusions [9]:

> The conventional horsecollar [front-mounted] style BC always floated a diver face up in an emergency.

Very few divers and instructors consider other potential emergency applications of the BC. During a recent diving trip in the Bahamas I encountered a boating situation which reminded me of the potential value of my BC in the event of a boating mishap. In attempting to maneuver through a narrow channel in the reef in heavy seas our boat nearly capsized. I realized that my diving buddy and I were the only persons wearing flotation equipment at the time of the incident. Since the boat was not equipped with life preservers, we had donned our front-mount BCs as a safety precaution prior to entering rough water.

At this time I do wish to assure the reader that I am not trying to discourage or encourage the use of one type of BC or another. I simply encourage divers and instructors to be aware of **both** the capabilities and limitations of their chosen equipment.

I have also observed some other interesting recent trends in recreational diving. Regardless of the current "buoyancy compensation only" attitude, I still consider my BC to be an "emergency flotation device," and I do use it for both skin diving and scuba diving. For the record, I still equip my personal BC with a secondary CO_2 inflation system. In fact, I do consider this to be a very important part of my flotation system. Since I do not have a "power inflation" capability (from the scuba) when skin diving, I consider the CO_2 system to be my primary emergency system in that mode of diving. I also advise my students to have CO_2 inflators on their BCs.

This certainly **isn't** the case for a large segment of the recreational diving community. Last spring one of my students bought a complete diving outfit from a major southeastern Michigan diving equipment retailer. As previously noted, despite trends I still ask my students to select a BC with a CO_2 inflation system. The student was purchasing an expensive BC with a power inflator and requested that the salesperson also install a CO_2 unit. The salesperson insisted that the student did not want such a device on his BC. This salesperson apparently would not sell him one. From my standpoint, the salesperson lost a \$35 to \$45 sale and placed his store in a potentially awkward position in the event that that student would be involved in a diving incident where the presence of an inflation device might save his life. Power inflators do little for you if you are skin diving.

Why are some people so opposed to the use of a CO_2 inflation system? Why is the apparent dissatisfaction so prevalent and aggressively supported? I am aware of CO_2 system corrosion and malfunction, and I admit that the quality of the present units could be improved. However, is this a reason for total rejection? I suggest that the CO_2 system can potentially be an important component in diving safety.

Divers must be taught both the advantages and the limitations of all components of their diving equipment, and the CO_2 inflation system is no exception. On the other hand, very few instructors discuss maintenance and repair of such components. To my knowledge, very few dive stores offer an inspection/repair service for BCs and CO_2 inflation systems. Even with proper maintenance, the CO_2 inflator will corrode and deteriorate in time and must be periodically replaced. Is this unreasonable? No! Divers maintain and periodically replace many components of their equipment. Is this an unnecessary expense? No! Personally, I will pay the added cost for the added margin of safety.

What about the "failure" aspect to which so many divers and instructors refer? Anything can fail, anytime or any place! I suggest that many of these failures are the result of careless inspection and maintenance procedures on the part of the diver. I remember one Instructor Training Course staff member that walked up to an instructor candidate and pulled his CO_2 inflator cord. The entire assembly fell off in his hand. The staff member handed the assembly to the candidate and walked away shaking his head. Who was at fault? The manufacturer? The staff member? The diver? The BC had been used by the diver for several years. However, the diver had apparently never pulled the CO_2 inflator cord. I suggest that the diver should have periodically tested his complete system to verify satisfactory operation.

It is an accepted fact that any item of diving equipment is subject to deterioration. This was recognized by the U.S. Navy years ago and complete instructions including disassembly, inspection, repair, and reassembly are included in their underwater swimmer manuals for maintenance of the CO_2 inflation system [3,4,5].

As long as I am discussing maintenance let's consider power inflators and AIR II's. Malfunction of a power inflator or BC exhaust valve can result in either uncontrolled ascent as a result of uncontrolled over-inflation or failure to maintain buoyancy because of air loss. How often do divers have these components inspected, lubricated, and overhauled (or replaced)? Divers, such failures have occurred! How many divers have their AIR II's inspected annually along with their regulators? Remember, this is your BC inflator/deflator **and** your alternate air source regulator.

Dependence! I fear that some divers are completely dependent on their diving equipment for survival in the sea. Every diver should be capable of surviving in the sea without the aid of any equipment. In my opinion a diver should not enter into a recreational openwater diving situation in which he **must** depend upon the equipment in order to survive. Can a diver **independently** survive a complete buoyancy system and scuba failure at 100 feet? Yes, if the diver has been properly trained and progressively develops both the physical and emotional skill to dive safely to this depth! In simplest terms, the diver should be able to release his ballast system and successfully complete a controlled emergency swimming ascent. It is well documented that most accident victims fail to release their weight belts in emergencies that could be resolved by establishing positive buoyancy.

I fear that many persons receiving diver certification cards lack the watermanship, physical fitness, and psychological preparation to deal with a diving adversity without the aid of their equipment. Should a diver be capable of maintaining surface flotation without the aid of a BC? Absolutely! A 1/4-inch foamed neoprene wet suit provides about 15 to 20 pounds of buoyancy **IF** you drop the weight belt.

What about rescues? Should a diver be capable of completing a rescue without the aid of a buoyancy system? Yes! Some diving instructors suggest that there is no place for conventional ARC-type life saving practices in scuba diving. Keep in mind that the buoyancy system is an **aid** to rescue, not a replacement for skill and fitness. I suggest that all divers should be encouraged to complete a standard lifesaving course where they can learn rescue and assist procedure without equipment aids. For those who feel this is "unnecessary" I simply say, "What is wrong with being a better swimmer and capable of unassisted lifesaving?" Please don't misunderstand me. I encourage the use of aids whenever available. However, I discourage total dependence on such aids.

CONCLUSIONS

Buoyancy and buoyancy compensation is a major aspect of modern scuba diving. The modern BC is used for both buoyancy compensation and as a rescue aid. However, the BC or any other item of diving equipment must not become a substitute for watermanship and physical fitness. The diver should be completely competent in the water with **or without** the equipment.

Is diving and diving instruction being complicated and, to some degree, compromised by our society's aggressive legal system! In a diving accident who is really at fault? The equipment? The diver? The instructor? These questions can only be answered in a court of law on an individual case basis. For the time being, divers and instructors must do their part to promote safer diving. I offer the following comments for your consideration regarding buoyancy and the scuba diver:

* Do not substitute a "buoyancy system" for watermanship and physical fitness.

* Inform the student of both the advantages and **limitations** of various buoyancy systems.

* Encourage students and divers to personally evaluate the performance and capabilities of their buoyancy system relative to various diving modes and conditions in a controlled environment.

* Encourage divers to establish a regular maintenance program for their buoyancy equipment and to replace components as necessary.

* Encourage divers to complete conventional lifesaving training **in addition to** scuba diver rescue training.

* Divers must select buoyancy equipment that is appropriate for their individual size and diving requirements. An improperly fitted or adjusted BC may actually compromise the diver's comfort and safety. A person who anticipates doing a considerable amount of skin diving may wish to consider the benefits of a front-mount BC. If this means purchasing more than one BC, then so be it!

* Encourage divers to **properly** weight themselves, "to the pound," taking into account individual variables. Divers should continuously evaluate their weight (ballast) requirements and make adjustments when appropriate.

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