EQUIPMENT CONFIGURATION

by Bill Gavin

INTRODUCTION

There are dozens, if not hundreds, of possible cave diving equipment configurations and to examine each of them would require an encyclopedic volume of text. Not only would this be boring, it would also be unnecessary, since most of these configurations would be less than optimal. A much more efficient way of approaching the subject would be to study a successful configuration and discuss why it works. Such a configuration would almost certainly come from a group of cave divers that are devoted to serious exploration. Out of necessity, these divers will have streamlined and optimized their gear in order to allow them to go farther, deeper, and stay longer, while searching for new passages to explore. There is probably no more driven an individual than one who is lured by the desire to swim through tunnels that have never felt a diver's presence, holding a reel in her hand and laying new line as she pushes back the edge of the world.

There is a configuration that has been used for several years by a group of Florida-based cave divers while exploring some of the most demanding cave systems in the world. Much of the success that this group has enjoyed can be directly attributed to a gear configuration that does not hinder a diver during extended exploration efforts. Simply put, if everything works every time you get in the water then dives are not aborted, gear does not hinder you, you go farther more often, and **FIND MORE NEW PASSAGE.** The relationship between the number of problem-free dives and the number of successful exploration dives is direct and obvious, yet it cannot be stressed enough. A gear configuration that reduces problems will inevitably improve a diver's chances of success as well as survival. Many cave divers have adapted part or all of this configuration when the benefits were recognized. While it is by no means universal it is still worthy of study based upon the record of successes enjoyed by those who have used it.

It must be stated that since this configuration was developed by and for Florida-based cave divers, it is not appropriate for cave diving in all parts of the world or even the USA. In fact, it isn't even appropriate for ALL caves found in Florida. In very small systems, where passage size precludes the use of back-mounted doubles, then some form of side-mount configuration is obviously superior. And in certain parts of the world, where logistics make it extremely difficult to transport heavy equipment, then perhaps composite cylinders are a better choice. However, the majority of cave dives are made in systems that are both large enough and accessible enough to use more conventional tank configurations. This has proven to be the case in every part of the world where extensive underwater systems have been found. Inevitably, when the cave got large enough or long enough, double 104's[1] were called for. While the future of cave diving certainly will see an increased use of composite cylinders and rebreathers as well, it is likely that 104's will be popular for a long time to come.

What becomes apparent as we examine this configuration is that every detail, no matter how small, is important. If you change one small thing about a cave diver's gear, she may never notice the difference. Change 8 or 10 of these seemingly insignificant details and suddenly this person is going twice as far in the cave, on less air, and with less effort. She is able to achieve this improvement because her equipment is no longer hindering her. This approach has proven successful with divers that had a decade of cave diving experience, as well as with relative novices. Many of these divers experienced a drastic improvement, virtually overnight, by altering a few "minor" details.

Of course, many cave divers are not particularly interested in exploration and might assume that gear is of less importance to them. This is partially true in that "tour dives" can be made successfully even if gear is not configured optimally. Yet, by applying the same principles, recreational cave divers can conduct dives that are easier, safer, and more enjoyable.

Regardless of a diver's personal capabilities, there is no limit on how good her gear can be. Every effort should be made to configure it in the best possible manner. Setting up your gear is like studying for a test. If you don't study carefully, and study the right material, you simply won't do well. Similarly, if your gear is not carefully prepared, you increase your chances of having problems before, during, and after the dives. On the other hand, if you are willing to put in the time and effort, you can offset a lot of personal deficiencies by improving your gear. People who weren't born with Einsteinian intelligence can still do well on tests by studying carefully. Similarly, a person who wasn't blessed with a low breathing rate can still go farther in a cave by optimizing her gear. It's a matter of preparation.

Gear can and should be perfect every time you arrive at a dive site. On rare occasions it may be necessary to repair a piece of equipment that fails just prior to a

[1]The 104 cubic foot cylinders referred to are no longer available from the manufacturer. However, they are still in use by many cave divers. The information presented is applicable to most back-mounted double-tank configurations. — Ed.

dive. This is an exceptional event and does not justify showing up to dives with gear that always needs to be rebuilt. If a diver has gear problems and failures on a regular basis, it indicates a lack of preparedness and a poor attitude. This type of person needs to reevaluate her approach to cave diving. If a diver's buddy exhibits this type of behavior, it should be a major warning sign and cause for serious discussion.

One of the key principles of gear configuration should be *KEEP IT CLEAN.* This cannot be stressed enough. Ev-erything should be as streamlined and low profile as possible in order to reduce drag and avoid line entangle-ment hazards. A corollary to this principle is, *IF YOU DON'T NEED IT, LEAVE IT AT HOME.* Carrying 5 reels on a dive that doesn't require more than one (or even none) is counterproductive. Cave divers have enough equipment that is vital without adding to the burden un-necessarily. You may be able to make tour dives while carrying every piece of gear you own, but when it comes to long exploration pushes you MUST be selective. No one ever reached the top of Mt. Everest by carrying a lot of equipment "just in case it might come in handy." Ev-ery dive should be planned to some extent and unneces-sary gear shouldn't be worn.

For years, many cave divers have had the mistaken impression that the more homely it looks the better adapted for cave diving it must be. This has resulted in some divers who look as though their gear mated with a roll of duct tape and a surplus store, with maybe an old inner tube thrown in for good measure. There is nothing efficient or even all that functional about "ugly" gear. It generally takes up more space (drag), and fails more of-ten. Part of this problem stems from the early days of cave diving when virtually everything had to be home-made. Today, very few cave divers build their own gear. Most of what they need has been developed and refined and can be purchased at any dive shop in a cave diving locale. Contrast this to the days when Frank Martz had to invent the auto-inflator by gluing a tank valve into a life vest. This does not imply that homemade gear is inferior but rather that it should be just as clean as commercially manufactured equipment if not better. Don't just throw something together with duct tape because it's quick and easy. Take the time to do it right.

HOGARTHIAN GEAR CONFIGURATION

The Hogarthian gear configuration is named after William Hogarth Main, who has the distinction of being a driven perfectionist who will not rest until every piece of gear he uses is at its absolute best. It has been the author's privilege to dive with and learn from this indi-vidual for the past decade. During this time a gear con-figuration gradually emerged which was the result of years of effort directed toward increased efficiency on long demanding dives. Originally it was referred to as the Hogarthian configuration in only a semi-serious manner. However, the name has persisted, and is a fitting tribute to the individual who inspired it. Many other people have made contributions to this configuration, and where it is possible (i.e. known) credit will be ac-knowledged. Each item or subsystem of gear will be discussed along with reasons for selecting and configuring in a particular manner. As stated earlier, it is not intended to cover all configurations that are possible. The principles involved are really what this chapter is about. Feel free to adapt this.

TANK CONFIGURATION

Not surprisingly, the tank configuration of choice is the double 104 c.f. setup as shown in Figure 5-1. These tanks have been the workhorse of cave diving for the past 15 to 20 years because of the tremendous volume of air they supply. However, all discussion of double 104 configuration applies almost universally to any double tank configuration.

A set of double tanks consists of three separate com-ponents.

1. The tanks
2. The manifold used to join the tanks
3. The bands used to stabilize the tanks

Occasionally it may be advantageous to attach some-thing else to the tanks but this should be kept to a mini-mum. Remember, KEEP IT CLEAN! Anything that pro-trudes from your tanks, particularly from behind, is a line entanglement hazard as well as increasing your profile, with the possible result of getting you STUCK. As little as 1/8 inch can make a major difference in going through a tight spot. Any piece of gear that is attached to the back of the tanks will receive severe abuse from impact with the ceiling.

Tanks

The tanks themselves are pretty simple and should be kept that way. Don't adorn them with tank boots which

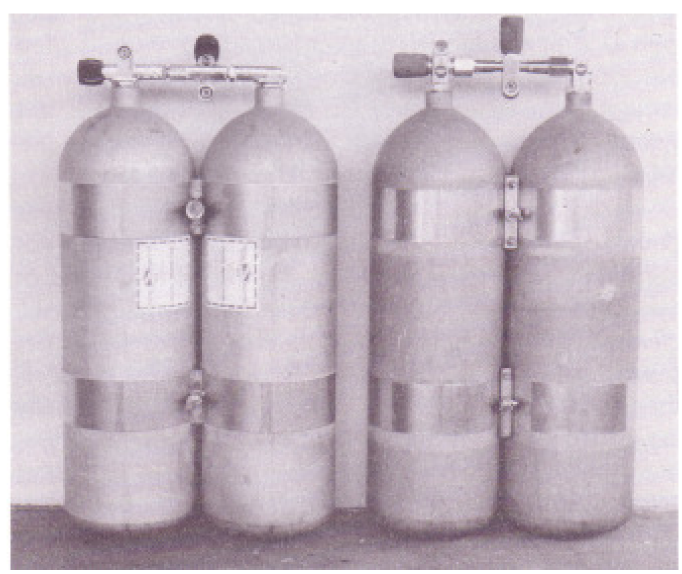


Figure 5-1 Standard double tank configuration.

raise your profile in all three dimensions. Boots also tend to hang up in tight rocky restrictions because they are relatively soft and dig into the rock. Hard steel slides through much easier provided it is free of projections created by misplaced gear.

Tanks require very little maintenance, but they benefit greatly from special attention at filling time. If the individual attaching the fill whip to your tanks doesn't carefully blow it dry, call it to her attention. It may be the 114th tank she's filled that day, but it's the first one of yours and you've got an investment to protect.

Manifold

The manifold that joins your tanks is one of the most important pieces of gear you will ever own. Years ago, cave divers dreamed of something called the *ideal manifold,* or more commonly the dual outlet manifold. The dual outlet manifold was envisioned as a manifold that would allow two tanks to be joined together with two regulators attached. The desire was for each regulator to be capable of being isolated in the event of a failure while still allowing the diver use of the ENTIRE air supply from both tanks. Dr. George Benjamin was the first to actually fabricate such a manifold and some of these "homemade valves" are probably still in use. The idea proved so successful that eventually diving equipment manufacturers began to produce the new type of manifold. This was a triumph for cave divers and the excellent safety record that cave diving has enjoyed must in large part be attributed to this breakthrough. Today it is hard to imagine what cave diving would be like if we couldn't go to the local dive store (at least in cave diving areas) and buy a dual valve manifold.

Recently, however, there has been a great deal of discussion about alternative valve configurations for double tanks. Many cave divers have done "paper analyses" of the pros and cons of manifolds vs. independent K valves, etc. Though some of these studies have been very thorough and somewhat interesting, they would be more useful if backed up by experience IN THE WATER.

While it is healthy to reexamine the way we do things from time to time, we must also be careful not to be seduced by *change for the sake of change.* If cave divers twenty years ago went to the trouble of inventing and fabricating the dual valve manifold, even though single K valves were certainly an available option, then maybe they had some good reasons. Obviously they had some excellent reasons, like being able to access their entire air supply while retaining redundancy in case of a regu-lator failure. The dual-valve manifold solved a lot of problems without creating a lot of new ones, which is not the case with independent setups.

The most serious problem associated with diving independent valves involves handling an out-of-air diver. Advocates of independent systems often state that if all divers used separate valves there would never be a catastrophic failure resulting in an out-of-air diver. There isobviously a serious flaw in this logic, in that it assumes that out-of-air situations are always the result of gear failures. In reality, THE OVERWHELMING MAJORITY OF OUT-OF-AIR SITUATIONS ARE CAUSED BY HUMAN ERROR. Cave diving is a very busy activity, both mentally and physically. Psychologists use the term *task loading* to describe a situation where a person is given many things to do at once. It is a known phenomenon that the more things a person attempts to do at one time the more often she makes mistakes. Whether a diver is too stressed because of task loading, or just pushes her critical air supply from carelessness or peer pressure, the result is the same. She is out of air because she had a mental failure and no gear configuration will change that fact. However, a gear configuration that places additional task loading on the diver does make it more likely that she will make a mistake. Once the error occurs, there is no amount of paper logic that will solve the problem. It is up to the diver with air to sort things out and she stands a much better chance of doing this if the valve arrangement she is using allows her to make simple decisions.

Imagine that your dive buddy has informed you of the depressing fact that she is out of air: how do you get her out of the cave using your independent valve arrangements? This is the time when the task loading caused by independent tank set-ups is at its worst and it couldn't happen at a more critical point in the dive. Which regulator do you give her? Do they both have long hoses? Which one is in your mouth? A diver who is shifting regulators back and forth during the dives is also changing her procedure for assisting an out-of-air diver unless she has at least three regulators. One way to avoid this is to dive at least one Y valve, attach your long hose to it, and clip it off. However, this prevents you from handing off the regulator that is in your mouth since it has a shorter hose (see discussion under *Regulators).* Since handing off the regulator from the mouth is considered by many to be the safest methodology, this is not a good alternative. Another option would be to dive two long hoses, but now you must find a way to cleanly store them where they won't become entangled with each other or anything else.

So where is the regulator you need to hand off? If you are diving independent valves with one long hose then you can only provide your buddy with air from one tank. What if she breathes faster than you during the exit? Chances are, even if your breathing rates are normally equal, the diver who ran out of air will be breathing much heavier during the exit. Should you give her the regulator that is attached to the tank with the most remaining air? If you have only one long hose, that is not an option. What happens if one tank is exhausted with a few hundred feet left to go? Buddy breathe the rest of the way? What about restrictions?

These problems have led some divers to actually dive twin Y valves with FOUR regulators and TWO long hoses. The sad part is that they don't realize that by cluttering and complicating their gear they have greatly increased their chances of problems occurring which are just as dangerous as manifold failure and much more likely to occur. Suppose this person actually has to hand off one of her long hoses. Visualize yourself as the out-of-air diver, watching your buddy fumble through four regulators try-ing to locate, unfasten, and hand one to you, amidst the snarl and tangle created by four L.P. hoses, two H.P. hoses, one or more inflator hoses, primary light cord, and other cave diving equipment. If you really want to terrorize yourself, add two primary reels and three gap reels to the picture. To say that this diver could literally drown with air on her back points out the high probability that you will drown before she manages to provide some FOR YOU.

Let's look at just one problem that might occur if the "swimming dive shop" actually manages to execute the regulator hand-off to the out-of-air diver. During the exit, her partner, excited a little by the situation, breathes heavily and exhausts one of the two available tanks. She must now convey the need to switch to the second long hose, execute this maneuver, and someone must store the now useless long hose #1, or drag it behind them as they continue their exit. The second or third time it hangs up will either convince them to store it or send the whole situation over the edge. When you consider the increased chances of blown 0-rings and the interesting search through four regulators to figure out which one to isolate, line entanglements, difficulty accessing and removing gear (regulators, back-up lights, reels, etc.), and the stress caused by these problems, it should become clear that twin Y-valves are one of the worst configurations imaginable. It is impossible to configure such a system in an uncluttered manner, thus violating principle #1—KEEP IT CLEAN!

Contrast any of these approaches with the diver using a dual outlet manifold who simply hands off her long hose and concentrates on getting out alive. It is easy to see that this diver has fewer decisions to contend with, which is fortunate since she probably couldn't tell you her name at that moment in time. That is the key point, that out-of-air situations are not calm and ordered events. They are unexpected and chaotic and reactions must be instinctive and immediate or they probably won't do any good.

The diver who thinks these are just hypothetical problems has probably never been in an out-of-air situation. These are very real problems that are difficult to handle even for the best divers. As many people will attest, an out-of-air diver will often grab the regulator from her buddy's mouth, despite training, discussion, and promises to the contrary. If out of air for long enough, anyone will react this way. At this point the diver with air (on her back if not in her mouth) had better have some quick solutions. In any conceivable out-of-air scenario, independent valves make the situation more complicated at a time when responding correctly and quickly can easily mean the difference between life and death.

If cave divers were perfect automatons that never made mental errors then the independent arrangement might be safer than the dual valve manifold, but cave divers do make mistakes and that is what many of these valve analyses fail to take into consideration. Given that we are human beings and prone to error, then it makes sense to select the simplest alternative when life support equipment is involved. The dual-valve manifold has none of the task loading problems that plague the indepen-dent valve configuration. While it is reasonable to con-sider all the possibilities, we must remember that after hundreds of thousands of cave dives, NO ONE HAS EVER DROWNED AS A RESULT OF A BROKEN MANIFOLD. This is a fact that advocates of independent systems seem to have completely overlooked. It makes no sense to switch to a more complex system because of a failure that rarely occurs and has never cost a life.Given this discussion, it is curious that there is so much interest in independent valve systems. After two decades of cave diving, representing hundreds of thou-sands of dive, we are trying to solve a problem that doesn't seem to exist except as a potential in someone's statisti-cal paper diving scenario. Whether this is misplaced enthusiasm or simply someone trying to make their mark on cave diving is unclear. The fact remains that the dual valve manifold has been and will continue to be the best choice for the vast majority of cave diving situations.

Valve Knobs

A potential failure with any valve involves the knobs used to turn the valve on and off. If these knobs are made from a brittle plastic they can break apart when struck against a ceiling. This leaves a diver with no way to isolate the associated regulator. If this impact also results in an unseated valve 0-ring, then the diver has just had a catastrophic air failure. Her valve is on, leaking madly, and she has no way to turn it off. The solution to this is simple. Replace all such knobs with a softer rubber variety that is not prone to this failure mode.2

Tank Bands

Tank bands are much less controversial items than manifolds, but should not be taken for granted. Pay particular attention to the quality of manufacture and be sure to use bolts of adequate strength (minimum 5/16 diameter). Bands should be fabricated from thin gauge stainless steel. Avoid thick, plastic coated bands, as they add to the profile of the tanks. In a tight, rocky restric-tion, anything that adds even 1/8 inch, as these bands do, is enough to ruin your day. Take the trouble to find or manufacture broad spacers for assembling the bands

[2]Metal replacement knobs are preferred by some cave divers. However, they don't absorb contact with the cave as well as the rubber ones. This means they are more likely to bend the valve stem, and perhaps cause a dive-ending air leak. Their advantage is that they slide off rock easily and are thus hard to turn off unintentionally in tight passage. — Ed.

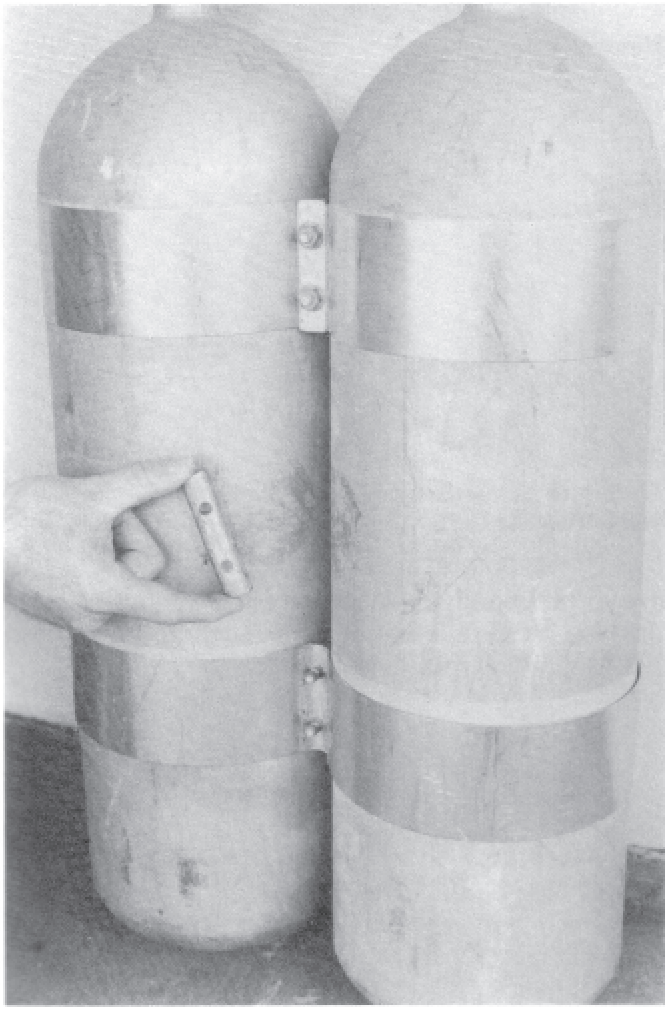


Figure 5-2 Band Spacers.

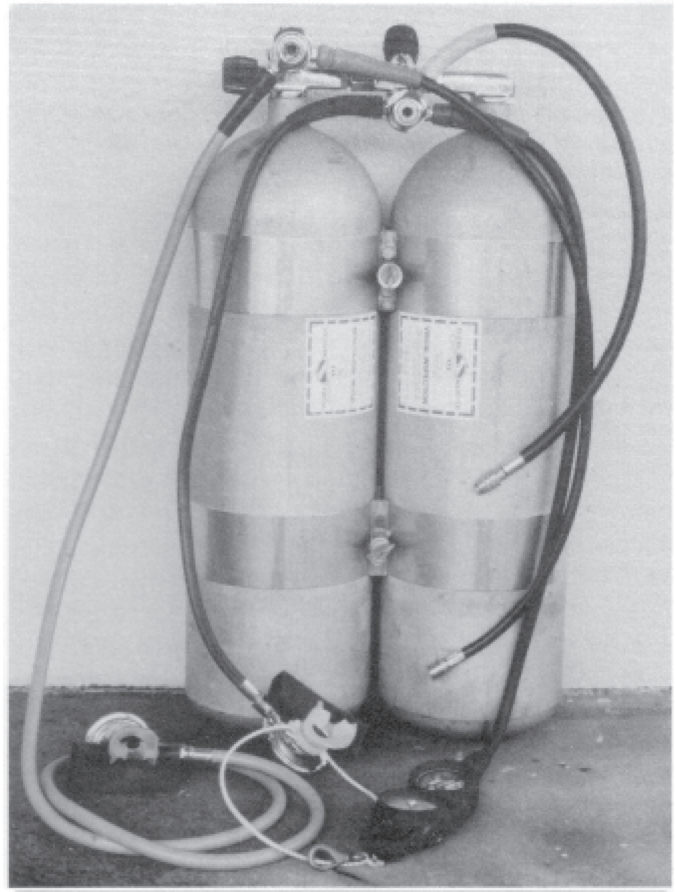
like those shown in Figure 5-2. These can be made by sawing a piece of 1 inch diameter aluminum rod in half, and cutting to the appropriate length (usually 1.5 to 2 inches). Washers do not provide enough strength or bearing area: the bands will deform and possibly fail.

REGULATORS

No subject in cave diving is more hotly debated than what type of regulators to use and how to configure them. Let's cover the obvious stuff first.

Regardless of what regulators you select, certain things apply. Remember—KEEP IT CLEAN!

On the subject of keeping it clean, EXTREME attention should be given to routing all hoses so that they do not protrude outside the profile of the tanks. This prevents damage to hoses from impact with walls, ceiling, etc. Surprisingly, many divers who should know better seem to ignore this. Hoses are attached to regulators with little thought and the result is both ugly and hazardous. Yet other divers consider this so important that it may be grounds for not using a particular first-stage regulator. Contrast the appearance of the two arrangements shown in Figure 5-3. Certainly the orientation of hoses should be considered when a regulator is selected.



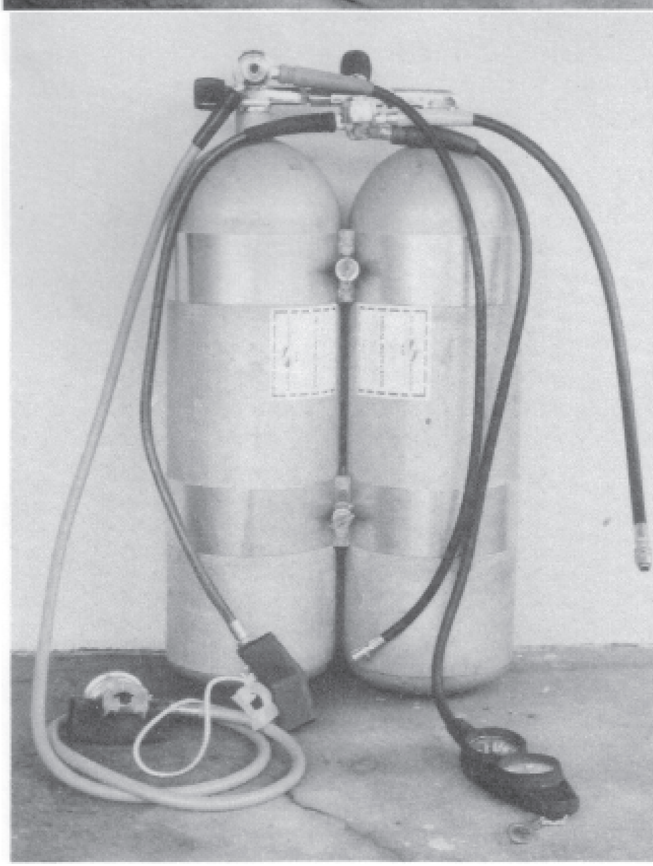


Figure 5-3 A streamlined vs. an unstreamlined configuration. This was achieved by replacing the center post regulator's first stage with a better

What kind of regulators should you use? Almost all modern regulators are safe and reliable, but obviously some are better than others. You can't rely on the manufacturers to tell you, so you'll need unbiased sources. Of course other cave divers are a good source of information. Find out what they're diving and how it works. Ask around a lot, though, because people have a habit of getting enamored of a particular regulator for some strange reasons. Pay attention to the way a person's gear is maintained when evaluating their advice on regula-tors. An individual who is meticulous in all aspects of gear selection will usually be more discriminating about the regulators she uses.

Remember that the most expensive regulators are NOT necessarily the best, i.e. they may not provide the ideal combination of performance AND reliability. In general, you want to avoid the bottom-of-the-line in regulators because they won't perform (breathe easily) at the depths and demanding work rates that cave divers encounter. You also want to be very careful of so called high performance regulators. Many times they simply aren't that good or they are very finicky. A regulator that breathes like a dream but fails often is of dubious value.

Figure 5-4A Proper hose arrangement using another brand of regulators and manifold.

It is almost impossible to predict how a regulator will perform at depth by breathing it on the surface (in the dive shop). Breathing a regulator on the surface will

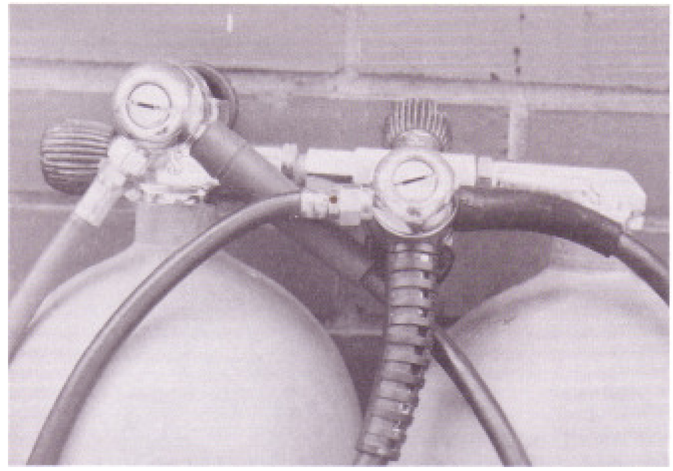


Figure 5-4B Streamlining first stage hoses with another brand of regulators.

give you a subjective evaluation of its cracking pressure. Cracking pressure is simply how much negative pressure you must exert in order to cause the demand valve to open and flow gas. However, the ability of a regulator to deliver high flow at depth is seldom a function of cracking pressure. For example, a regulator that requires two inches of water negative pressure to begin flowing gas, may deliver much more gas at depth than a high performance regulator that begins flowing gas at only 0.5 inches of water. This has to do with the orifice size in the regulator and the amount of travel that the demand valve can move through (how far it opens). The fact is that at deeper depths and/or higher breathing rates the cracking pressure has little impact on the work of breathing associated with a regulator. So how do you know whether a regulator will perform well at depth? Ask cave divers that make frequent deep dives what regulators they use.

Another good rule to follow is not to test a brand new regulator in cave diving situations. Wait until a unit has been on the market for a year or two and someone else has discovered all the problems it may be plagued with. Cave divers tend to use dive gear at extremes that

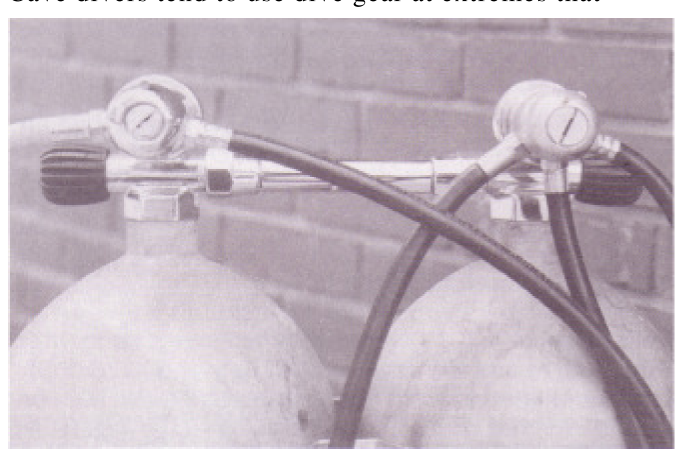


Figure 5-4C Streamlining using the same brand of regulators as Figure 5-48, but with DVM with DIN fittings instead of yokes.

sport divers don't encounter, so wait until a regulator has a proven track record before you spend a lot of money on it.

Hose Configuration

The greatest debate in cave diving may well center around the configuration of regulators. The main point of contention is whether you hand off the regulator in your mouth to an out-of-air diver, or give her your secondary that is attached somewhere else. In the Hogarthian configuration, the primary regulator is equipped with the long hose. This is the regulator that is normally breathed during the dive, and it is also the regulator that is handed off to an out-of-air diver. Advocates of this methodology are often reluctant to make serious dives with someone who hands off the secondary. For numerous reasons, some even refuse.

Figure 5-5A Handing off regulator with long hose stored under arm & around neck: diver removes second stage & inverts it.

It is obvious that the regulator you want to hand off is the one with the long hose, but why should this be the one that is normally in your mouth? There are several reasons. First, this is the easiest regulator to find in a stressful situation. Your buddy informs you she's out of air. You realize you've got to do something FAST, and the vacuous feeling in your stomach doesn't help matters at all. At this instant all the paper theories dissolve in the water that surrounds you and the simplest of facts requires the mental effort of differential calculus. Taking the regulator from your mouth and handing it off is much simpler than locating and unfastening one. Obviously you know where it's at: you're breathing from it. There is

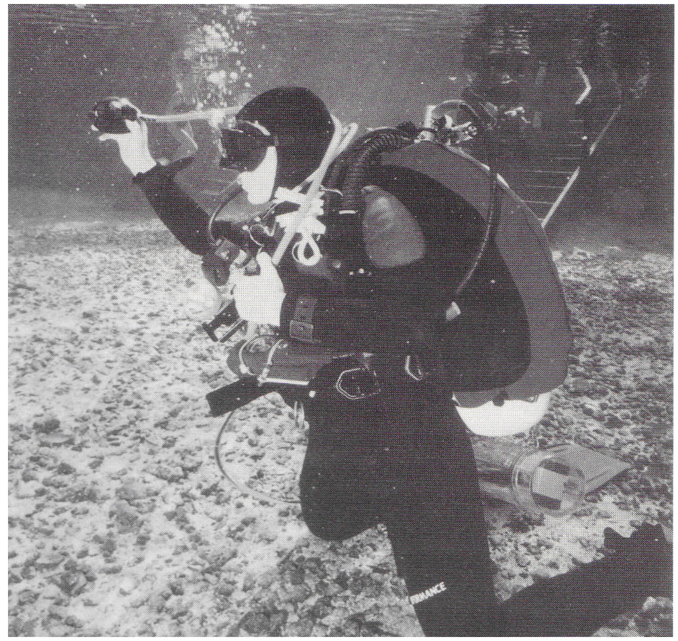


Figure 5-5B Diver bends head forward as the long hose is extended toward the partner.

Figure 5-5C As it is offered, long hose clears diver's head & extends out from under arm.

no snap to hang up, so you can release it instantly. This provides the out-of-air diver with a regulator in the fastest and most reliable way possible. Contrast this with the diver who must first locate her secondary (how many time shave you groped repeatedly for a piece of gear that you knew was right there?) and then unfasten it from whatever clip, pouch, velcro, rubber band, or other device she is using to hold it. There have been several instances where a diver attempting to hand off a secondary regulator (i.e. not from her mouth) had difficulty in locating and unfastening the second stage. Meanwhile, her out-of-air buddy was getting more, well,...out of air. Remember, nothing is as easy to do underwater as you think it will be, and nothing is EVER easy in a stressful situation. Any regulator methodology which makes the out-of-air diver wait longer than she already has is asking for trouble.

Now suppose that you don't get the chance to hand off the regulator at all. A very real possibility (probability?) is that an out-of-air diver may be so stressed either from being out of air for too long or just from panic that she is going to rip the regulator out of your mouth. If it's the one with the long hose then she's got what she needs. All you have to do is pick up your secondary and put it in your mouth. This is much easier for you since you have not been out-of-air for nearly as long as she has. If you wear your secondary *around your neck on a neckstrap* then it is absolutely simple — it's right there in front of you where you need it and doesn't even need to be detached. Some divers will even wear the neckstrap so short that they can reach their secondary with their mouth without using their hand.

Another realistic scenario is an out of air situation in bad visibility. If your buddy (or you) runs out of air in zero visibility, then the basics apply. Like, everybody has a head, and everybody's head is in about the same place. Similarly, the mouth is usually located at the front and bottom of the head and there IS AIR THERE! In this situation, an out-of-air diver WILL take the regulator from your mouth: count on it. She has no way to signal you that she needs air and would like for you to locate and deliver a regulator for her. It is also unlikely that she will be able to remember exactly where and how you attach your secondary, since there is no universal method. She may not even know who she is trying to get air from if the dive team is larger than two. But, if they are all hu-man then she'll know where to reach for what she needs. If you're lucky she'll give your second stage a gentle tug before she takes it from your mouth. This will give you maybe 0.5 seconds to realize that you need to find your secondary — FOR YOURSELF. By now she already has your primary. It's much better if the regulator she just took from you has a long hose.

Another problem associated with handing off the secondary regulator is that its operating condition at the instant needed is unknown. Specifically, secondary regulators tend to fill up with silt and debris during many dives. Although it is generally not difficult to clear them, it is not a task that should be imposed on an out-of-air diver. A diver who has been breathing normally can afford to choke on a little mud for a few seconds, but this is enough to send an already stressed diver into a full state of panic. Some people might argue that they do not want to hand off the primary regulator and then be forced to deal with a malfunctioning secondary. The point here is that you are going to have to deal with this anyway. The out-of-air diver is not going to be satisfied with a regulator that doesn't work — she is going to take the one out of your mouth, which is the one you SHOULD have given her in the first place. So keep your secondary in good condition and remember that it's better to swallow some mud than to have a panic stricken diver cause you to swallow lots of water.

Divers who advocate handing off the secondary have made vague comments about two divers being out-of-air if you hand off the regulator from your mouth. This is ridiculous since it takes only a matter of seconds to hand off the regulator and switch to your secondary. Are these people saying that it is okay for an out-of-air diver to wait during this time, but not them? The fact is that in an out-of-air situation one diver already needs air BADLY. You do not have time for reasoning like, "I'll give you some air when I can find my other regulator but I'm not going to risk my safety by giving you the one I'm breathing."

What is the diver going to do if for some reason she cannot deliver air to her buddy via her secondary because it is hard to find, detach, or filled with sediments? Write her a note that says she's sorry? Does she think this person is going to calmly die while she fumbles for her extra regulator? If she does not give this person air in a reasonable length of time HER BUDDY IS GOING TO GET THE AIR EVEN IF THIS ENDANGERS BOTH OF THEIR LIVES — period. There are plenty of statistics to back this up. Any reasoning that ignores this is unrealistic. One final point: how do you feel about diving with a person who has blatantly expressed by the way she wears her gear that she is unwilling to give you the regulator she is breathing from if you need it?

Remember the earlier discussion about diving independent valves with a K valve, Y valve, and the long hose regulator clipped off? Having read the section on regulators it should now be obvious why this configuration was considered unacceptable. Many times an out-of-air diver cannot wait and WILL take the regulator from your mouth. Indeed, some situations FORCE this action. The diver who is wearing her regulators in the Hogarthian configuration is prepared to deal with this. In fact it is common practice for many such divers to advise their partners to simply take the regulator and not pretend that they are going to have time for elaborate signals and discussion of the topic. If they do have time to signal, fine. If not, at least you know what to expect.

Excuses For Not Breathing The Long Hose

So why is there a debate about handing off the regulator from your mouth? Apparently there is a natural reluctance to give up the regulator you are using, particularly in a stressful situation. All divers probably feel thisto some extent, but when this anxiety becomes great enough to affect the way a person responds to a critical situation then the safety of the dive team iscompromised.

One reason that is cited for not handing off the regulator from your mouth is that the long hose causes a loss of regulator performance. These people want the ultimate in ease of breathing and feel that breathing through the long hose during the dive is not acceptable. Divers who claim this seem to be saying that the regulator performance is inadequate for normal diving situations, but is okay to hand to an out-of-air diver in an emergency. This is dubious reasoning at best. While the long hose does cause some loss of performance it is minor at the depths encountered in normal cave diving. At deeper depths the introduction of helium into the gas mixture causes reduced density and improves regulator performance. The work of breathing for a typical regulator supplying air at 200 fsw, is roughly the same as that regulator supplying a Heliox mixture at 1000 fsw.

The worst case for regulator performance is in the intermediate depth range from 150 fsw to 200 fsw, where air is still commonly used on many dives. Recently, a large bore, 7 foot-long hose became available which reduces the pressure drop through the hose, thus restoring much of the performance loss caused by the length.

Another reason cited for not breathing the long hose is that long hoses with proper fittings are not available for some high performance regulators of foreign manu-facture. Divers using these regulators are forced to breathe from the short hose regulator and hand off the secondary with long hose. This is in fact an issue of money more than availability and a very poor excuse. A diver that can afford such a regulator can afford the expensive hose or custom adaptor required.

Some divers rationalize that the high performance regulator they wish to use is too sensitive to be used as a secondary. These divers do not wish to be forced to switch to a regulator of lower performance in an out-of-air situ-ation. This implies that what is good enough for their out-of-air buddy is not good enough for them. What is wrong with the regulator they intend to give you if you need it? For their sakes it had better work or they will soon be separated from their high performance toy any-way.

Many years ago, cave divers began diving octopus regulators to make a buddy-assisted exit from a cave more feasible. Then a diver named Ray Elman had the bright idea that a longer hose on this regulator would make this much easier. However, this raised a question. Which regulator should you breathe? Most active cave divers at that time chose to breathe the second stage on the long hose and still do today. The decision to breathe the long hose was based upon sound judgment. Divers who have used this configuration for almost two decades have found no reason to change and many reasons not to.

An issue that has arisen lately is the question of how much long hose is long enough. For years, the five foot long hose was the standard and few people deviated from it. However, since 1985, more and more divers have been purchasing diver propulsion vehicles, or scooters, and using them in caves. This has led to a re-evaluation of the buddy-assisted exit scenario. The seven foot long hose is quickly replacing the five-foot hose as the standard for cave divers. It provides the extra length needed for buddy-assisted exits on scooters. Hoses longer than seven feet are more difficult to store and are generally not considered necessary, though this depends upon both the gear configuration and the type of scooter used. The best advice is to practice with a seven foot long hose and only go to a longer one if you absolutely must.

Long Hose Storage

Which brings up another topic of heated debate. Having covered whether to breathe the long hose or not, we are now faced with the problem of how to store it. Before we discuss the most commonly used methods lets talk about some desirable features of hose storage. First of all, it has to be CLEAN. We can't have this hose dan-gling all over the place nor can we have it protruding beyond a reasonable profile. Second, but of equal im-portance, we have to be able to get it deployed FAST, first time, every time, with no chance of snags or screw-ups. Third, it has to be stored in such a way as not to damage or weaken the hose. Fourth, we MUST be able to deploy this hose and restore it in its normal position while in the water. This last one may seem odd but as we shall see, it is important. Having laid down the ground rules for hose storage, let's look at the two most com-mon methods.

Method number one is the "coiled behind the neck" method shown in Figure 5-6. In this method the hose is doubled over several times, wrapped with a rubber band or similar device, and stuffed between the manifold and the diver's head. The profile of the hose is within that of the tanks, but it is located in an unfortunate position. The manifold area is a very busy spot to begin with. It is important that a diver be able to reach both her on/off valves, and it is desirable that she be able to feel indi-vidual hoses to check for leaks that she cannot see. Such leaks may be caused by a bad 0-ring or hose and can develop during the dive. In the event of a totally blown 0-ring, the diver must quickly determine which regulator to isolate (it isn't always obvious), and she must reach the correct valve. Having the long hose in the way while

Figure 5-6 Coiled behind the neck storage.

trying to feel for escaping air is an unnecessary hindrance to say nothing of actually isolating the regulator. Perhaps the worst aspect of this hose storage location is that it is in an area that is often involved in line entanglements. Trying to sort out a line tangle that you can't see is bad enough without having seven feet of hose coiled up in the same area. Based on these problems, this doesn't seem to be a clean method of hose storage.

What about deployment? Provided the hose does not snag on a regulator yoke knob or valve handle, or get tangled in another hose, it comes out okay. Depending upon your point of view, that may or may not seem like a satisfactory situation. If you are the person waiting for air it probably won't.

One modification to this method is to attach a piece of plastic pipe to the manifold and shove the hose in this pipe. Alternatively, this pipe may be oriented vertically along the side of the tank. It reduces the chance of a snag during deployment and offers some protection for the hose. This technique goes a long way toward solving many of the typical coiled-behind-the-neck problems. However, the size of the pipe must be kept small in or-der to reduce bulk and this causes strain on the hose at bends. This is a problem with the rubber band method as well, but it is probably worse with the small diameter pipe.

Last but not least, what about replacing the hose in this configuration underwater. Very few people have the flexibility necessary to replace the long hose in this con-figuration without assistance from their buddy. For many reasons the hose may be pulled out during the dive. Whether it is for an S-drill, gets snagged, or is actu-ally handed off to an out-of-air diver, it is difficult to re-place. What if you're doing a stage dive and have a fail-ure after dropping your stage bottles? Once you have managed to get the out-of-air diver back to those bottles, the most efficient (i.e. fastest) way to exit the cave is to get her off your air and on to her stage bottle, which should take her all the way home. At this point it is nec-essary that you replace your long hose in its normal po-sition. It is probably not reasonable to expect an already stressed partner to delay the exit while she assists you with your hose. It is obvious that there is a problem with replacing the hose in this position because many of the divers who use this method are extremely reluctant to pull it out for a normal S-drill (safety drill) at the start of a dive. Perhaps a variation of this method can be devel-oped which addresses these problems, but the typical rubber band behind the neck has many drawbacks.

The second method is the one that is employed by the Hogarthian style diver. The origin of this method is obscure but it is known that veteran divers such as Exley, Goodman, Sullivan, Eckhoff, Main, and many others were using this method at least as early as the late 70's. In those days, the most common length for long hoses was five feet. The hose was run under the diver's arm, around her neck, and IN HER MOUTH. To hand off, the diver simply took the regulator from her mouth, passed thehose over her head by raising the second stage slightly, and handed it to the out-of-air diver. This was easily ac-complished in one swift motion. The diver with air then put the secondary regulator, located on a strap around her neck, in her mouth and the dive team exited the cave. In the event of having the regulator ripped from her mouth by an out-of-air diver, the diver with air simply lifts the coil of hose over her head. Fairy tales about being choked by the hose were simply not true. Once the out-of-air diver gets your regulator she isn't going anywhere with-out you. This method kept the hose close to the body, eliminating any chance of snags. It could be deployed very rapidly, with virtually no chance of a severe hang-up that would prevent access, and it placed no sharp bends on the hose, therefore not weakening or damag-ing it. Finally, it could be restored by the diver, quickly and without assistance, to its normal position.

This method worked perfectly with five-foot hose, but the extra length of a seven foot hose created a prob-lem. Wrapping the regulator under the arm and around the neck simply didn't take up enough length. A solution to this has been to route the hose under the light case, around the neck, and in the mouth, as shown in Figure 5-7. The extra distance to go under the light case takes care of the extra two feet of hose. This method works

Figure 5-7 Long hose tucked under light case.

well if you wear your primary light case on your right side. Practice with this method has indicated that the regulator can be handed off quickly and the 7 foot hose is long enough that it can be cleared from under the light case AFTER the out-of-air diver HAS AIR. An alternative to routing the hose under the light case is to place a loop under the waist belt to take up the extra length. Then the hose is looped around the neck and IN THE MOUTH.

Perhaps the best method would be some type of flat pouch oriented along the divers right side or beside the tanks. Problems with fabricating and attaching such a pouch will have to be solved, but this might be superior to any current method. A variation of this has been used in Mexico, but it involved shrouding the double tanks with a fabric cover. While this looks great on video, it creates drag and would probably suffer from abrasion.

Accessory Hoses

It has been argued that dividing up accessory hoses is advantageous so that when a failure occurs that requires isolation of a regulator you will still have something that works (pressure gauge or inflator). This is somewhat dubious since there is no way of predicting which regulator will fail, and you are going to exit the cave at this point anyway. The accessory you need most at this point is your inflator. This will speed your exit and save air. While it would be reassuring to have a working pres-sure gauge, it doesn't buy you much at this time. So the overriding consideration when arranging these hoses is — KEEP IT CLEAN! One thing that does bear consider-ation: if you are using a dry suit with an auto-inflator, then every effort should be made to place this inflator hose on a different regulator from your BC inflator hose. This way you will always have one source of automatic buoyancy control. You can even switch this hose back and forth between your suit and your BC if the fittings are compatible.

In keeping with a clean configuration, it may be necessary to shop around for hose lengths that are shorter or longer than normal. For example, LP inflator hose and corrugated inflator hose as well, are often much longer than one would desire. It will take a little more effort, but finding a shorter hose may pay off significantly in how clean your configuration is. Both inflator hoses and submersible pressure gauges must be securely fastened in an out-of-the-way spot to prevent entanglements. Quite often, divers will attach the pressure gauge but neglect the inflator hose, leaving it to float above their heads. This not only makes the hose difficult to access quickly it also increases chances of entanglement and may cause

Figure 5-8A Inflator hose secured.

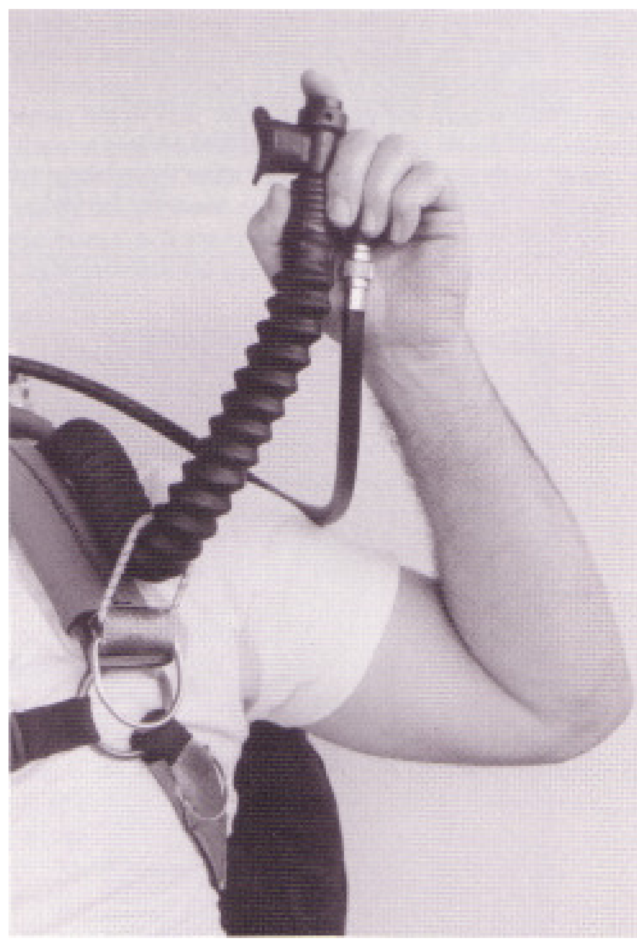


Figure 5-8B Accessibility for venting inflator hose.

damage to the cave, especially in delicate systems with extensive vadose formations. Two methods of attaching the inflator hose are available. One uses a piece of bungee cord while the other runs the LP hose under the arm. The bungee cord method allows the hose to ratchet up and down on the corrugations of the oral inflator hose. It is pulled out to dump air and then pulled back up to keep the inflator out of the silt (Figures 5-8A & 5-8B).

A quick word about consoles before we leave regulators entirely. Small consoles that house the pressure gauge and one other gauge, such as a depth gauge, CAN be used for cave diving if desired. They are somewhat inconvenient since you must detach your console from wherever you have it stored each time you want to check any of the gauges located on it. For this reason, they are not suited for survey work as you will have to unhook the console at each station to read the depth. The same applies if the compass is housed on the console. Most divers doing extensive survey work either mount the compass on the survey slate as shown in Figure 5-9, or hold it in their hand. The depth gauge is worn on the arm so it can be read quickly at each survey station.

There are many variations on where to place the pressure gauge. The main features are that it must be easily accessible and not increase the chances of entanglements or hang-ups in small restrictions. Some divers like to attach the gauge in a position in front of them so that they can see it without using their hands. Others prefer to attach the gauge off to one side so that it does not increase their profile and cause snags in tight restrictions. A few mount the gauge on their arm in the same manner as a depth gauge. There are advantages to each of these methods and each diver must experiment to determine what is best suited for her. Wearing the gauge on the front however, does seem to place it in a position more likely to be damaged or to snag on outcroppings.

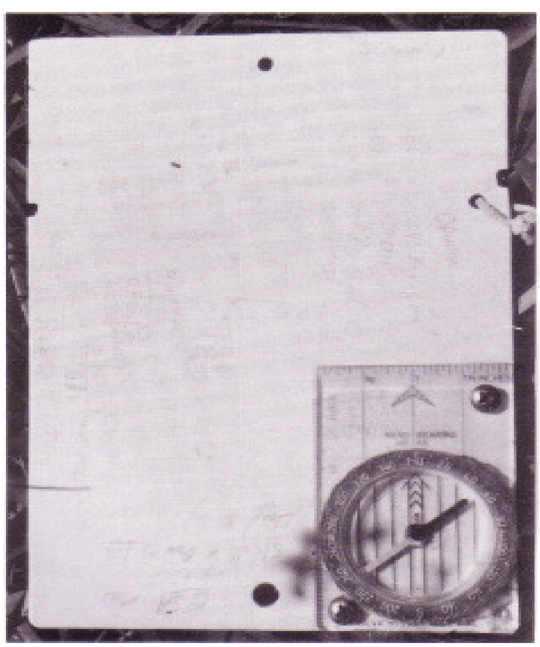


Figure 5-9 Slate-mounted compass

BACKPLATES AND BCD'S

It is safe to say that the vast majority of cave divers have chosen the back-mount buoyancy compensator backplate over all other configurations. This is because of the stability that is provided by placing the BC near the tanks as well as the comfort and simplicity of the design. What few divers know is that Greg Flanagan originated the backplate design in 1979. The first backplate was fabricated from sheet aluminum that had started out life as a road sign. Flanagan used this material to fabricate a prototype that was as clean and functional as any backplate produced today. His idea has affected cave diving almost as much as the dual-valve manifold.

There is little to be said about this configuration that isn't obvious. It is the most stable buoyancy system available because it places the center of buoyancy (which is the BC) near the center of gravity, the tanks. Having CG and CB at about the same point is a natural characteristic of the submerged human body. That is why a swimmer can remain in almost any attitude in the water with little effort. However, when we introduce a large mass external to the body, in the form of tanks, we upset this relationship. To offset this mass, we use a buoyancy compensator to keep us from falling to the bottom. This BC has relatively little mass but a large net buoyant force acting on it. The farther apart these two devices are, the more unstable the diver is in any attitude where CB is below CG, as with front worn compensators. Of course, if the diver is upside down, with tanks toward bottom and BC toward ceiling, then she is VERY stable but not very happy. After years of fighting the force couple that was created from "belly bags" and heavy tanks, the backplate and backmount compensator system was a welcome development. Though jacket-style BC's saw brief popularity, they have essentially been abandoned because of their inherent drag and problems associated with shifting air. The backplate and backmount buoyancy compensator system has become the accepted state

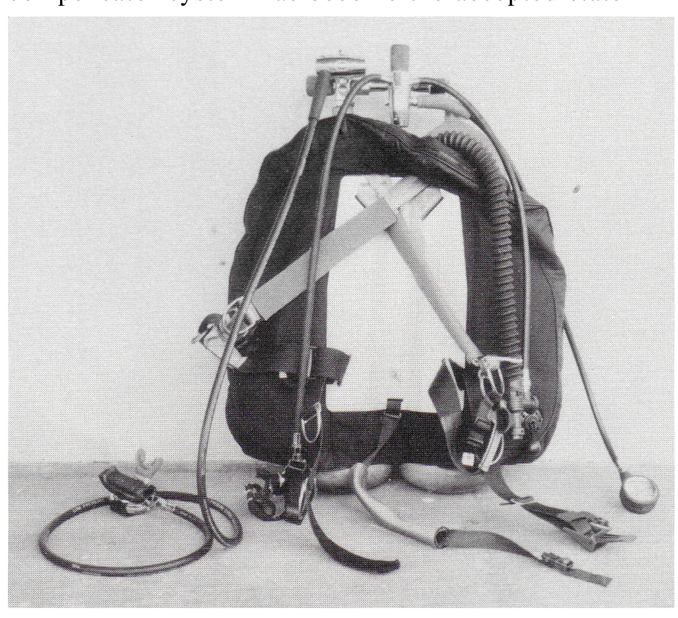


Figure 5-10 A set of double 104's with regulators, wings and backplate attached.

of the art for all double tanks configurations.

PRIMARY LIGHTS

Primary lights come in a great variety of sizes and shapes with differences in both the type of batteries used and the type of light heads or bulbs. This is because different caves as well as different cave divers are served better by some light styles than others. For the purpose of discussing the pros and cons of lights we will divide the issue into two topics, namely batteries and bulb style.

Batteries

The next several years will be an exciting time for cave divers that are interested in light technology. The promise of rechargeable lithium batteries of sufficient capacity for diving lights is just around the corner. What this will mean is smaller lights of greater capacity. For now, though, we must be content with available technology in rechargeable cells. Primary, or non-rechargeable cells, do not present an economically attractive alternative. (The word *primary* as used to describe batteries has nothing to do with the way cave divers use the word to describe their main lights.) There are three types of rechargeable cells that are commonly used to provide power for cave diving primary lights. They are:

1. Wet cell NiCads (nickel cadmium)
2. Dry cell NiCads
3. Gel cells (typically lead calcium)

Wet cell NiCads are swiftly becoming a thing of the past for primary lighting systems. Though they were extremely rugged and served for many years as the battery system of choice, they also were very messy and maintenance intensive. Constant attention was needed to keep the packs clean, filled with electrolyte, and cycled to provide full capacity. Their main advantages were their ability to tolerate abusive discharge rates and then be recharged at rates which would destroy most other cells. As batteries became available which did not require as much time and effort to maintain, fewer and fewer cave divers elected to use wet cell NiCads.

Dry cell NiCads overcame many of the maintenance problems associated with wet cells, but there were some sacrifices. Divers could no longer fast charge their battery packs off their car batteries. However, most divers found they were willing to purchase multiple packs in order to avoid the maintenance hassles of wet cells. Unfortunately, these cells have one other problem. Typical of NiCads, they would develop a “memory” if not cycled regularly, and then fail to deliver full capacity. This was especially noticeable in small rechargeable back-up lights which often failed within a few minutes of being turned on. Main was among the first to suggest that ordinary alkalines were better suited for back-up lights than rechargeable NiCads. Since these lights are rarely used they do not get cycled often enough to keep rechargeable batteries at full capacity. But this fact also makes the use of non-rechargeable alkalines a perfect candidate for back-up lights. Some divers developed the habit of burning their back-up lights during decompression to cycle the cells, not realizing that the high intensity lamps used in these lights had a short life span — about 20 hours). As cave divers discovered that their rechargeable back-ups were highly unreliable the switch was quickly made to alkalines. But, there was still a desire for lower maintenance rechargeable batteries for primary lights.

Lead acid batteries, utilizing a gelled electrolyte, solved the maintenance problems associated with wet cells and did not exhibit the memory problem that NiCads were prone to. Their main drawback is that they have a lower specific energy density than NiCads (power to weight ratio). In spite of this, they have become by far the most commonly used cells for primary lighting systems today. The combination of low maintenance and reliable burn time have outweighed other considerations for most cave divers. They are inexpensive and are available in a variety of sizes and capacities, which gives the light designer tremendous flexibility. Though there are still a few hold outs who cling affectionately to their NiCads, there is little doubt that Gel cells will continue to dominate the primary light arena until further advances in battery technology occur.

SPECIFIC ENERGY DENSITY OF COMMON BATTERIES USED TO POWER CAVE DIVING PRIMARY LIGHTS

CELL TYPE	WATT-HRS/LB (5HR RATE)
Lead-acid	6-10
Nickel cadmiium	12-15
Lithium chlorides*	50-100

**There are many different chemistries being investigated for Lithium cells and energy densities vary. All values given here are approximate and for comparison only. Energy density is also affected by packaging design.*

Bulb Styles For Primary Light Heads

Light heads come in various bulb configurations as well as various designs for each of these. For the purpose of this discussion we will categorize them according to the type of bulb used (Figure 5-11). These categories are:

1. Sealed beam heads
2. Test tube heads
3. Projector bulb heads

Sealed Beam Light Heads

Say what you will, there is little doubt that the sealed beam light head has been, and still is, the most successful style light head in cave diving. There are, of course, many reasons for this. Sealed beam bulbs (almost always in size PAR 36) come in a variety of wattages that happen to fall in the useful range for cave divers. *Useful* is defined as bright enough for a primary light without requiring a battery pack the size of a stage bottle (although underwater cinematographers may take exception to this definition). Indeed the most common definition of *acceptable brightness* for a primary light is based on the light output of a 30 watt sealed beam bulb, although these have largely been displaced by the 37.5 watt quartz halogen sealed beam bulb. Most lists of cave diving equipment requirements will include a statement like: "Primary light of intensity equal to or greater than a 30 watt sealed beam."

The early innovations of Frank Martz no doubt paved the way for much of the sealed beam bulb's popularity. And it didn't hurt when Bob Goodman began building and selling primary lights of legendary quality using sealed beam heads and wet cell NiCads. These lights provided extraordinary reliability, adequate burn times, and ample brightness. For all these reasons they are still popular today, though most divers have replaced NiCads with Gel cells. The highly polished reflector and precisely manufactured bulb provide an efficient and consistent light source. No matter what the origin of a sealed beam head it should provide the exact light output as someone else's for a given wattage and voltage. Still, sealed beams aren't perfect. They have a nasty habit of imploding on extremely deep dives (usually in the 300 fsw range, plus or minus 50 fsw).

Test Tube Light Heads

Many divers who wanted a light head that would survive extremely deep dives have selected the test tube style configuration. This style light head uses a small halogen bulb, enclosed in an 0-ring sealed glass tube, and mounted in a polished parabolic reflector. The main advantages of this configuration are its depth capability and the fact that bulbs of extremely high wattages (100 watts and higher) are readily available. This can be very useful in lighting up rooms or tunnels that exceed 100 feet in width. The negative side of this is that large battery packs must be carried or burn times will be very short.

One advantage that is often cited for test tube style heads is the ability to focus the light output from tight spot to broad flood by moving the parabola back and forth. However, this feature is mostly defeated by the fact that specific parabolic reflectors are generally designed to do one or the other (i.e., broad illumination or tightly focused beam) and lose efficiency when applied otherwise. Thus, a reflector that was designed for a tight spot beam will result in concentric bands of shadows when "focused" for broad illumination. A reflector that was designed for a flood type beam can rarely be positioned too provide a tight spot pattern at all.

There are some disadvantages associated with the test tube style light head which deserve mention. Test tube heads are generally more fragile that sealed beams because of the fragile, exposed test tube. However if thick walled glass test tubes are used then this disadvantage is mostly negated. Test tube style heads are also GENERALLY less efficient because the light from the bulb must travel through the water before being reflected off the parabola. This means that a 50 watt sealed beam will probably put out more light than a 55 watt test tube style head, especially in murky or turbid water. Test tube heads are also highly variable in light output from a given bulb, depending upon the reflector used. There are dozens in use, salvaged from all manner of sources, some very good, and some not much good at all. If you elect to purchase this type head be sure you see what the light looks like IN THE WATER. The refraction caused by water improves some and hurts other reflectors, but it will definitely change. Trying to make a comparison in air is almost useless. Try to make a dive using the test tube light you are interested in with another diver who is using a sealed beam of comparable wattage. Then make your decision after factoring in the type and depth of diving you typically do.

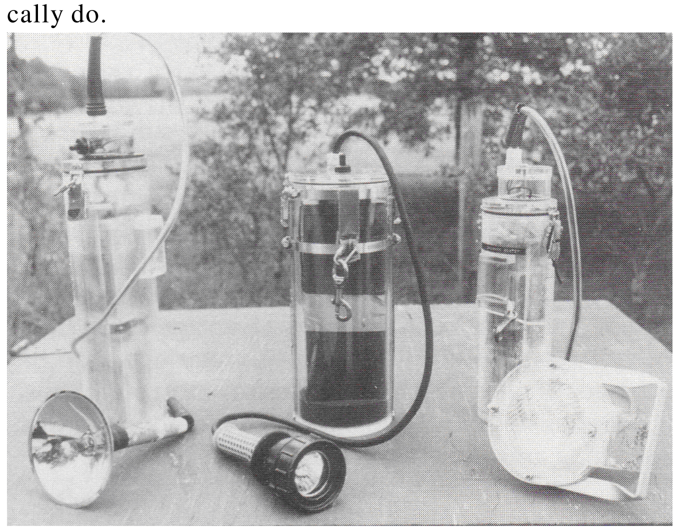


Figure 5-11 Test tube, projector bulb, and sealed beam light heads.

Projector Bulb Light Heads

Projector bulbs come in a variety of voltages and wattages, making it possible to have one light do many things. Projector bulb light heads are very small and compact which reduces drag and makes it easier to construct rugged light heads that will handle great depth. However, this small size has a disadvantage. The small reflector makes this type bulb somewhat less efficient than sealed beam or test tube style heads with larger parabolas. This means that greater wattage bulbs must be employed which requires larger battery packs. While many of these bulbs are ideally suited for underwater cinematography they may be less than ideal for typical cave diving.

Goodman Handle

One thing that is certain about light heads is the advantage afforded by the Goodman style handle shown in Figure 5-12. The diver slips her hand through the handle, with the head resting on top of her hand and her fingers free to pull through the cave, operate an inflator, read a pressure gauge, or hold on to a scooter. The flash-light style handle does not leave the fingers free to perform other tasks, thus rendering one hand useless except to hold the light. With the tremendous surge in popularity of diver propulsion vehicles in cave diving, many divers are finding the Goodman style handle more suited to their needs. The odd thing is that prior to scooters the Goodman style handle was probably even more valuable since it made pulling your way into a high flow cave much easier. Divers who are unfamiliar with this style of handle consider its appearance strange, but its contribution to speed and efficiency on long dives is impressive.

Having covered primary lights in some detail it is now appropriate to make a couple of general comments. First, a primary light should have a burn time long enough for the dives you plan to do with some margin of safety. A minor delay can turn into a major problem if you run **out** of light before the dive is over. This has in fact resulted in fatalities where air planning was adequate but light planning wasn't. How much reserve you need depends on the specifics of the dive, but at least 30 minutes is advisable. As a general guide, a primary light should provide two to three hours of burn time. Second, the useful range of wattage for typical primary lights is from about 30 to 100 watts. From 37.5 to 50 watts is ideal for most situations. Remember that a 100 watt bulb is going to require at least twice the weight and size bat-tery pack that a 50 watt needs to achieve equivalent burn time.

Back-Up Lights

It may seem unnecessary, but for the sake of thoroughness, lets define what a back-up light is. A back-up light is any light that is used in the event of a primary light failure, regardless of its size or shape. According to this definition we could dive with three large canister lights, using two of them for back-ups in the event of a primary light failure. In the past this might not have been such a bad idea since the high voltages associated with over-volted NiCad packs caused frequent bulb failures. Today though, the switch to Gel Cells has pretty much eliminated this problem. It is not unusual to make 200 to 400 dives without a primary light failure. In view of this, we would be hindering ourselves unnecessarily by car-rying more than one primary, unless we had some spe-cial purpose like underwater photography. If a primary light does fail, we are going to exit the cave at this point. From then on, we are no longer sight seeing: in fact, we are just trying to follow the line out without getting lost or wasting too much time. Because of this, back-ups do not have to be nearly as bright as primary lights. We want these lights to be bright enough to exit the cave with, but small enough not to hinder us during a normal dive. They must also be extremely rugged and reliable since when we need them we really NEED them. They had better be able to provide this reliability with minimum maintenance and their configuration must be one that is easily stored. Quite a bit to consider. Let's make a list of the choices we have to make:

1. Number require (and desired)
2. Style (size, shape, etc.)
3. Brightness required
4. Burn time required
5. Type of batteries (rechargeable or not)
6. Where to carry them

For many years the standard requirement for cave diving had been a minimum of three lights per diver.

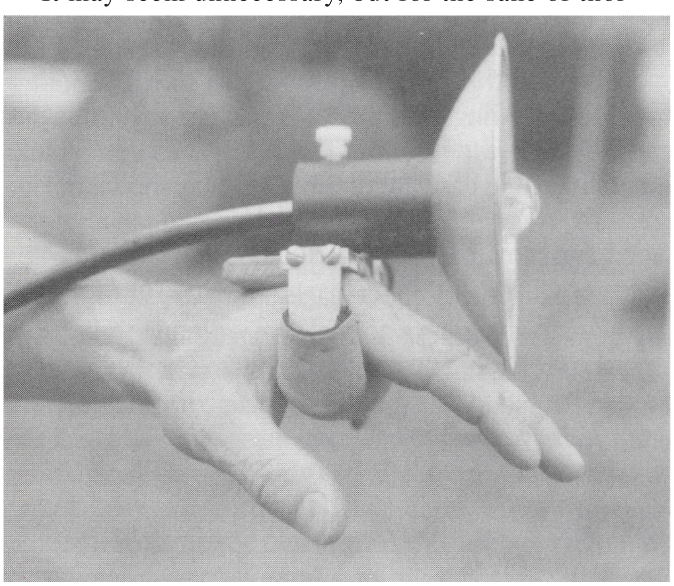


Figure 5-12 Goodman style handle.

Figure 5-13 Assorted back-up lights. The more streamlined the better.

This dates back to an early estimate that the probabilities of a light failure occurring during a dive was about one in fifty. Therefore the probability of two lights failing on the same dive was one in 2500, and for three lights this shrunk to one in 125,000. Pretty good odds even with-out considering that your buddy has three more. This makes the odds of a total light failure (all yours and all of your buddy's) one in 15,625,000,000. In spite of this there have been instances where divers claim to have witnessed a half dozen or more light failures in a single dive. What's wrong with this picture? The most likely explanation was that the lights didn't "fail" but rather they burned down right on schedule. If your light has a burn time of 90 minutes and you're doing a 90 minute dive, don't be surprised if your failure rate is high. The next explanation is one that few will admit to but is probably widespread: poor equipment maintenance.

The fact is that today's cave diving lights are much more reliable than those in past years. Their MTBF (mean time between failures) may be as high as 200 dives or more. If your lights fail frequently there are two possibilities. Either you've got the wrong light — or the lights are on and you're not home. Actually this may literally be the case. The most popular back-up light used in cave diving employs a screw down lens to turn the light on. If not backed off several turns past where the light goes out the batteries can discharge even though the light doesn't appear to be on. These lights can also be pressure acti-vated if not backed off far enough. In this case the light didn't fail at all — the diver did because she burned the light before she needed it.What all this is leading up to is that three lights per diver is still an adequate number. In fact it is more so today than ever before. If a diver is solo diving (or just nervous) then carrying a fourth back-up light is fine. But carrying five or six or even more lights is both a hindrance on long dives and probably a safety hazard. Reducing your chances of a total light failure to one in 10 trillion while increasing your chances of a line entanglement to one in ten is a poor trade off. Actually it goes beyond just a line entanglement hazard. Every extra piece of gear that you carry makes it harder to access every other piece that you're already wearing, for two reasons. First, they get in the way of each other and second, you've got to remember where more things are.

The most popular style of back-up light for cave diving is probably the three C-cell cylindrical light using a screw down lens as the on/off switch. These lights are inherently simple and rugged. They provide enough brightness for following line while still being small enough to store cleanly and not hamper a diver. Remember to back the lens off until the 0-ring is just covered and they will rarely fail. These lights provide a baseline for both brightness and bulk. A light that is significantly less powerful is going to make following a line more difficult. A much larger light will be difficult to store cleanly and will hinder you unnecessarily.

Primary alkaline cells are the most suitable batteries for back up lights because of their long shelf life, ex-

Figure 5-14A Hogarthian back-up light configuration: secured.

tended burn time, and low cost. Maintenance consists of rotating new batteries into the light every few months (if not used) and cleaning the 0-ring. Since back-up lights are generally not maintained as well or as often as primary lights they must be simpler in nature. This makes the use of rechargeable cells for back-ups undesirable.

One of the neatest (and simplest) innovations in cave diving gear configuration was Bill Main's solution to the problem of where to carry backup lights. In the late 1970's he began attaching his back up lights to his shoulder straps using D-rings and pieces of bicycle inner tube cut into 3/4 inch wide bands. The result was completely streamlined and easily accessible lights as shown in Figure 5-14. This became the standard Hogarthian configuration and remains unchanged today.

One final word about back-up lights. Because we rarely use them during a normal dive we tend to take them for granted. We use them during decompression, or after the dive, or just to take the trash out at night. The problem is that bulbs (as well as batteries) have a limited life. If the bulb in your back-up light has an average life span of 20 hours and you've spent 19.5 hours using it to read during decompression then you're going to have a problem some day. Remember that the next time you reach for a cave diving back-up light for some nonessential purpose.

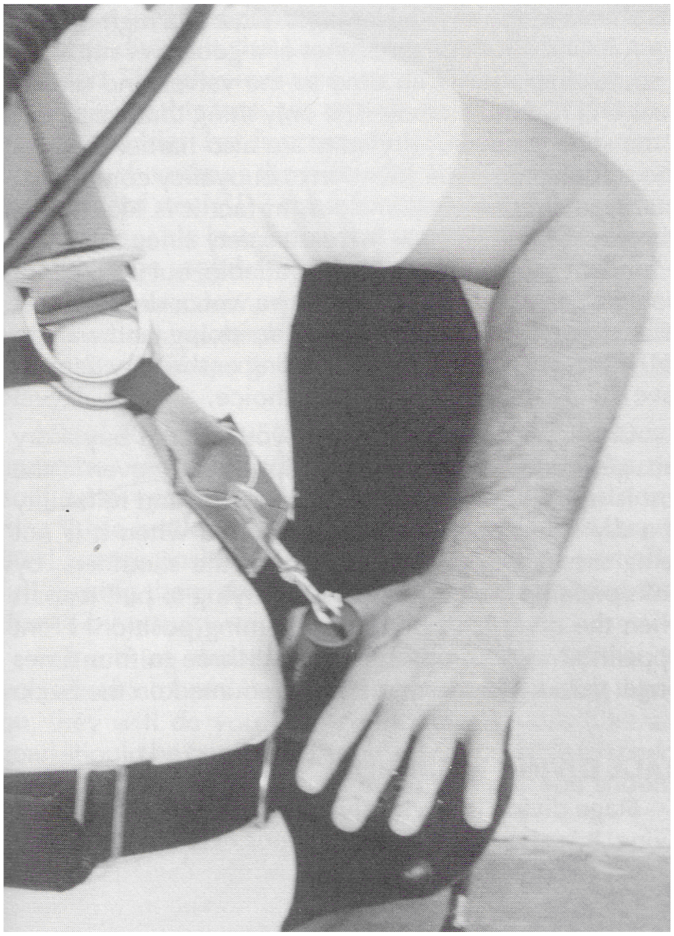


Figure 5-148 To use, grasp light as shown, then ...

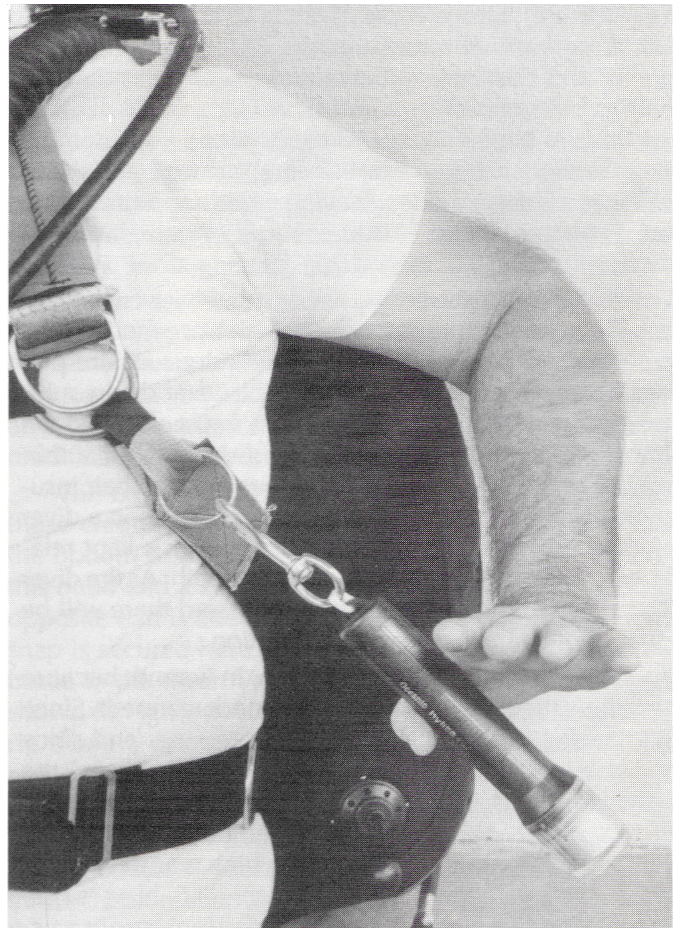


Figure 5-14C Pull light free of retaining band & release clip.

DIVE EXPOSURE SUITS

Cave diving is an activity that takes place all over the world in almost every climate. Thus the degree of thermal protection needed will vary considerably. If you are diving in very warm water (as found in Mexico's Yucatan peninsula) then the requirements for keeping warm are not very severe. For shorter dives a thin (1/8 inch) neoprene wet suit may be all that is needed. However, because of the extremely long nature of most cave dives, more protection than this is usually required in most parts of the world. The decision that most cave divers must make is whether to buy a good 1/4 inch farmer-john wet suit or to go for broke (sometimes literally) and buy a dry suit.

Wet Suits

Wet suits have the advantage of simplicity, which makes them cheaper and in some ways more reliable than a dry suit. Since they have no seals or waterproof zippers to deteriorate, wet suits will generally last longer with less maintenance than dry suits. They are also easier to learn to dive since they do not represent an air volume which must be adjusted in order to achieve buoyancy control. Wet suits also produce less drag in the water giv-ing them a slight advantage over dry suits in swimming (or scootering) speed. And finally, with the newest and stretchiest neoprene suits, there is a greater flexibility and range of motion with wet suits.

Unfortunately, wet suits do not keep a diver as warm as a dry suit even in shallower water. On deep dives (approaching 200 fsw and beyond) they are almost completely ineffective because of suit compression. This would seem to indicate that wet suits are suitable for shallower dives or for short deep dives. While this is for the most part true, there is one caveat. Very deep dives, with the associated extreme suit compression, can permanently reduce a wet suit's thermal insulating qualities.

The general trend among divers using wet suits for very long dives is multiple layering. By wearing thin tunics or even full 1/8 inch suits in addition to their 1/4 inch farmer-johns they seek to eliminate water move-ment in and out of the suit. There is of course a trade-off in that the more neoprene you put on, the less flexibility you have. This negates at least one of the advantages of diving a wet suit.

Dry Suits

Dry suits have been the object of a love-hate relationship with cave divers for many years. We love them when they work and when they don't we contemplate alternative hobbies. Dry suits are more complex and require much more maintenance than wet suits. The fact that they are more complex results in an availability of suits from various manufacturers that range widely in quality and cost. As a general rule, a dry suit is not a thing to be economical about. That is, if you've decided you have to have one, spend every penny you can. The cheaper dry suits won't last as long or work as well as the more expensive ones, leaving you disappointed and wet. Expect to spend $1000 or more on a high quality dry suit.

Dry suits can be loosely described by two catego-ries. There are neoprene dry suits which are made of the same material as wet suits. Neoprene dry suits are per-haps a compromise between wet suits and fabric dry suits. They are generally close fitting, like a wet suit, and are almost as flexible. They allow the diver to wear a thin sweater or undergarment, but achieve most of their insu-lation from the thick neoprene. These suits keep a diver much warmer than a wet suit because she is kept rela-tively dry, but they are still affected by depth. As the diver descends and the neoprene is compressed there will be a loss of buoyancy as well as insulation.

Fabric dry suits offer the ultimate in warmth because they allow the diver to wear a heavy undergarment. Since air is added to the suit to equalize pressure (and since the undergarment has open interstitial air spaces) the undergarment is not compressed and thus retains its insulating quality. By far the best material for an undergarment is Thinsulate, a 3M product which was developed into dry suit undergarments during the U.S. Navy's Passive Diver Thermal Protection System programs. Thinsulate retains more of its insulating value when wet or damp than any comparable material. For very long or very deep dives, or any combination of the two, a high quality dry suit with Thinsulate underwear offers the highest degree of warmth.

Dry suits present the opportunity for yet another advantage in warmth. Since many long or deep dives involve helium mixtures, it is necessary to carry a separate small tank to inflate the dry suit. This is because the thermal conductivity of helium is so high. (For comparison, an 80/20 $He0_2$ mixture has a thermal conductivity 84 times greater than air.) While this at first seems like an added nuisance it can be a major plus. Rather than using air in this bottle the diver can substitute argon, an inert gas. Argon has a thermal conductivity of about 0.68 times that of air. This means that you will stay considerably warmer in a dry suit that is filled with argon versus one filled with air. Of course you will still lose heat through respiration and any unprotected extremities, but it does amount to a significant difference. Carbon dioxide would theoretically be an excellent choice also, but has problems associated with the formation of carbonic acid if the diver sweats (causing a burning sensation like sunburn) and CO_2 inside a dry suit might increase the chances of skin bends. Argon seems to have none of these problems and is readily available.

Dry suits offer a tremendous advantage in thermal insulation over wet suits, especially on deep dives. There are of course some disadvantages. Cost of a high quality dry suit is about three times that of a good wet suit. This is somewhat offset with time as the valves and underwear will last indefinitely. The only thing that wears out is the shell itself. But dry suits are also harder to dive. They require the same attention to buoyancy control that a buoyancy compensator does. In fact it is like diving with two BC's. This may increase safety since there is a redundant source of buoyancy available, but it does task load the diver. The decision to buy a wet or dry suit must be based on the type of dives you are doing (and want to do). If you contemplate the very long or the very deep in cave diving then you have little choice.

One final piece of advice. If you elect to buy a dry suit, get one with a front style zipper entry even if the cost is significantly higher. The durability and reliability of a dry suit zipper is greatly increased when it is not being stressed by arm movement at the shoulders, by tanks pressing on it, or air pressure trying to pull it apart when the diver is in normal swimming position. Front zippers have been observed to last three to four times longer than the same type zipper mounted on the back.

STAGE DIVING EQUIPMENT

Stage diving is obviously an advanced form of cave diving. It is also a vital part of serious exploration. Many people will cave dive for years without ever stage diving. Others will use this technique almost every time they get in the water. Stage diving should only be attempted once all other gear problems have been sorted out and the diver has gained experience. If there are still problems with gear or technique then stage diving will only aggravate them. Once a diver has mastered the normal equipment of cave diving she can greatly expand her capabilities by moving on to stage diving if she has the desire.

Stage diving is not just a way to go further in a cave. It is a way to increase safety. The presence of additional sources of air in the cave should make any dive safer if it is planned correctly.

Stage Bottles

Almost any single tank can be used as a stage bottle but some are more suitable than others. In general the tank should not be extremely negatively or positively buoyant. This rules out many tanks such as 104's. A negative tank will slow a diver and cause her to work harder since she must over-inflate her BCD. Many divers have tried using larger capacity stage bottles to increase their range only to find no advantage. Some realize immediately that the heavier bottle is hindering them to the point that the extra air is barely able to cover the extra work. Others remain confused as to why they can't go much, if any, farther on a larger cylinder. They overlook the most important aspect of a stage bottle, that it be close to neutrally buoyant.

By far the most popular and perhaps best suited tank for stage diving is the Luxfer aluminum 80 cubic foot cylinder. The physical size, air volume capacity, and buoyancy of this tank are as near an ideal compromise as any cylinder :hat is presently available. Next on the list are such tanks as the Kidde 80, the Catalina 80, and the standard steel 71.2 cubic foot tank. All of these tanks have reasonable buoyancy characteristics and are large enough to be useful as stage bottles.

Some tanks that are definitely not recommended for stage bottles are: steel 104's (Sherwood/Pressed Steel), steel 95's (Scubapro's Faber), and aluminum 90's (US Navy).

Steel 104's and 95's are simply too negatively buoyant to be used efficiently as stage bottles. Adding buoyancy tubes will increase drag and make doffing and donning these bottles more difficult. Aluminum 90's (Navy 90's) are too positive. They will float when still partially full making them awkward to handle and upsetting the diver's buoyancy.

One thing should be noted about stage bottles. If you waste a lot of time taking them off and putting them on, they will do you little good. Stage bottles (like all gear) should be configured as cleanly as possible to speed up the process of getting them on and off. You should practice with your stage bottles to the point that you can remove or replace one in less than one minute. Otherwise you are wasting valuable time and gas. Few things are as frustrating as watching your buddy struggle for five minutes with her stage bottle while you waste your own gas and get colder by the minute. It is interesting to note that many people who take inordinate amounts of time to don stage bottles are the same ones who are searching for larger capacity bottles to use.

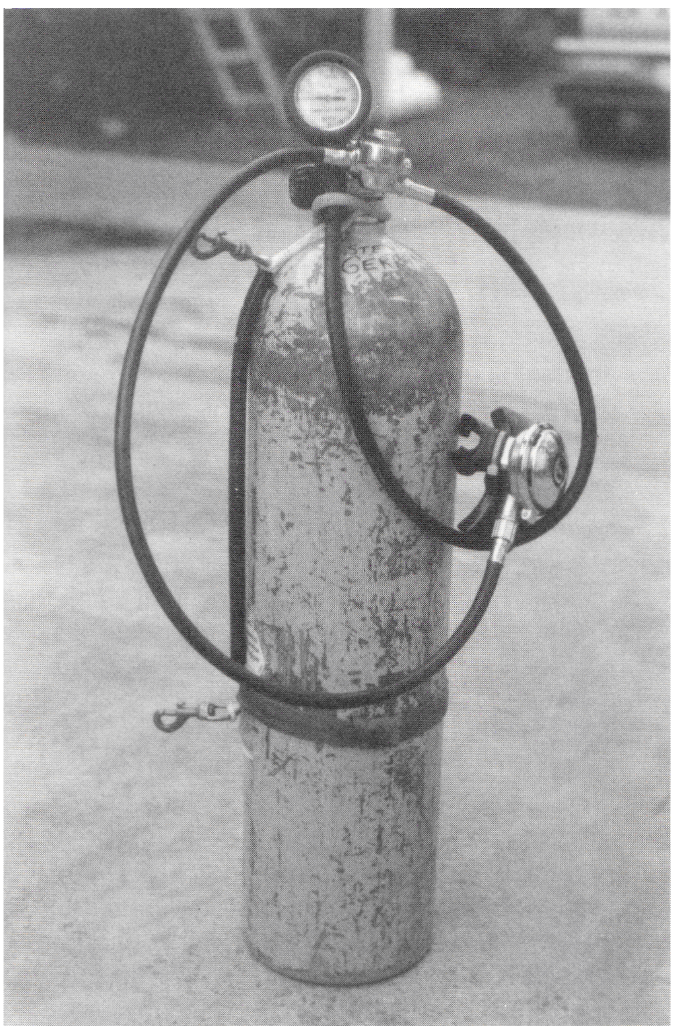


Figure 5-15 Stage bottle rig.

Regardless of which tank you choose to fashion into a stage bottle, the method and hardware will be about the same. There are many variations on this theme, but only one will be addressed. The differences are minor and only experience will determine which particular modifications are best suited for each individual.

The basic stage bottle rig consists of a metal band (hose clamp, etc.) mounted about 1/3 of the way from the bottom of the tank. A strap or rope is placed under this band and a clip or snap is attached at this end. The opposite end is attached to the tank valve and a second snap is secured here. The two snaps serve to attach the bottle to the diver. This author began using the method shown in Figure 5-15 in 1988. It is faster and simpler to rig a bottle using rope like this than the traditional flat nylon strap. The rope is first doubled and pulled through a piece of tubing (rubber, nylon, etc.) about 1 foot long. This makes for a more comfortable handle for transporting the bottle. The looped end of the line is then passed through a brass snap and the handles passed back through the loop. This end is then placed under the metal band which is tightened in place. The brass snap is held in place below (not under) the band and prevents the rope handle from pulling free. The opposite end of the rope consists of two free ends which are led around the valve after being looped through a second brass snap. Trim the leftover rope, burn the ends, and you're finished. If desired, a rubber strap may be placed on the tank before the rope is secured to the valve. This is handy for securing the pressure gauge hose, etc. Simple enough? If you are using a Luxfer 80, the nylon hose should be about 15 inches long. You will need about 5 feet of 1/4 inch braided nylon rope. The rubber strap can be cut from an old tire inner tube.

Stage Bottle Regulators

The stage bottle regulator is often chosen without much thought and is frequently a "leftover" regulator of questionable condition and quality. Since the stage bottle is not the diver's primary source of gas there is a tendency to put less effort into its preparation. The consequences of this are predictable: frequent failures and aborted dives. Choose the regulator for your stage bottle as though your life depended on it, since obviously it DOES. Many divers will pay top dollar for the highest performance regulator available to use as their primary and use anything they can get a good deal on for their stage bottle regulator (not to mention their secondary). Maybe this is why some people don't want to hand off their primary regulator. The point is that EVERY regulator you breathe from is just as important as ANY other. (The only exception to this is a regulator that is strictly for decompression. This regulator will generally be used at shallow depths and low work rates and can be switched underwater if necessary in an emergency.) Your stage bottle regulator is used at the point during the dive when you are probably working the hardest because you are carrying the most gear. Don't cut any corners in its purchase and maintenance.

There are two choices in routing the second stage supply hose from your stage bottle. The traditional method is to fold the hose in front of you so that the second stage can be placed in the mouth right side up. Though this is not an issue with some regulators, it is still necessary to place a bend in the hose. Many people find this uncomfortable since it places a twisting or tugging force on the mouth piece. This can be especially aggravating when riding a scooter (DPV).

An alternative method is to use an octopus length hose and route this around your neck and in your mouth, much the way the hose would normally come over your shoulder if you were using a single tank with backpack. This is much more comfortable and has the advantage that the second stage is easily located if dropped from your mouth. There is a disadvantage to this method if you are wrapping your primary (long) hose around your neck. Care must be taken not to cross the two hoses and not to confuse them. Different color mouth pieces help avoid this confusion. While this hose is around your neck it will be difficult to hand off your long hose, but this should not be necessary anyway if your buddy is also staging. If you must assist an out-of-air diver while you are staging, the simplest procedure is to hand off the stage bottle regulator and then immediately hand off the entire stage bottle to the out-of-air diver. This is another good reason for practicing stage bottle removal. If you are fortunate enough to have a stage bottle available when your buddy needs gas, count your blessings.

SUMMARY

A diver's cave diving ability is a function of three things. The first is her natural physical and mental ability. Some of this is innate, but all of us can improve in this area by hard work. The second is gear. No one has any predisposed advantage in this area. You may not be making record setting dives, but your gear can be as good as anyone who is. The last is desire. It determines how much effort you will put into the first two areas, and how far you will decide to go with the ability you develop. Physical ability, skill in the water, experience, and judgment can only be developed over many years, but gear can be perfect just as soon as you make the effort.

This chapter can be looked at on two levels, and hopefully it is valuable on each. First, it can be viewed as a presentation of a specific gear configuration that has proven very successful. While this is worth something to the reader it is perhaps less important than the second level. The second level can be thought of as "Zen and the Art of Cave Diving Equipment Maintenance." It is more subtle and requires that the reader look for under-lying values. To put it as simply as possible, a cave diver must care about the work she is doing on gear and the quality of the final result. She must put aside ego, impatience, and excuses, and settle for nothing less than perfection. Those who do so will discover on their own the value of such effort. Those who don't will never quite understand what the others are talking about.