GUE Fundamentals
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&
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The history of underwater exploration is filled with striking personalities and noteworthy actions. However, with the emergence of scuba diving, underwater exploration took on a new form. Initially driven by commercial and military interests, underwater exploration with scuba would later grow to include recreational divers, who embraced underwater exploration as their life’s passion and who sought to develop the best tools possible to complement their exploration needs. While the sport was in its infancy, and choices were limited, these divers did not vary greatly in terms of their equipment and configuration. Furthermore, given that training options at the time were also limited, these divers also shared very similar As more people took up scuba diving, however, variation in equipment, training, and equipment configuration grew. With ever-growing numbers of people finding pleasure in open water, no decompression diving, came a collective identity reflecting the interests of its participants - recreational diving. An entire industry would soon follow to serve these interests. Concurrently, another identity would take shape, one tied to a group of divers, some coming from within recreational diving, some from without, that pushed the limits of recreational diving, by committing themselves to the exploration of increasingly more demanding environments; e.g., ice, caves and deep wrecks. Over time, these two groups would diverge and each would follow its own trajectory. The somewhat vague (in part arbitrary) categories of “technical” and “recreational” diving were set up to describe these two trajectories.

Given the different orientations of recreational and technical divers, it should come as no surprise that different training practices, equipment choices, and configurations would emerge to answer to the wants of each. The evolving idea of what it meant to be “recreational” led to some divergence regarding what one needed to know to remain safe during dives of minimal difficulty. Therefore, dive training tended to become shorter, with minimal treatment of topics such as gas planning, breathing gas concerns, decompression and crisis management. Likewise, this shift led to greater variation with respect to equipment choices and to how this equipment would be configured. However, the needs of technical diving required generally greater knowledge of these areas, more precision, more attention to detail, refined skills, practiced crisis management, a sound configuration, and well-crafted and well-maintained equipment. Conventions foreign to the recreational diving community, such as the “thirds rule,” the use of a long hose, and the use of a redundant regulator, emerged expressly to address the needs of the technical diver. However, in time, it became apparent that the more precision and the more proficiency that
were required to pursue exploration-level technical diving, the more need there was for a unified system. This is because it was impractical, if not impossible, to operate efficiently as a team if individuals were not functioning under a common set of constraints.

Regardless of environment, there exists substantial variation among divers with respect both to the value they place upon efficiency and to how intensively they seek to extend the limits of their diving practice. I would argue that what position divers take on issues of efficiency is largely tied to the nature of their diving. For instance, it is clear why early divers did not consider the need for standardization urgent. This is because their diving was less aggressive and, thus, less likely to call attention to the value of efficiency. However, as diving becomes more aggressive and more complex, the benefits of precision and efficiency become progressively more obvious; individuals undertaking such dives quickly realize the benefit of standardizing nearly all aspects of their diving to make it more efficient. So, when evaluating different equipment configurations—from those used in the early days of underwater exploration, to those representing general Hogarthian ideas, to the evolving principles of Doing It Right - it would be useful to keep in mind the ties linking efficiency to complexity.

As a greater number of divers (both recreational and technical) discover the value of efficiency as a means of improving the quality of their diving, standardization, in both training and equipment, seems the likely future of diving practice.

The public first became aware of the movement toward standardization, and of its value, when the Hogarthian diving system became popular. This scheme was composed of a rough set of ideas and equipment recommendations that served as useful standards for measuring desirable aspects of diving configurations. Cultivated by a small collective of cave explorers—e.g., Bill Gavin, William “Hogarth” Main, Lamar English, George Irvine and myself—the idea behind this “system” was that there were preferred methods of configuring equipment, and that these methods had a profound effect upon diving efficiency. Bill Main invested considerable time seeking the most streamlined configuration possible, which resulted in his middle name being chosen to represent the overall “system.”

Though useful, the Hogarthian system did not require the use of a specific piece of equipment or a particular configuration. Therefore, it did not provide divers with an objective diving standard that would ensure efficiency in the water and was thus limited in its utility. However, by promoting the idea that a careful selection of equipment and configuration could substantially impact the success of a dive, Hogarthianism introduced a dynamic, new paradigm to divers and encouraged them to seek improvement through minimalism and streamlining. Armed with this new perspective, many divers (myself and the above explorers included) sought to assemble the most efficient equipment configuration possible, often sharing our findings with the public at large.
Rather than provide divers with an objective standard to assemble their configuration, Hogarthianism offers a loosely knitted set of ideas that, in the interest of diver efficiency, promotes an ethos of careful gear selection. However, this lack of an objective standard does not permit divers to understand what exactly constitutes a Hogarthian diving configuration; instead this “system” varies according to how different advocates of Hogarthian diving see the links tying together equipment, streamlining and efficiency. This disparity of opinion, along with Hogarthianism’s singular emphasis on equipment (versus general diving practice) has led to considerable confusion among the diving public (it is extremely difficult to standardize, in both theory and practice, what, in all respects, is largely subjective in nature). Eventually it became clear that both a more complete system and greater standardization were needed; to be as useful as possible, the components of the system would need to be objectively arrived at and standardized. George Irvine and I, having worked extensively with the Hogarthian system, and having written extensively about it, worked toward this new paradigm. This new paradigm emerged as Doing It Right or DIR.

As the first holistic diving system ever crafted, Doing It Right began to gain significant popularity in the mid-1990s; a key component of its success was the detail and care that guided its growth. By adhering firmly to standardization, DIR initially faced opposition from diving quarters that saw the loss of “personal preference” as a notable sacrifice. Even so, with the gradual recognition that it is impossible for a team of divers to be efficient in the water without notable uniformity in equipment, training and configuration, opposition began to erode and today continues to erode. This is because divers have begun to realize that in terms of wasted energy and effort there is a significant penalty for stubbornly seeking to maintain an individual “style.” Why reinvent the wheel alone when there is a proven system that ensures safety, efficiency and success in the water?

Because DIR’s insistence on standardization is frequently misunderstood, it sometimes becomes a source of tension among divers. This is because some see the insistence on uniformity as an indictment of practices that do not abide by DIR principles. However, there is nothing essentially hostile or critical about DIR; in its most basic form, it is ultimately pragmatic, promoting the concept of uniformity within and among teams of divers. However, to be fair, there is a certain degree of legitimate tension generated by imprudent advocates of DIR, who, having personally benefited from the system, take it upon them to become almost evangelical in the promotion of what they understand to be its tenets. However, this is not an intrinsic weakness of DIR; all successful movements have their zealots.
DIR, by crafting a set of objective standards meant to regulate diving practice, triggered a paradigm shift in diving, one that will forever modify the way that divers evaluate their diving. It is now part of our ethos to believe that divers acting cohesively and with shared purpose are more efficient. Nonetheless, considering standardization in isolation is unfair to the system’s holistic approach.

As a well-defined, standardized system, DIR was designed to maximize efficiency across multiple environments in order to promote safety and fun. Among its key principles are:

**Unified team**

Central to the DIR diving system is the concept of a unified team. This system pairs divers of similar capacity within an environment that they are properly prepared for. Teams of individually capable divers produce a level of safety and efficiency beyond what is capable while diving independently. Few things are as rewarding as diving within a group that maintains a similar degree of care and focus. Any diving activity where the concept of a team is marginalized will always fail to maximize its potential with respect to fun and safety.

**Preparation**

For DIR, preparation for diving involves five primary components. These are: pre-dive preparation, mental focus, physical fitness, diving experience and dive planning. Divers who try to circumvent any of these areas are not adequately prepared for the dive and stand a good chance of experiencing reduced comfort, a missed dive opportunity, or even a dangerous situation. With ill effects, far too many divers assume that dive preparation begins the day or even hours before the dive.

**Streamlined equipment**

The elements comprising a standard DIR equipment configuration have been endlessly discussed and are now well known. For those seeking more information on this subject, please refer to my book, *Doing it Right: The Fundamentals of Better Diving*.

In short, the DIR configuration was designed to work in all situations and to ensure safety and promote a diver’s efforts, not undermine them. Streamlined and minimalist in nature, the DIR configuration was designed to maximize a diver’s efficiency while minimizing his/her risk. Items should not hang free or protrude from the diver’s body, increase drag or cause entanglements.
Balanced rig

The DIR rig is a carefully weighted rig; one that ensures that while a diver is not overweight, s/he is able to hold a decompression stop in the face of a catastrophic gas loss. This requires a careful assessment of the component parts of one’s configuration, and how these each impact - statically and dynamically - on the buoyancy characteristics of the configuration as a whole.

Cylinder labeling

DIR embraces the uniform practice of marking cylinders with the Maximum Operating Depth (MOD) in a clear and easily identifiable manner, and utilizing only this data to identify bottles. This practice prevents divers from becoming accustomed to unreliable identification procedures.

Standard gases

DIR promotes reliance on standard gases for all phases of diving. Standard gases help to insulate divers from the risks of inappropriate gas ratios, provide a common platform for cylinder marking and gas mixing, ensure team symmetry and vastly simplify decompression logistics.

Conservative gas parameters

DIR promotes conservative gas parameters for all phases of diving. Among these are: ENDs of <100, working PO2s of 1.4 and less, PO2s of 1.6 and less for decompression. To offset the toxic effects of oxygen, nitrogen and carbon dioxide, DIR recommends the liberal use of helium together with the conservative use of oxygen.

GUE diving

To a careful reader, a casual review of diving history will reveal a movement toward greater standardization. DIR’s place in history is assured given its role in introducing a new paradigm to the diving public, one where standardization provides divers with the key to efficiency, safety, enjoyment and success. Though there is still variation among divers, in time, the desire for proficiency will force them to migrate toward a known paradigm that through its insistence on standardization ensures phenomenal success in both extreme diving projects and recreational venues. For this reason, the trajectory that the history of diving will follow will speak volumes to the effects of the DIR movement.

However, as with all great movements, comes inevitable corruption and fragmentation. Today, DIR has spread to every corner of the globe, with self-appointed DIR groups emerging in dozens of different countries. Given their physical separation, their lack of centralized direction, their own specific agendas, beliefs, power struggles and constraints, these satellite groups cannot
help but to promote a version of DIR that is uniquely their own. This version of “DIR” will likely have little resemblance to the original. This will be the case, however well-intentioned, however devoted to the founding principles of DIR, these satellites may be.

The unavoidable division of DIR is the result of many factors, ranging from breakdowns in channels of communication, to differing interpretations, to personal agendas, to private experiences, to power plays, to simple disagreements among proponents. As individuals and groups appropriate DIR they will often make choices very different from those that I and other founders of DIR would have made. It is now necessary for us to recognize that DIR will be repurposed by those it has influenced in ways that serve their own interests. Nonetheless, in the end, I believe that these systems that appropriate DIR can only benefit the future of the diving industry. Even so, I believe that to enhance the safety, fun and efficiency we sought to ensure when we first started to build DIR, it is necessary for us to ensure greater standardization across a series of domains.

From the outset I believed that a diver’s training, his/her equipment, his/her configuration, his/her knowledge and skill set should all contribute to greater safety and enjoyment in the water. For this reason, I founded GUE. The DIR system is at the core of GUE training. This is not surprising, given the extent to which my efforts helped to shape both DIR and GUE. However, with the passage of time, GUE has shaped its own identity, one that is not identical to that of DIR. And though being DIR is a necessary condition of being a GUE diver, it is not a sufficient condition; it is not enough. There is more to being a GUE diver than being DIR, among other things, it entails a standardized measure of competence (training) and commitment to both civility and non-smoking, aspects to which DIR in-itself does not speak. Over time, GUE Vice-President and long-time DIR supporter Dr. Panos Alexakos and I came to see that there was really no way to reign in the particular interpretations of the ever-growing numbers of DIR advocates and that it would be a waste of resources and energy to struggle with them over the correct interpretation of DIR. With this in mind, we have struck out on a new road, a distinctly GUE road that looks fondly upon DIR as the foundation that can empower the organization toward a new and unique future.
Accident management strategies
by Jarrod Jablonski

Recovering an unconscious diver from depth

Managing an unconscious diver while under water is a problematic scenario. It is clear that a range of nuances create some doubt about the perfect management. Furthermore, different scenarios likely result in additional complexity; it is impossible to craft a strategy that operates independently of these variables. Yet, it is nearly impossible to revive an unconscious diver while at depth, making it likely that an efficient ascent is the most successful strategy. Very calm and proficient rescuers may be able to manage multiple aspects of a rescue without compromising an efficient ascent. Yet, most rescuers should focus on a few important points, ensuring they do not sacrifice safety or efficiency. We would argue that three areas should be the rescuers primary focus; these include maintaining control, keeping an open airway and ensuring a smooth ascent. Failure to properly manage any of these areas is likely to result in a failed rescue.

Upon reaching an apparently unconscious diver the rescuer should evaluate the environment and the victim; this ensures that the diver is, in fact, unconscious and also provides an opportunity to evaluate any associated risks, including loss of visibility, lost direction, current, depth and equipment. After evaluating the victim and environment the rescuer should prepare the victim for ascent. It is preferred to manage the ascent using only the victim's buoyancy compensator; this reduces the number of variables to be considered. Both dry suit OPV valves should be identified, left open, and oriented to allow venting. The rescuers BC should be empty though in some cases the victim's BC might not contain sufficient lift; in this case some gas is left in the rescuers BC. Ideally the rescuer will "ride" the slightly positive victim slowly to the surface; the negative ballast of the rescuer acts to trap the victim, keeping the victim roughly horizontal. In some environments (i.e. cave or wreck) this horizontal position is very useful to facilitate an exit that is not vertical in nature. Of course, where direct ascents are needed this aspect is less important. Yet, it is usually easier to maneuver with a victim in the recommended horizontal position.

While managing the victim during ascent it is usually easier for the rescuer to use the right hand to keep the airway open. The regulator is left in place (if the regulator was originally found in the mouth then it is kept in this position - otherwise it is left out of the mouth). The right arm is often able to assist in stabilizing the victim; for example, this can be done by trapping the victims right tank valve in the crook of the arm. The rescuers left hand is also used for stability usually by grasping the victim's BC near the OPV; this hand is also used to adjust buoyancy (adding gas or dumping from the OPV/deflator). The particulars of this hand placement should be refined during training and
adjust based upon comfort/capacity. These details are less important than the primary objectives; these include maintaining control, keeping an open airway and ensuring a smooth ascent. Rescuers need to be cognizant of the big picture so they can adjust to small changes in equipment or stature (i.e. diver/rescuer size).

Positioning the diver as indicated allows the rescuer significant latitude in managing various scenarios (overhead, slow diagonal ascent etc). However, the most important factors remain the need to maintain control, keep an open airway and ensure a smooth ascent. If the rescuer is in doubt over a change to procedure the maintenance of these priorities always takes precedence. It is possible to rescue a victim with countless procedures that span the management of dozens of variables. Yet, one must remember that an unconscious diver has precious little time and failing to bring a victim to the surface will result in certain death. Given these options it is incumbent upon the rescuer to be as efficient as possible with the nuances of a rescue but to remain aware of the main priority; this is bringing the victim to the surface during a controlled ascent.

Ventilating an unconscious diver at the surface

The ventilation of an unconscious diver is usually accomplished in the same manner as for most non-breathing victims; the preferred method is mouth-to-mouth breathing. It is possible to ventilate a victim using a Scuba regulator; however, this is not preferred unless the conditions make it difficult to ventilate without getting water in the victim's mouth. Regulator ventilation is not preferred as it creates several problems. These problems include difficulty in creating a proper seal between the regulator and the mouth; the difficulty in preventing gas from venting out the exhaust diaphragm (instead of entering the lungs); the likelihood of sending gas into the stomach (again instead of into the lungs); and finally the potential problem of over inflating the lungs. However, regulator ventilation is a consideration where conditions might make mouth to mouth impractical (such as from heavy surf conditions).

It is also possible to use a regulator for under water ventilation though this is generally not recommended. There are likely few situations in which this might be useful; moreover, few rescuers are likely to be successful in managing the added complexity of under water ventilation. However, rescuers trying to remove a victim where the ascent is likely to be notably delayed (such while removing an unconscious diver from a cave) might consider the use of a regulator for under water ventilation. In this and similar situations the severity of the situation as well as the low probability of victim survival justify consideration of this procedure. Ventilation of the victim is least dangerous while traveling at a relatively constant depth; very experienced divers on a
protracted ascent are the only individuals that should consider this technique. Of course the biggest problem with ventilation while underwater is the risk of over inflating the lungs. Embolism of an unconscious diver would negatively impact the likelihood of survival.

**Rescuing a toxing diver while at depth**

The management of a toxing diver while under water is very similar to the management of an unconscious diver as discussed above. The primary peculiarity relevant for a toxing diver is the potential increased risk of embolism due to oxygen toxicity seizures (during the toxic phase). In this case, it is recommended that the rescuer allow the seizure to cease prior to surfacing with the victim. It is hoped that this seizure will last approximately one minute though some complications may be present.¹ Should the seizure continue or the conditions degrade the rescuer is obliged to take the risk of a controlled ascent to the surface. The risk of death is certain while under water, prioritizing a controlled ascent followed by surface management of the victim.

¹ Some issue could be made regarding complexities associated with oxygen toxicity. Namely these include the consideration that this reaction can be considered in two parts; these include tonic (rigid phase while glottis is obstructed) and clonic (jerking phase where glottis may or may not open spontaneously). As the seizure continues excess oxygen is metabolized; over time (perhaps 1 - 3 minutes) these seizures will cease. It is conceivable that a victim might still be in the tonic phase; yet, this may be difficult to identify due to stress, dive gear etc. Furthermore, it is conceivable that a victim with significant O₂ and/or CO₂ accumulation might continue to experience ongoing symptoms. This sees unlikely in most diving scenarios and, in any case, is not something with a practical solution while diving. In the end, the rescuer will have to judge a time of least risk, ascending slowly and hoping to do no greater harm. Continued in-water immersion is tantamount to certain death while not breathing while embolism may or may not be present.
Breathing gas concerns

by Robert Bourke

Selecting an appropriate breathing mixture involves balancing several competing interests; these include toxicity concerns, decompression, gas density, narcosis, thermal considerations, and expense. One may use an array of calculations to choose the “best mix” for a given dive; yet, these increase complexity and the consequent risk of the dive. Moreover, they reduce team standardization, familiarity, decompression consistency, and mix convenience; the benefits of these aspects make standard gases an ideal choice. The foundation of standard mixtures involves a sound understanding of the interaction among the applicable gas laws: Boyle’s, Dalton’s and Henry’s as well as the characteristics of various gases and human physiology.

The normal functions of breathing and circulation have developed at the surface. Once we submerge in water, pressure creates a range of changes. The weight of the gas surrounding us from “land” to outer-space is measured as one atmosphere (1 ata) of pressure. In order to determine the total amount of pressure at any depth we have to add the pressure at the surface to the pressure exerted by the weight of water. Every 33 ft/10 m of water adds another ata to the pressure. For example, at a depth of 99 ft/30 m feet there are 4 ata’s: one for the weight of gas at the surface and one for each 33 ft/10 m. The number of ata’s or total pressure will help us understand the effects of pressure.

Unlike liquids and solids, gases (air) can be easily compressed by pressure. Pressure moves molecules of a gas closer together and makes the space it occupies (volume) smaller. For example, picture a balloon filled with air at the surface. Submerge the balloon to a depth of 33 ft/10 m. At that depth, the balloon would “shrink” to half its size at the surface. The air didn’t escape from the balloon, so there still would be the same amount of air. The same goes for the air in our lungs; at 33 ft/10 m the air would be twice as dense in half the space. This is the concept behind Boyle’s law: volume is inversely proportional to the increase in pressure and density is proportional to the increase in pressure.

Back at the surface our balloon and our lungs are filled with air. For the most part air is made up of oxygen (about 21%) and nitrogen (about 79%). When you add these up you get 100%. If we only talk about oxygen in relation to air, that is only a portion of, or a partial amount of what makes up air. Stated another way the 1 ata of pressure at the surface equals the sum of the partial pressure (pp) of oxygen (0.21) and the partial pressure of nitrogen (0.79).

Now we need to bring Mr. Boyle back into the picture. Let’s take our balloon back to 33 ft/10 m. If, as Boyle says, at 33 ft/10 m (2 ata’s) the air is twice as dense then the oxygen and nitrogen, each, must also be twice as dense. So now we take 2 ata’s and multiply it by each partial pressures: oxygen $\rightarrow 0.21\ \text{pp} \times 2.0\ \text{ata} = 0.42\ \text{pp}$, and nitrogen $\rightarrow 0.79\ \text{pp} \times 2.0\ \text{ata} = 1.58\ \text{pp}$; totaling 2.0 ata’s.
Breathing gas concerns

The math works, there are 2 ata’s at 33 ft/10 m. Breathing air at 33 ft/10 m, our lungs have an oxygen partial pressure of 0.42 ata’s and a nitrogen partial pressure of 1.58 ata’s. This is the concept behind Dalton’s law: the sum of the parts make up the whole.

We’ve lived at the surface for a long time so the blood and tissues have the same amount of oxygen and nitrogen dissolved in them as is in our lungs. At 33 ft/10 m the partial pressures of oxygen (0.42 pp) and nitrogen (1.58 pp) in the lungs will eventually force the partial pressures in the blood and tissues to be the same as the air in our lungs (equilibrium). This is the concept behind Henry’s law: The amount of any given gas that will dissolve in a liquid at a given temperature is directly proportional to the partial pressure of that gas.

We forgot something though. When we breathe we not only inhale we also exhale. So our lungs are taking in oxygen and nitrogen and getting rid of nitrogen, oxygen, and carbon dioxide. Carbon dioxide is a by-product of our metabolism. It follows the same rules as other gases. When oxygen, nitrogen, and, don’t forget, carbon dioxide partial pressures get high enough they become toxic and/or narcotic. The onset of narcosis and toxicity is unpredictable; not only from person to person but also day to day in the same person.

Oxygen partial pressures in excess of 1.6 have been shown to cause Central Nervous System (CNS) problems and with longer exposure lung (pulmonary) problems. CNS toxicity targets your central nervous system. The symptoms of CNS include nausea, abnormal vision or hearing, breathing difficulty, anxiety, confusion, fatigue, lack of coordination, twitching of your face, lips, or hands, and convulsions. Convulsions can appear without warning, and can easily lead to drowning. Pulmonary oxygen toxicity primarily targets your lungs, producing chest pain and coughing. This can occur after a 24-hour exposure to pp $O_2$ of 0.6 pp.

Nitrogen partial pressures in excess of 3.16 (equivalent to air at 100 feet) have been shown to impair a diver’s ability to think clearly and degrades motor skills. This degradation also includes the muscular activity associated with breathing. The results of one study (Meyer-Overton) have been used to predict that the anesthetic potency of a gas is inversely related to its lipid solubility. The more lipid soluble gases produce narcotic effects at lower concentrations than less soluble gases. Based on lipid solubility oxygen should be more narcotic than nitrogen.

Partial pressures of carbon dioxide that fall above or below a very narrow range have been shown to cause narcosis and toxicity. Carbon dioxide toxicity, or hypercapnia, is an abnormally high level of carbon dioxide in the body tissues. The average normal range of $CO_2$ is considered to be 35-45 mmHg (millimeters of mercury). Signs of $CO_2$ toxicity are usually evident at $PACO_2$ (partial pressure of $CO_2$ in the alveoli) = 60 mmHg on the high end and 30 mmHg on the low end. A rise to 80 mmHg or decrease to 20 mmHg would be incapacitating. Normally, your body keeps your arterial $CO_2$, almost without
exception, within 3 mmHg during both rest and exercise, a narrow range. Also, several studies have shown that carbon dioxide reduces mental and physical capacity at subanesthetic concentrations. Therefore, the build up of carbon dioxide should be a concern from both a narcotic and toxic standpoint.

These realizations induce concern and cause one to ask what is needed to reduce the risks of toxicity and narcosis? We can change the content of what we breathe. If we replace some of the nitrogen in air with more oxygen, so that at the surface we have 0.32 pp of oxygen and 0.68 pp of nitrogen (This is called Nitrox 32). However, if the oxygen pp is higher at the surface, then at depth there is more potential for oxygen toxicity because of increased pressure. That’s why we establish the working range for Nitrox 32 as 0 – 100 feet (100’/30m or 4ata x 0.32 = 1.28 pp of oxygen). This 1.28 pp of oxygen is below the maximum where most studies have shown an increase in the probability of experiencing symptoms of oxygen toxicity. Also, by keeping the oxygen partial pressure low we attempt to minimize the probability of the incidence of oxygen narcosis as predicted by Meyer-Overton.

If you want to go deeper, we introduce helium. A mixture of 0.30 pp of oxygen, 0.30 pp of helium and 0.40 of nitrogen (Trimix 30/30) keeps oxygen toxicity and narcosis, and nitrogen narcosis in the acceptable ranges and less than 100’/30m respectively. A mixture of 0.21 pp of oxygen, 0.35 pp of helium and 0.44 pp of nitrogen keeps oxygen toxicity and narcosis within the acceptable ranges. We can also make it easier for our bodies to move the gas around by adding helium. With a higher density of gas it is more difficult to breathe, at 100’/30m it is four times as difficult. (See table 1 for densities at the surface and 99 feet.)

If our bodies can not efficiently move carbon dioxide from tissues to our lungs and out of our bodies the levels begin to rise. Several factors increase our production and elimination of CO2; these factors range from breathing resistance to gas density and fitness. For example, unfit divers may produce about twice as much CO2 as that of a fit diver. In addition, gas density can combine with increased depth to make a gas especially hard to breathe (due to continued increases in density). Regardless of the specific reasons for increased CO2 accumulation the body attempts to compensate by increasing the breathing rate. Very often this results in rapid but shallow breathing which is not efficient at removing CO2. Considering that CO2 is highly narcotic, this narcosis together with any narcosis experienced from other gasses can significantly impair the diver. In addition, the rapid shallow breathing that might result from trying to exert (particularly with dense gasses) can lead one into panic and/or CO2 toxicity and unconsciousness.
Breathing gas concerns

<table>
<thead>
<tr>
<th>Gas</th>
<th>0°C, 1 ata</th>
<th>0°C, 4 ata</th>
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2 Used up to 100 fsw
3 Used from 80 to 120 fsw
4 Used from 120 to 160 fsw
Cardiovascular conditioning and diver safety

by Cameron Martz

[Cardiovascular conditioning does not prevent the bends, nor does it guarantee that a diver will have a reduced risk of DCS on any given day. This article describes the effects that cardiovascular conditioning may have on a diver’s risk of DCS over the long term.]

The American College of Sports Medicine classifies cardiovascular endurance as "the ability to perform large muscle, dynamic, moderate-to-high intensity exercise for prolonged periods." Some experienced divers believe that since they already have a good breathing rate and efficient water skills, exercise will do little for their diving. This is a very limited view of what their heart and lungs do for them. Achieving a high level of cardiovascular fitness does much more than just improve gas consumption. It may also increase the safety of dives in several ways:

1. Increased physical reserves to handle problems.
2. Delayed/reduced panic response.
3. Increased rate of inert gas elimination.
4. Reduced cost of free phase gas formation.

Increased physical reserves

The more fit you are, the more physically demanding a task you can handle successfully. You can swim faster and farther. You can manage larger amounts of equipment. Your heart rate and respiration are lower, and gas consumption will increase less for a given increase in workload. There are no more obvious results of cardiovascular conditioning than these. Imagine being able to upgrade your car from the current engine to one that is more powerful and gets better gas mileage. As muscle cells adapt to exercise, they increase their number of mitochondria (the energy achines of the cell) and their quantity of aerobic enzymes (the oxygenutilizing chemicals). With these adaptations, muscle cells become stronger and much more efficient with the oxygen they receive. A fit diver will be able to perform more work with each breath of gas, or use less gas to perform the same amount of work as a less fit diver. Not only does this improve capacity to do more during each dive, it also increases the chance that any problems can be solved.

The panic response

An important side benefit of a reduction in heart rate and respiration relates to the panic response. The human brain responds to an increase in heart rate and respiration with an increased emotional response, whether it is love, anger or panic. A feedback loop forms in a tense situation when a diver senses danger,
then responds with an increase in physical activity. This causes the diver’s heart rate and respiration to increase, which causes the brain to increase its perception of danger, which then elevates the diver’s heart rate and respiration, which then further increases the brain’s perception of danger, and so on until the diver can no longer perform the appropriate response. A fit diver will always be further from the panic threshold than an unfit diver, merely because the diver’s heart rate and respiration are not as affected by increasing physical demands.

**Increased rate of inert gas elimination**

The rate at which inert gas is eliminated from body tissue for a given pressure gradient depends upon the solubility and vascularity of the tissues and the efficiency of the lungs. Fat tissue offgasses much more slowly than lean tissue. Because of its relatively high water content, fat tissue holds a greater quantity of dissolved gasses. This storage problem is further compounded by the tissue’s low vascularity. Cardiovascular training, when combined with a healthy diet, results in an increased ratio of lean tissue to fat tissue in an athlete’s body. The body of a fit diver should off-gas as a system faster than that of an unfit diver. However, a reduction in adipose tissue, or body fat, reduces the amount of natural insulation a diver has, increasing the importance of adequate protection from the water.

Cardiovascular training also increases the efficiency of the lungs through several mechanisms. As the cardiovascular system is overloaded through exercise, the lungs are stimulated to exchange carbon dioxide and oxygen, primarily, at a much faster rate. The body adapts by increasing the vascularity of the lung tissue as well as the surface area of the lungs at the alveoli. Not only is a greater quantity of blood present in the lungs of a fit diver, but the vascular changes also allow a faster rate of gas diffusion for each unit volume of blood. Fortunately, these adaptations are not specific to oxygen or carbon dioxide- a pressure gradient for any gas will result in an increased transfer of that gas from blood to lungs.

**Reduced cost of free phase gas formation**

Any dive can produce bubbles, whether it be a thirty-minute shallow reef dive or a world record setting deep cave penetration. The size and amount of bubbles formed depend largely upon the amount of dissolved gas and the rate of ascent. Mismatch the rate of ascent for the amount of dissolved gas, and the bubbles set in motion a series of problems, known to divers as Decompression Sickness (DCS). Contrary to popular belief, bubbles are not the only cause of blockages in the circulation. The arterial capillaries are generally large enough to allow the passage of many free phase bubbles. It is believed that the secondary effects of these bubbles cause many of the blockages, or emboli, associated with DCS.
The emboli believed to be associated with DCS result from several sources. The body releases many types of chemicals in response to the vascular insult resulting from bubble formation, and these chemicals reduce the blood supply to the tissues, even without the presence of gas emboli. Additionally, certain proteins involved in the body’s defense against illness may adhere to the bubbles themselves, causing blockages and decreasing the permeability of the bubbles. These proteins not only increase the size of the bubbles, but they also increase the time required to clear the bubbles out of the bloodstream.

Divers must remember that lungs are the first defense against the effects of breathing compressed gas. Their diffusing capacity is much greater than needed at rest. This built-in safety factor is what allows the lungs to act as a very effective bubble filter in the event of free phase gas formation in the bloodstream.

The alveoli are designed to trap both solid and gaseous emboli, preventing them from traveling farther through the circulatory system. Gaseous emboli are eliminated through diffusion, which as described above, is improved through cardiovascular conditioning. Cardiovascular conditioning further increases this safety factor by allowing the lungs to trap a greater quantity of bubbles within their increased surface area and vascularity. Not all emboli are filtered by the lungs, however. Small bubbles can pass through the pulmonary circulation only to collect and form emboli elsewhere in the body. Also, the accumulation of proteins and platelets occur throughout the circulatory system as a result of free phase gas formation. This is where the other vascular effects of cardiovascular conditioning may become so important.

The diameter of blood vessels varies based upon a number of factors, including vascular insult. However, cardiovascular conditioning increases the maximum possible diameter of many existing blood vessels. Thus, an embolus may travel farther downstream before becoming lodged, potentially blocking fewer branches and affecting less tissue. Cardiovascular conditioning increases collateral circulation, which means that a given mass of tissue may have more pathways from which to receive oxygen-rich blood. Thus, if an embolus becomes lodged in one pathway, the tissues of a fit diver may receive more blood than those of an unfit diver via other pathways.

Cardiovascular conditioning also increases the efficiency with which cells utilize the oxygen they receive as the tissues of a fit diver require less oxygen to maintain their base metabolic rate than those of an unfit diver. This is due to an increase in aerobic enzymes contained with in the cells, as well as a few other structural changes to the cells. Therefore, tissues of a fit diver may better survive a reduction in blood supply compared to those of an unfit diver.
Summary

Even the most experienced diver can benefit from an exercise program designed to increase endurance. However, the adaptations described in this article do not happen overnight. While the human body has an amazing adaptative capacity, it requires consistent training and a healthy diet to elicit these gains in cardiovascular fitness. No matter what your current level of fitness may be, there is always the next level.

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Quest - Developing a personal fitness program

by Neal W. Pollock, Ph.D.

There are many benefits associated with good physical fitness. Most practically, any given level of effort will represent a smaller fraction of the capacity of more fit individuals, leaving a greater reserve that can be drawn upon to meet additional demands. The comfort and confidence that comes with a healthy fitness reserve can make a huge difference in how well emergent events can be managed. Having a solid reserve is clearly of value to divers who work in a medium that is generally supportive, but also fairly unforgiving.

Recent articles in this space have considered the caloric cost of diving (1), the level of physical fitness desired for diving (2), and how physical fitness, particularly aerobic fitness, is measured and estimated (3). This article will consider practical strategies to improve and maintain physical fitness as part of everyday activity. Some of the terms used in the current article were defined in greater detail in previous pieces.

Adherence

The biggest challenge to maintaining or improving fitness is staying with the effort. There are so many distractions (e.g., work schedules, television, computer games, the Internet) and conveniences (e.g., cars, elevators, escalators) that it is easy for people to fall into patterns of physical inactivity. The challenge increases as we age; not only do we have more demands on our time and access to more conveniences, but we also have the “maturity” to keep us from skipping when we can walk.

The best way to maintain high levels of fitness is to make physical activity an integral part of daily life. Success is generally greater when activities are matched to individual preferences and abilities. Adherence can be improved by incorporating a variety of activities, scheduling them to fit most comfortably into the normal schedule, and by developing a positive feedback system that works. The latter may include focusing on the pleasurable rather than the “medicinal” benefits of activity, developing a peer group with which to share activities, and seeking occasional opportunities that can make you appreciate your abilities. A progressive series of small evolutions can help develop a lifestyle that supports a high fitness level with minimal disruption.

Those who welcome loose structure may appreciate the most basic of recommendations. The simplest is to participate in some physical activity most days of the week, achieving “training-intensity” efforts three or more times a week. Those who prefer structured plans may value the exercise prescription.
Exercise prescription

Questions as to how much exercise is required to see a positive benefit vary from activity to activity and as a function of the fitness level of the participant. The basis for training recommendations is the exercise prescription.

The exercise prescription is based on the application of the FITT principle. This mnemonic refers to the key elements of the prescription:

- Frequency (how often the exercise should be completed per week);
- Intensity (of the prescribed exercise);
- Time (or duration of the exercise per session); and
- Type (or mode of exercise to be employed).

The key to an effective prescription is that it be appropriate for each individual. Differences in ability, physical limitations, interest and goals must be taken into account.

While the FITT principle is conceptually simple, its application requires further consideration. For example, a planned aerobic exercise session can be divided into five phases: 1) static stretching; 2) warm-up; 3) target level; 4) cool-down; and 5) static stretching. Static stretching (slow and steady, no bouncing) should be used to increase flexibility and prepare the muscles and/or joints for the aerobic activity to follow. The stretching program should include the major muscle groups and body regions: neck, shoulders, arms, trunk, low back, quadriceps, hamstrings, calves and ankles. Stretching should be done cautiously to reduce the risk of injury, particularly by the novice. “Ballistic” stretching (employing rapid bouncing movements) is more likely to cause injury. The stretching conducted before exercise should be fairly light. The post-exercise stretching can be comprehensive, including three to five repetitions of each stretch after a short recovery period. Stretching programs can significantly improve flexibility over a fairly short period of time. Be aware, though, that excessive stretching can cause injury and impair the ability to exercise.

The warm-up phase of an aerobic exercise session allows the skeletal muscles and cardiorespiratory system to make gradual adjustments upward to the target level of aerobic effort. The target level may be considered a steady-rate effort, but, particularly for “real world” activities, minor fluctuations are expected throughout the session. For example, an outdoor runner maintaining a nine-minute-mile pace might apply more effort on the uphill sections and less on the downhill sections. Recovery from the brief bursts of increased effort during sustained exercise can be a potent training stimulus.
The most appropriate aerobic exercises employ large muscle groups used rhythmically for a sustained period of time. Examples of exercises that fulfill these requirements include running/jogging, walking, hiking, swimming, skating, cycling, rowing, and rope-skipping. The duration of the target-level phase will depend upon the subject’s current fitness level and physical skill, typically lasting fifteen to sixty minutes.

An often-neglected part of exercise is the cool-down phase. Immediately following the target-level effort, an exerciser should engage in an active recovery by means of lower-intensity effort. The active contractions of the muscles aid in returning blood to the heart, as well as helping to remove lactate from the muscles, which may otherwise contribute to soreness. The cooldown should be five to ten minutes in duration, continuing for several minutes after heart and respiration rates have returned to near-resting levels. Following the cool-down period, the static stretching described above helps increase flexibility and eliminate muscular tightness and soreness.

Individuals can do the homework themselves or find personal trainers (at fitness facilities or independently) to help develop appropriate exercise prescriptions.

**Measuring exercise intensity**

Exercise intensity should be measured at intervals to ensure that it remains in the target range. As fitness increases, it will take a greater effort to generate the same relative intensity (i.e., the same percentage of maximal ability). For aerobic exercise, a simple method to evaluate intensity in healthy individuals is based on the percentage of maximal heart rate (HR$_{max}$). Age-estimated maximum heart rate (typically assumed to be 220-age in years) is computed, and a target range of exercise intensity established (usually between seventy to ninety percent of HR$_{max}$). Individuals are encouraged to maintain their exercise intensity at the low end of the range when they are starting out, gradually increasing both intensity and duration as they become accustomed to the exercise. The top end of the range represents the maximal recommended intensity for sustained exercise. The range corresponds to approximately fifty-five to seventy-five percent of maximum aerobic capacity (VO$_2$ max).

**Effectiveness of Aerobic Training**

Aerobic capacity is sensitive to training. VO$_2$ max can generally be increased by 25% relatively easily in untrained individuals with a reasonable training schedule. Additional gains can occur as body composition changes and the ratio of muscle mass to fat mass is improved. There are two primary stages of adaptation. The first comes in two to three weeks, primarily in the form of an increase in body fluid volume. The second begins after six weeks of training. At this point, the regular exercise is stimulating the increase in metabolic potential within the muscle cells.
The primary adaptation to regular aerobic exercise is an increased work capacity. This increases the reserve potential to meet emergent needs and reduces the strain on the cardiorespiratory system from any sub maximal work rate.

A similar pattern of detraining will be experienced if a training program is suspended. The fluid-volume increase will be lost within the first two weeks, and a decline in the metabolic readiness will follow. Fortunately, the same degree of effort required to improve aerobic fitness is not required to maintain it. Maintenance training that is of lesser duration but similar intensity can protect aerobic capacity.

Physical Activity choices
The discussion here has been limited to aerobic exercise. A comprehensive training program, however, will also include strength and dynamic/flexibility components. Programs can be traditional or idiosyncratic to best motivate the participant. Examples of strength activities include manual labor, weightlifting, kayaking, rowing or climbing. Examples of dynamic/flexibility activities include volleyball, squash, racquetball or yoga. In some cases, a single activity may contribute to more than one component. The key is to find options that keep training interesting while minimizing the risk of injury. Low-impact activities are better for lifetime enjoyment, particularly as aging bodies are more prone to injury and slower to recover. Comparatively, cycling and swimming are easier on joints than running. The relevance of swimming to diving is an additional benefit.

Health and exercise issues specific to diving
Regular aerobic exercise can produce many positive benefits. The major effects are well established. The physical demands of diving, both normal and exceptional, will be easier to meet. The susceptibility to chronic diseases that can limit future involvement will be reduced. Additionally, while the data specific to diving are preliminary, there is some evidence that elevated aerobic fitness can positively affect decompression safety. More work has to be completed to validate these findings, but the fundamental concept that high levels of fitness are beneficial for divers is uncontested.

References
Patent Foramen Ovale: Background and impact on divers

by Dr. Neal W. Pollock

Common anatomical defects of the heart were identified as risk factors for decompression sickness in the 1980s. Between 17% and 35% of the normal population are found to have an anatomical atrial septal defect, or patent foramen ovale (PFO), beyond infancy(1). The incidence among divers who have suffered from serious neurological decompression sickness symptoms was reported to be as high as 61% (2) or 66% (3). This article will present an overview of the condition with emphasis on the implications for the diving population.

Fetal circulation

Fetal humans rely on placental circulation and the maternal pulmonary system for gas exchange. Since the growing lungs are not yet functional, they require only enough blood delivery to support their own development. The fetal cardiovascular system has two primary shunts to allow blood to bypass the lungs. It is the interatrial septum that allows blood in the right atrium to flow directly into the left atrium that is the concern of this discussion.

Placental circulation is lost at birth and the infant must start breathing independently. After one or more gasps, the previously unused lungs will start to expand. Upon expansion, a redistribution of pressure causes a tissue flap within the left atrium of the heart to be pushed against the septal wall to functionally close the foramen. In the normal course of events, the septal tissues will fuse within the first year after birth to make the closure permanent. However, in a post-mortem review of 965 normal hearts, patent interatrial openings were observed in 27% of the non-infant population (4).

Evaluation of interatrial shunts

Post-mortem autopsy examination is the most reliable means of identifying anatomical foramen ovale. However, anatomical (or probe) patency does not equate to functional (or physiological or hemodynamic) patency. Being able to work a probe through the cardiac septum at autopsy does not indicate the degree of lateral shunting that was present in the living system. This is why in vivo studies usually report lower incidence rates than post-mortem studies. Functional patency was reported in 9% of 1,000 consecutive patients being scanned by transesophageal echocardiography (5).
Functional patency is reliably evaluated using two-dimensional bubble contrast echocardiography (6,7). This technique involves the venous injection of small amounts (5-10 mL) of normal sterile saline solution that has been agitated in the presence of air to ensure the presence of large numbers of microbubbles. Bubbles are highly reflective targets easily detected by the ultrasonic pulses used in echocardiographic instruments.

Injections of bubble contrast are made repeatedly during resting breathing while the echocardiograph captures a cross-sectional view of either all four chambers of the heart or the two atria. The microbubbles are clearly visible as they enter the right side of the heart. Functional patency is confirmed if bubbles are seen to cross the septum, and no further testing is conducted.

If bubbles are not seen to cross the septum during resting trials, further injections are made during or just prior to the release of the strain phase of a Valsalva maneuver. Injections are repeated until crossover is seen or a pre-established maximum number of test cycles has been reached. As a control, the pressure generated by the Valsalva maneuver will usually be standardized, generally within the range of 40-60 mmHg above ambient.

The dominant pattern of interatrial shunting is left-to-right since the left heart pressure is significantly greater than the right. The Valsalva maneuver is useful in assessing foramen ovale patency by augmenting or prolonging a transient pressure gradient reversal that encourages right-to-left shunting. Septal crossover is usually evident following the release of the strain phase.

The presence of a functional patent foramen ovale may have no adverse effect under normal conditions. A minor left-to-right flow would reduce cardiac efficiency, since blood would be sent to the lungs repeatedly, but this may not be problematic. Right-to-left shunting is a greater concern since blood bypasses the lungs and is sent directly through the body (systemic circulation).

Minor right-to-left shunts may not affect oxygen content appreciably, but major shunts can limit physical performance. A more insidious problem is the introduction of potentially embolic materials (e.g., gas bubbles, blood clots) to the systemic circulation that would normally be filtered out in the pulmonary bed. Right-to-left shunting is the suspected agent in a significant number of unexplained or "paradoxical" stroke cases (8).

A number of factors may increase right-to-left shunting. These include coughing, the Valsalva maneuver, pulmonary hypertension, chronic obstructive pulmonary disease, and the use of positive pressure ventilation (5). It has also been suggested that a spontaneous reversal of the normal left-to-right pressure gradient may occur during the early phase of ventricular contraction (9).
Impact of interatrial shunts on the diving population

Divers face risks from right-to-left shunting beyond those experienced by the non-diving population. The first is a direct result of the action of Boyle's Law. Any bubble present in the systemic circulation is subject to expansion during ascent. Initially non-problematic microbubbles that are shunted systemically could potentially become large enough to cause circulatory blockages. Right-to-left shunting may explain some cases of paradoxical arterial gas embolism (referred to as "undeserved embolism") when classic signs and symptoms are not accompanied by appropriate history or clinical indications of pulmonary barotrauma (10).

Interatrial shunting may also alter bubble formation. While the mechanisms of bubble formation and decompression sickness have not been completely resolved, there is strong evidence that micronuclei "seeds" of some nature will initiate or exacerbate bubble formation. Materials shunted right-to-left (that would normally have been filtered out at the pulmonary bed) could serve as "seeds" and increase an individual's susceptibility to bubble formation (2). A substantial bubble load (number and size) may trigger the cascade of events resulting in decompression sickness. The pattern of right-to-left shunting may also be influenced by the activity of diving. It has been demonstrated that the hydrostatic compression of the legs during immersion will increase the cardiac volume prior to contraction (the end diastolic volume or Ôpreload') such that stroke volume may increase up to 30% (11). Right atrial pressure can also be increased by 13 mmHg (12). The reduced difference between right and left heart pressures may make gradient reversals easier to achieve. Cardiac tissue distension arising from preload increases could also cause tissue distortions that might transiently increase the size and/or patency of the foramen (2).

The first major review of foramen ovale patency in divers found that 11 out of 30 divers (37%) treated for decompression sickness had right-to-left interatrial shunts demonstrable by contrast echocardiography. More importantly, the authors reported that 11 out of 18 (61%) who presented with serious signs and symptoms demonstrated shunting during resting respiration (2).

An independent group of investigators reported patency in 15 out of 63 divers (24%) in a control group with no history of DCS. This contrasted a patency of 66% (19/29) in divers who had experienced neurological symptoms within 30 minutes of surfacing (3).

More recent analyses have employed logistic regression to estimate the relative risk associated with patent foramen ovale. Bove (13) computed a 2.5-fold increase in the odds ratio for developing serious decompression sickness. Schwerzmann et al. (14) suggested a 4.5-fold increase in the odds ratio for developing decompression sickness, but this was a relatively weak study based on retrospective self-reports.
One of the issues raised but not resolved in the available literature is the relationship between patent foramen ovale and brain lesions. While it has been suggested that patent foramen ovale is associated with greater numbers of brain lesions (14,15), there is no evidence that this is related to functional deficits.

**Implications for the diving population**

The presence of a functional patent foramen ovale does appear to increase the risk of decompression sickness. The issue of how to proceed, however, remains contentious.

Some investigators encourage the broader use of contrast echocardiography to screen potential divers (16), while others maintain that routine screening is not warranted (13). There is risk associated with introducing contrast bubbles into the bloodstream (17), although the established morbidity rate of bubble contrast echocardiography (0.07% in 41,000 studies) is lower than that of other accepted diagnostic techniques (for example, exercise testing for ischemic heart disease at 0.09% in 518,448 tests) (16).

While the debate regarding screening continues, the overshadowing question is how to counsel the diver with a patent foramen ovale. It is probably safe to say that functional patency does represent a relative contraindication for diving. This does not imply that it should be an absolute contraindication.

There are several arguments against using patent foramen ovale as a disqualifying factor. Even if the relative risk is higher, the absolute risk is still very small. Tripling a very small risk still results in a very small risk. And unlike many disqualifying conditions, the risk from foramen ovale patency may be moderated if divers adhere to dive profiles that minimize bubble development. Finally, interatrial crossover represents only one of several potential pathways for the arterialisation of bubbles. Extra-alveolar shunts and pulmonary crossover may occur independent of patent foramen ovale. The frequency and import of these pathways has not been evaluated.

Further investigation is required and it is likely that prophylactic evaluation of divers will increase in the future. Evaluation may be most useful for professional divers who may be obligated to more severe exposures. The standard of care for decompression research studies is also evolving.

Doppler ultrasonic monitoring for venous bubbles has served as the standard for almost 20 years. Laboratory procedures are now beginning to add two-dimensional echocardiographic imaging to identify any bubbles that may be arterialised.
Guidelines for diving practice

All divers or potential divers should be made aware of the hazards of patent foramen ovale and the availability of testing options. Dive profiles should be selected to minimize bubble formation. Equalizing techniques employing the least Valsalva strain should be used.

Summary

The association of serious decompression sickness and foramen ovale patency indicates a need for continued investigation. The true risk and optimal course of management remain to be determined. Current opinion is divided and standards are vague; but divers should be informed of the potential problems and testing options. In addition, divers should also be encouraged to adhere to dive profiles that can limit bubble formation.

References


The impacts of smoking on diving

by Art Ranz, dds

Cigarette smoking is one of the largest preventable health and death risks in the United States. It receives enormous amounts of negative media attention and yet millions of people start smoking every year. Unfortunately, it is frequently difficult to have a prudent, scientific discussion about the risks of smoking with someone who is addicted to nicotine. The addiction leads smokers to rationalize or deny the risks of smoking. However, this "head in the sand" response allows them to ignore the obvious impact that smoking has upon their bodies and the more subtle ways it effects many aspects of their lives, such as scuba diving.

The effects of smoking are especially significant for persons who participate in scuba diving. A review of scientific literature about the body's reaction to smoking and nicotine addiction illustrates how smoking can effect diving performance. While the diving and health limitations imposed by tobacco use vary according to the degree of use, tobacco always has some impact on individual health.

The most extensive, long-term, prospective study on smoking and other health issues is the Framingham study. This ongoing study has followed 5,000 people for more than 34 years, providing a wide range of statistical information. For instance, the 30-year-old who smokes 15 cigarettes a day - or less than one pack - shortens his life by five years. Smokers experience a 20-fold increase in lung cancer and greatly increased cancer rates in other organs, including skin, bladder, pancreas, mouth and throat. Smokers have twice the risk of cardiovascular disease, 2.2 times the number of strokes and 3.5 times more intermittent claudication expressed as leg cramping due to a lack of circulation. At any given age, the risk of dying for any reason is twice that of a non-smoker. Smokers have seven times the normal incidence of airway damage and respiratory distress. Children who smoke beginning at age 14 only develop 92% of the lung function, on average, that a non-smoking child does. This loss of function is permanent. Obviously, efficient lung function is essential to managing stressful situations and promoting efficient inert gas removal from a diver's blood. Poor circulatory efficiency can have dangerous impacts on inert gas elimination and oxygen delivery to needy muscles, greatly effecting a diver's personal safety. Atherosclerotic plaques in blood vessels form twice as fast when smoking is added to a high fat diet.

There are great increases in the LDL ("bad cholesterol") that reduces circulatory efficiency and complicates inert gas removal. Inert gas (especially nitrogen) appears to lodge in fatty deposits, creating likely sites for bubble congregation and growth. Furthermore, 90% of patients with infections after spinal surgery are smokers and bone marrow density in men is decreased almost 20% and in women 25-30%, while the incidence of back pain from a work related injury increases from one in five to one in two for smokers.
Hyperbaric bone damage (osteonecrosis) has gained increasing concern among medical professionals as researchers strive to demonstrate the cause of occasional bone degradation. To be sure, reduced bone density due to smoking aggravates the problem and some researchers are suggesting a more careful analysis of the relationship between hyperbaric damage and tobacco smoking.

**How does tobacco cause such dangerous repercussions?**

There are four groups of dangerous substances present in cigarette smoke:

1. Carcinogens and co-carcinogens are mostly polycyclic aromatic alcohols that directly initiate cancer formation. These affect areas in direct contact with the smoke and also distant organs through absorption into the bloodstream.

2. Irritants cause immediate coughing and broncoconstriction, inhibit ciliary action in the lung and stimulate mucus secretion.

3. Chronic exposure to nicotine induces an increase in the number of nicotinic cholinergic receptors in the brain, causing structural and functional changes in the brain and nervous system. It induces tolerance and physical and psychological changes upon withdrawal. These are classic developments from an addictive drug.

4. Toxic gases are inhaled, including carbon monoxide, hydrogen sulfide and hydrogen cyanide.

Smoking related cancer is tragic, costly and largely preventable, but the direct impact to diving is often less obvious. By way of illustration, the irritants present within smoke induce a chronic inflammation of the alveoli causing the body to produce proteolytic enzymes that eat away at the alveolar wall. Cilia are microscopic hairs that fan and carry harmful particles out of the lung. The irritants present in smoke impede these ciliary actions. With the addition of increased secretions, the lung has now lost a significant part of its defenses from outside agents. Chronic bronchitis develops, making smokers more susceptible to emphysema, viral and bacterial infections. As this process continues over the years and more alveolar damage occurs, there is a loss of capillaries in the walls which causes "ventilation-perfusion abnormalities."

This damaging chain of events leads to a reduction in the area of alveolar membrane available for gas exchange and also to perfusion of unventilated areas and ventilation of unperfused areas. In simple terms, gas exchange is compromised and air (or other gases) is not reaching the blood for exchange. General lung function is often severely compromised in the smoking population as is evidenced by several clinical measurements in the lung. The standard measure of lung function is the forced expiratory volume in one second or FEV1. This is the amount of air that can be exhaled in one second.
The Framingham study showed the FEV1 to be decreased to 80% of expected values in smokers. This decrement in lung function creates less efficient ventilation on exertion and decreases the force of the cough (a vital protective mechanism for the lung) and may indicate a general degradation of lung health. The forced vital capacity (FVC) is another common measure of lung function and measures the amount of air one can expel from a full inhale to a full exhale. On average, smoking reduces FVC by 10% in moderate smokers. A 10% reduction in vital capacity is a significant indication of lung dysfunction and an obvious deterrent to pulmonary exchange in decompression.

Nicotine is not only a powerfully addictive drug, but a potent pharmacological agent. Nicotine promotes platelet aggregation and fibrinogen formation, which are precursors to the clots that obstruct small blood vessels. An obstruction initiates negative repercussions that increases the risk of diving and decompression. The heart rate increases, elevating oxygen consumption and the shrinking of small blood vessels increases total peripheral resistance. The resistance, in turn, causes more problems such as increased blood pressure and poor circulation in the periphery of the body. Peripheral circulation involves the miles of very small blood vessels all over the body. The vessels are problematic in efficient inert gas elimination. For example, the extremities contain numerous areas of reduced circulatory efficiency such as the joints (responsible for the majority of decompression sickness). When divers begin to get chilled, a natural reduction in blood circulation to the peripheral system occurs to maintain a reasonable core temperature. Smoking exacerbates this problem as studies show that the circulation in small blood vessels is reduced 19% after just two cigarettes. Poor gas exchange and increased risk of decompression sickness results.

The problem with carbon monoxide

It is important to understand the Oxygen Dissociation Curve when reviewing the impact of smoking on oxygen transport mechanisms. This curve illustrates the assimilation of oxygen in large amounts even with low oxygen pressures in the lungs. Hemoglobin picks up the oxygen from the lungs and transports it to the tissues where it is released. Several factors control how easily the oxygen is released from its hemoglobin carrier. Higher concentrations of carbon dioxide in the blood cause the body to react as if there is poor ventilation and a greater need for oxygen. This environment initiates the release of more oxygen to the tissues. Under these conditions the hemoglobin affinity for oxygen is reduced, making it easier for oxygen to be released. In reference to the Dissociation Curve, this condition is sometimes referred to as a "shift to the right" and results in a greater supply of oxygen to the tissues. However, a "shift to the left" prevents oxygen from being released to the tissues. This condition is prominent with the carbon monoxide accumulation that results from smoking.
The impacts of smoking on diving

The primary mechanism behind the risk of carbon monoxide impact is twofold. First it binds to hemoglobin 250 times better than oxygen, making a compound called carboxyhemoglobin. This compound replaces the oxygen in the hemoglobin molecule and prevents the leftward shift of the Oxyhemoglobin Dissociation Curve. The increased affinity of hemoglobin for oxygen results in a decrease in oxygen carrying capacity and impaired release of oxygen once it reaches the tissues. Non-smokers have about 1% carboxyhemoglobin while smokers have close to 15%. To illustrate the severely harmful effects of CO in the blood, imagine that an individual has 50% of their hemoglobin bound to CO. Compare this individual with another person who has lost half of their hemoglobin (due to severely bleeding ulcers, chronic gastrointestinal bleeding or massive injuries, for instance). The individual who has 50% of their hemoglobin bound with CO will die. But, the person who has a 50% loss of hemoglobin will still not experience hypoxia while in a resting state.

Furthermore, chronic hypoxia (reduced oxygen) results from the smoking induced impairment of oxygen transport and causes the production of more red blood cells. The red blood cells are the containing mechanism for oxygen transport in the hemoglobin. The Framingham study has shown that smokers have a significant increase in the percentage of red blood cells in the blood.
The impacts of smoking on diving (increased hematocrit). Normally the red blood cells are about 35-40% of the blood by volume. Smoking can cause this to increase by 20%, making the blood much more viscous, inducing obvious complications to efficient circulation. This problem is further aggravated by the pressures found below the surface and causes sludging of the red blood cells in the small capillaries, damaging the cells lining the blood vessels (endothelium). The transport of hydrogen cyanide to the lungs during smoking creates additional decrements to health and diving safety. This noxious gas directly prevents use of oxygen by the cells by interfering with the cellular engine- the mitochondria. Even small amounts of hydrogen cyanide are deadly. The presence of this toxic substance causes direct injury to the lung by interfering with the alveolar enzymes normally responsible for maintaining the integrity of the alveolar membranes. Hydrogen sulfide is another dangerous substance in cigarette smoke and is a direct toxin to most all cell life, especially to tissues it directly contacts such as the lungs. The numerous impediments to a healthy circulatory and respiratory system establish an insidious cycle of unacceptable risk to safe diving practices.

For instance, when increasing environmental demands require the delivery of more oxygen, the smoker is at a serious disadvantage. An increased supply of oxygen in the inspired air does not help delivery of more oxygen to the tissues where it is needed. There are two ways to increase oxygen delivery with increased demand: increasing blood flow through the tissue and raising the coefficient of oxygen usage. The former is compromised by the inferior cardiovascular condition of the smoker (consider the number of serious athletes who smoke). The latter is increased by two things that happen automatically: greater partial pressure of oxygen between blood and tissue (resulting from the increase in oxygen consumption in the tissues) and the rise in carbon dioxide as a byproduct of increased metabolism. This increase in carbon dioxide causes the hemoglobin curve to shift to the right and allow more release of oxygen. This typically beneficial reaction is countered by the smoker's CO poisoning and the shift back to the left. The really adverse effect of smoking is the 20-30% rise in peripheral resistance (closing or restriction of small blood vessels) caused by the presence of nicotine. Small blood vessels are where the exchange of gases takes place and a reduction of circulatory efficiency in this area may be significant. Reduced blood flow and impeded oxygen release prevent efficient oxygenation especially when it is needed most. Therefore, the simple act of smoking initiates circulatory reactions that place divers in harm's way. Whether from decompression illness risk or ineffectual response to stressful environments, the smoker intentionally places himself and his team at greater risk.
Understanding smoking's short term impact on diving

Smokers and those who choose to dive with them should consider not only the long-term health impacts, but the immediate implications of smoking and diving. Consider the increase in sudden cardiac death, the reduced ability to absorb and deliver oxygen to the cells, the obvious cognitive impairment, the likely increased risks of decompression illness, the increased likelihood of lung overpressurization injuries and the many other dangerous effects of smoking and diving. With all of the damage and risk associated with smoking and diving, what possible justification (save addiction) can there be to continue? Individuals with drug addictions, which is clearly what smoking is, must be encouraged to seek assistance and be freed from this damaging habit.

Consider that many "diving deaths" are thought to be cardiovascular in nature: cardiac arrhythmias, myocardial infarcts and strokes just to name a few. The smoker's incidence of these maladies is much higher. With this in mind, can a smoker be a responsible diving buddy? Can they help other divers out of trouble or are they merely likely to create problems? With increased anxiety, the heart beats faster and the breathing rate increases. Increased heart rate is the number one cause of increased oxygen use by the heart muscle and the heart of a smoker has a reduced ability to deal with the increased demand for oxygen. As a result, pulmonary exchange is poorer and utilization of breathed gases is compromised, leading to greater gas consumption and reduced ability to assist other divers. All dives are decompression dives. The list is long on how smoking causes decreased gas exchange and potential for decompression sickness. The ability of the lungs to filter bubbles is a major reason that every dive does not result in clinical decompression injury. The lungs are directly damaged by smoking. Ventilation, monitored by FEV1, is decreased, and the Forced Vital Capacity, or FVC, is decrease by at least 10%. With decreased pulmonary function, the lungs' function as a big bubble trap is compromised and the risk of decompression illness is increased.

Nicotine causes significant peripheral constriction, further compromising elimination of gas in the areas most difficult to get the inert gases out — the small vessels and the area they perfuse. It causes increased platelet aggregation and fibrinogen production which only gives the body a head start on the same process that bubbles produce in occluding vessels and damaging vessel walls. One prominent theory of decompression illness suggests that bubbles in the bloodstream cause damage to the endothelium, the lining of the blood vessel walls, setting off a cascade of body reactions to repair itself. With nicotine in the body this process is aggravated and accelerated, causing platelets and blood clots to clog the small blood vessels. This reduces the body's ability to get rid of inert gasses. Nicotine gives the body a head start on the bad things that happen with bubble formation. The smoker has increased numbers of red blood cells per volume, or increased hematocrit, which sounds good, but actually makes the blood "thicker." Increased atmospheric pressure from diving causes sludging of red blood cells in small vessels and the clogging of these vessels is
aggravated by the increased hematocrit of the smoker. This is more bad news for perfusing the small vessels in the decompression part of the dive. Increased hematocrit may be directly involved with the endothelial damage which has been implicated in DCS. Carbon monoxide inhibits the transportation of oxygen mostly in its effect upon the hemoglobin and the hemoglobin disassociation curve. Smoking directly reduces pulmonary blood volume and the number of open capillaries in the lung, causing a ventilation to perfusion impairment with the obvious impairment of gas transfer at a time when every little bit is vital.

Acute nicotine withdrawal causes severe performance degradation, memory impairment, confusion, impulsiveness and slowed reaction time, just to name a few. Any of these are serious problems when simple decisions become life or death decisions under water. In a recent study of "undeserved hits" (a dive where supposedly all decompression limits are met and ascent rates are appropriate, but the diver still suffers from decompression illness), smoking and lung damage from smoking seemed to play a key role. Two groups emerged, those with intra-cardiac shunts and those without. Those with shunts had more brain symptoms and none smoked, while those without shunts, 50% smoked, a remarkable number. These divers experienced mostly spinal neurological sequelae and had deficits identical to divers with rapid ascents and pulmonary barotrauma. This implies that the smokers had occult lung disease that precipitated the pulmonary barotrauma giving more evidence of hindrance on the body's bubble filter. This makes perfect sense when considering the damage caused by smoking on the small airways and the alveolar walls which allow bubble to pass though the system instead of being filtered. Please think about these facts before picking up that next cigarette or diving with someone who smokes. If you smoke, see your doctor for help with overcoming the addiction. Make your diving safe and fun.

References


10. Kwiathkowski, Timothy C. Cigarette smoking and its orthopedic consequences. Amer J Orthop 1996 Sept 25(9) 590-


Evaluating the narcotic potential of breathing gases

The effects of narcosis vary from subtle decrement in judgment to total incapacitation; this reality asserts the importance reducing or more preferably eliminating narcotic impairment. Narcosis can be produced by a very wide variety of species, from simple gases as xenon and nitrogen to complex hydrocarbons used to produce general anesthesia. Although the narcotic effect of gases has been studied for over 100 years, a full understanding of how gases produce narcosis (and anesthesia) is lacking. Much of what is know about the narcotic effect of nitrogen is derived from study of anesthetic gases. Around 1900, Meyer and Overton independently observed that the potencies of general anesthetic gases correlated with solubility of the gas in a simple organic solvent, olive oil. These observations have become known as the Meyer-Overton rule, which predicts that anesthetic potency of a gas is inversely related to lipid solubility. In other words, more lipid soluble gases produce narcotic effects at lower concentrations than less soluble gases. Table 1 lists Bunsen’s solubility coefficients for common gases.

Thus, based on lipid solubility, helium should be the least narcotic and nitrous oxide and xenon the most narcotic gases. The anesthetic potency of these gases in animals and humans closely parallels the lipid solubility. Highly soluble gases as nitrous oxide and xenon can be used as anesthetics at normobaric pressure. Some interesting observations follow from this evaluation of lipid solubility. Notice that oxygen is considered to be twice as soluble as nitrogen, and thus should be twice as narcotic. However, evaluations of oxygen are more complex because this gas is metabolized by the body; the increase in tissue partial pressure of oxygen in one’s tissues does is not the same as the increase in inspired oxygen partial pressure. Despite this complexity it is prudent to assume that oxygen is narcotic. Similarly a review of lipid solubility demonstrates that carbon dioxide is extremely soluble in lipid tissue; as we expect it is also very narcotic. In fact, CO2 is so narcotic that it has been used as an anesthesia in animals. Increased arterial partial pressure of carbon dioxide above 60 mm Hg produces narcosis in humans, and arterial pCO2 greater than 100 to 120 mm Hg may result in loss of consciousness.

Because the Meyer-Overton rule is based on lipid solubility, it would lead one to believe that gases exert narcotic effects by dissolving in cell membranes, which are composed of lipids. Consciousness is controlled by the central nervous system (CNS) and alterations of function of the CNS lead to reduction in consciousness. Like all cells, the neurons in the CNS have lipid membranes as well as embedded proteins that serve as ion channels or receptors for extracellular compounds. Lipid soluble gases are proposed to alter neuron function by dissolving in the lipids and interfering with normal cellular function. There are a number of mechanisms by which altering the lipid membrane could interfere with neuron function; this might occur either by directly altering the properties of the lipid membrane, or by indirectly affecting...
the properties of embedded proteins. When anesthetic gases dissolve in lipid membranes, they disorder the normal closely packed ordering of the lipid molecules, and increase the fluidity of the membrane. In addition, this disordering pushes lipid molecules apart and increases the area of the membrane. The increased area of the membrane may impinge on embedded proteins, interfering with their function.

As good as the Meyer-Overton rule is it fails to predict anesthetic potency of a number of compounds and is likely an incomplete description of actual events within the body. With organic hydrocarbons such as alcohols increasing the chain length of the hydrocarbon increases the lipid solubility and the anesthetic potency; however, this is only valid up to a point. With most series of organic compounds when the chain length reaches 10 to 14 carbon atoms there is a sudden loss of anesthetic effect. Although this compound is lipid soluble it does not produce narcosis. The Meyer-Overton rule cannot explain this sudden loss of anesthetic effect. In addition, molecular isomers (the same atoms, but arranged differently) of clinically utilized anesthetics have identical lipid solubility but different anesthetic potencies. Again, based on the Meyer-Overton rule, they should have identical anesthetic potency. Based on these discrepancies there are likely to be factors involved in anesthetic effect of gases other than lipid solubility. The full complexity of narcosis and general anesthesia is not fully understood; yet, our grasp of the main mechanisms of narcosis and the primary agents responsible seems sufficient toward our making good decisions about the gases that we breathe while diving. The complexities of the Meyer-Overton rule are not especially relevant given the gases and depth of our diving, making this rule a useful tool toward reducing narcosis and associated diving risk.

Experimentation with narcotic gases helps us to resolve important questions relating to the safety of dives. This research, together with the Meyer-Overton rule, helps us to identify safe diving parameters for various gases; this knowledge also weighs heavily in the selection of GUE standard gases. This research also helps us to understand that some divers wrongly assume narcosis can be managed through adaptation. Objective measurement of divers using narcotic gases shows that there is no adaptation in reaction time; there is also no reduction in their tendency to make mistakes while impaired. However, individuals studied do wrongly perceive a reduction of narcosis; although the divers imagined they were less impaired there was no objective evidence that they were less impaired.

Depression of the CNS by illicit drugs, alcohol, and antihistamines may further exacerbate narcosis. Carbon dioxide retention can also exacerbate narcosis; the interaction between carbon dioxide and nitrogen suggests that the two are additive, notably increasing the total narcotic affect. While one might avoid the use of drugs, carbon dioxide retention may be more complicated. Arterial
partial pressure of carbon dioxide may be elevated by a number of factors, including exertion at depth, rebreathing expired CO₂ (i.e., a large dead space in breathing equipment), restrictive suits, and regulators with high breathing resistance.

In summary, one should recognize that our knowledge of narcosis is incomplete. However, the complexity of the issues affecting narcosis encourages the sensible diver to insist upon a conservative approach to the use of narcotic gases; gas selection at various depths should assume a worst case scenario. These concerns, together with a long history of aggressive diving, form the basis of GUE’s standard gases.

Bibliography


Evaluating the narcotic potential of breathing gases
Surface Consumption Rate

By Bob Sherwood

Given the importance of maintaining sufficient breathing gas supply divers must become familiar with calculating the quantity of gas breathed each minute at a given depth. Being familiar with this process is necessary for calculating the time a given gas supply will last; it is also essential for calculating the volume that must be reserved to return safely from the planned depth while also considering the potential for an emergency i.e. the loss of one diver’s gas supply.

The SCR (surface consumption rate) is the amount of gas that a diver will consume per minute at the surface; this value is also sometimes known as surface air consumption (SAC). The SCR is normally calculated while diving at depth; certain calculations (physical laws) then allow us to infer the amount of gas we would have consumed were we breathing at the surface. This evaluation is feasible because the gas consumed is directly proportional to the total pressure.

A diver’s SCR allows for the determination of the following:

1. How long your gas supply will last at a given depth.

2. The amount of gas you’ll need for a given dive.

SCR rates (as with one’s susceptibility to DCS, CNS toxicity and narcosis) vary from person-to-person and from day-to-day. Your SCR rate is affected by many factors, including fitness, comfort and exertion. An SCR between 12 and 15 is considered good. A SCR between 15 and 20 is considered average. A SCR rate between 20 and 25 is considered poor.

Determining your SCR

Divers need to know their working and deco SCR. The most accurate way to calculate your working SCR is to swim at a fixed depth for a fixed period of time or to use a meter to calculate the average depth for a given period of time.

Example:

Consider a diver wearing a single 12 L cylinder. The diver uses 100 bar in 20 minutes while swimming at 20 m. At 20 m this diver’s consumption rate is:

$$\frac{\Delta P}{\Delta T} = \frac{100\text{ bar}}{20\text{ min}} = 5\text{ bar/ min}$$
Now convert this value back to the surface and express it in terms of liter per minute, i.e.

\[ 5\text{ bar} ÷ 3\text{ ata} = 1.666 \text{ bar/min} \quad \leftarrow \text{At 20m = 3 ata, a diver consumes air three as fast as (s)he would on the surface.} \]

\[ 1.666 \text{ bar/min} × 12 \text{ L} = 20 \text{ L} \quad \leftarrow \text{Recall, to covert bar to liters we multiply the pressure by the tank volume.} \]

On this dive the diver’s working SCR rate was 20 L/min.

More simply, the SCR rate formula is: \( SCR = \frac{\Delta P}{\Delta T} \times \frac{1}{D_{\text{ata}}} \times V \)

**Determining your average SCR**

Since your SCR rate varies from day-to-day, you should determine your average SCR rate. To determine your average SCR rate, sum your recent SCR rates and divide by the number of SCR rates observed.

**Example:** Determine the average SCR rate for a diver given the following SCR rates.

\[ 14 \quad 16 \quad 12 \quad 18 \quad 14 \quad 15 \quad 14 \quad 12 \quad 14 \quad 16 \]

\[ \text{Average SCR} = \frac{14 + 15 + 16 + \ldots + 14 + 16}{10} = 14.5 \text{ L/min} \]

**Student exercises**

1. Suppose a diver wearing twin 12’s uses 50 bar in 15 minutes swimming at 30 m. What is this diver’s working SCR rate?

2. Suppose a diver doing deco with a 7 L tank uses 40 bar in 10 minutes at 6 m. What is this diver’s deco SCR rate?
Gas management

Gas management is an essential though often undervalued aspect of dive planning. Divers often estimate the gas required for a given dive; this guess is based partly on experience and partly on one’s estimate of the variables likely encountered on any given dive. Of course, the actual amount of required gas varies in accuracy depending on the diver’s consumption and the variables encountered.

A more responsible approach to gas planning involves evaluating one’s gas consumption over several dives in various conditions and adjusting the anticipated consumption based upon an established dive plan. For example, a drift dive would require less total gas than a dive in which the team planned to return to the dive boat. When planning for the amount of gas a diver will require during a dive one must also account for the worst case scenario i.e. the loss of one diver’s gas supply while at maximum depth. In this case the gas reserved for an emergency ascent from depth assumes both divers are breathing from one cylinder.

After completing this section, you should be able to:

1. Convert between bar and liters in a cylinder
2. Calculate the ‘minimum gas’, allowing 2 divers to ascend while sharing gas.
3. Calculate the portion of your gas supply that is usable during the dive.
4. Calculate the time your gas supply will last at a given depth.
5. Calculate the amount of gas you’ll need for a given depth/bottom time.

Calculating liters for a given bar

Different volume sized cylinders carry different quantities of gas when under the same pressure. Therefore, when relating gas quantities we prefer to express this value in liters; this value can be converted back to an equivalent bar for any given cylinder.

For example, 50 bar in a single 12 L tank is NOT the same quantity as 50 bar in a single 15 L tank. The difference between these cylinders is equivalent to nearly 15 bar in the 12 L tank. In order to determine quantity of liters for a given cylinder volume one merely multiplies the pressure (bar) by the volume of the cylinder. For example, one can calculate the liters of 50 bar in a 12 L as follows: $50 \text{ bar} \times 12 \text{ L} = 600 \text{ L}$

Converting a given quantity of liters to bar for a particular tank is accomplished by dividing the liters by the bar. For example, one can calculate the pressure of 1200 liters in a 12 L tank as follows: $1200 \text{ L} \div 12 \text{ L} = 100 \text{ bar}$
Gas management

Determining the amount of gas you’ll need for a given segment of the dive.

To determine how much gas is needed for a given segment of the dive, we will use the following formulas:

1. Volume needed = Time × SCR × Depth in ATA
2. Pressure needed = Volume needed ÷ Tank volume

Determining the ‘minimum gas’ that should be reserved.

Prudence would dictate that you should reserve AT LEAST the amount of gas that you and your buddy will need to ascend from depth while sharing gas. There are many cases in which greater reserves are necessary.

Note: When diving with stage decompression bottles you need to reserve the amount of gas that you and your buddy will need to ascend to your first gas switch.

Example: Approximately how many liters of gas should a diver reserve to safely ascend to the surface with an out of gas (OOG) buddy from 18 m? Assume the following:

- A SCR (surface consumption rate) of 30 L/min for each diver is used for calculation; experience demonstrates this is a useful guesstimate which can be adjusted over time with experience. [60 L/min considers the needs of both divers]
- One minute at 18 m to deal with the emergency- please note that this is a minimum amount of time used for calculation purposes and should be adjusted as needed.
- An ascent rate of 9 m/min.
- Minimum deco, i.e. 30 second stops at 9 m, 6 m & 3 m.
- 30 second ascent between stops.

<table>
<thead>
<tr>
<th>Depth</th>
<th>Time</th>
<th>SCR</th>
<th>Data</th>
<th>Liters</th>
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<td>1</td>
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</tr>
<tr>
<td>1</td>
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<td>×</td>
<td>60</td>
<td>2.35</td>
</tr>
<tr>
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<td>0.5</td>
<td>(0.5)</td>
<td>60</td>
<td>1.9</td>
</tr>
<tr>
<td>6</td>
<td>0.5</td>
<td>(0.5)</td>
<td>60</td>
<td>1.6</td>
</tr>
<tr>
<td>3</td>
<td>0.5</td>
<td>(0.5)</td>
<td>60</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Minimum Gas 597 or 600
Note:

- The numbers in parentheses represent ascent times, i.e. it takes one minute to ascend from 18 m to 9 m at 9 m/min (average depth = 13.5 m) and 0.5 minute to ascend between minimum deco stops.
- For two divers to safely ascend from 30m, it takes approximately 1200 liters. [See Student Exercise #1.]

Example: For a 30 m dive, what minimum gas should be reserved, assuming a 12 L cylinder is used?

In order to convert volume to pressure, divide the required volume by the tank volume as follows;

Using a 12 L tank, divide the required volume (1200 L) by the tank volume (12 L) = 100 bar

Example: What is the minimum gas for a dive to 30 m using a single 15 L?

\[
1200 \text{ L} \div 15 \text{ L} = 80 \text{ bar}
\]

Shown below is the minimum gas (bar) for single tank divers.

[Double tank divers should halve the listed pressure.]

<table>
<thead>
<tr>
<th>Depth</th>
<th>11 L</th>
<th>12 L</th>
<th>15 L</th>
<th>18 L</th>
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<td>50 bar</td>
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<td>110 bar</td>
<td>100 bar</td>
<td>80 bar</td>
<td>70 bar</td>
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### Usable gas

Depending upon the dive, individuals may choose to use different gas rules to account for various diving situations. For example, a drift dive in which the team is picked up by a boat does not require as much reserve as a dive in which the team would like to return to the boat. We refer to the former situation (drift diving) as an “all usable” dive while the latter situation (prefer to return to the boat) is referred to as a “½ usable”. In situations where the dive team must return to the staring point the “½ rule” is used. All these rules are based upon the diver first subtracting their “minimum gas” from the total supply.

The formulas to determine the amount of usable gas are shown below:

- ½ Rule: Usable = ½ (Fill Pressure – Minimum Gas)
- ⅓ Rule: Usable = ⅓ (Fill Pressure – Minimum Gas)
- All usable: Usable = Fill Pressure – Minimum Gas

---

\(^5\) Never use less than 40 bar Minimum Gas. Also be aware that gauges may become inaccurate in the lower regions. Adjust this figure as necessary.
Gas management

Determining how long your gas supply will last at depth.

To determine how long your gas supply will last at depth use the following formulas:

1. Calculate time using a given bar: \( \text{Time} = \frac{\text{bar} \times \text{Tank volume}}{\text{SCR} \times \text{Depth in ATA}} \)
2. Calculate time using a given liters: \( \text{Time} = \frac{\text{L}}{\text{SCR} \times \text{Depth in ATA}} \)

Example

Suppose 2 divers are planning a dive with an average depth of 24m and they prefer to return to the ascent line. Diver A’s twin 12’s are filled to 200 bar and Diver B’s twin 15’s are filled to 200 bar. Assume a SCR of 20 L/min for both divers.

(a) What is the minimum gas that both divers need to reserve for this dive?

24 m average depth, so use 30 m (round up to be conservative) \(^6\)

Diver A: Twin 12s use 50 bar
Diver B: Twin 15s use 40 bar

(b) What are the turn pressures for both divers? Please note that the “turn pressure” is the pressure at which the diver’s will turn the dive.

Note: This is a dissimilar volume example.

Prefer to return to the ascent line, so use the \(\frac{1}{2}s\) Rule.

<table>
<thead>
<tr>
<th>Diver A</th>
<th>Diver B</th>
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<tbody>
<tr>
<td><strong>First calculate usable gas:</strong></td>
<td><strong>First calculate usable gas:</strong></td>
</tr>
<tr>
<td>(Available = 200 - 50) bar</td>
<td>(Available = 200) bar – 40 bar</td>
</tr>
<tr>
<td>( = 150) bar</td>
<td>( = 160) bar</td>
</tr>
<tr>
<td>(150) bar (\times 24) L</td>
<td>(160) bar (\times 30) L</td>
</tr>
<tr>
<td>( = 3600) L</td>
<td>( = 4800) L</td>
</tr>
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</table>

Using \(\frac{1}{2}s\) Rule, the usable gas is:

3600 \(\div 2 = 1800\) L or 70 bar (round down)

\(TP = 200\) bar – 70 bar
\(TP = 130\) bar

Using \(\frac{1}{2}s\) Rule, the usable gas is:

(remember use lowest volume)

3600 \(\div 2 = 1800\) L or 60 bar

\(TP = 200\) bar – 60 bar
\(TP = 140\) bar

(c) Approximately how long will it take each diver to hit his/her turn pressure?

---

\(^6\) The rounding accounts for the fact that the team may, in fact, be slightly deeper when encountering a problem. Therefore, it is best to be conservative and round to the max depth of the dive and to allow some leeway during the planning.
Diver A: \[ \text{Time} = \frac{P_{\text{usable}} \times V_{\text{cyle}}}{SCR \times D_{\text{ata}}} = \frac{70 \times 24}{20 \times 3.4} = 25 \text{ min} \]

Diver B: \[ \text{Time} = \frac{P_{\text{usable}} \times V_{\text{cyle}}}{SCR \times D_{\text{ata}}} = \frac{60 \times 30}{20 \times 3.4} = 26 \text{ min} \]

**Minimum fill pressure.**

The formulas to determine the minimum fill pressure for a desired amount of usable gas are shown below.

- ⅓ Rule: Minimum Fill Pressure = 3 x bar Needed + Minimum Gas
- ½ Rule: Minimum Fill Pressure = 2 x bar Needed + Minimum Gas
- All is usable: Minimum Fill Pressure = bar Needed + Minimum Gas

**Example:** What is the minimum pressure that a single 12 L needs to be filled in order to do a 25 minute drift dive at an average depth of 18 m? Assume a SCR of 20 L/min.

Liters needed: \[ \text{Time} \times \text{SCR} \times D_{\text{ATA}} \]
\[ = 25 \text{ min} \times 20 \text{ L/min} \times 2.8 \text{ ATA average depth} \]
\[ = 1400 \text{ L} \]

Bar needed: \[ \text{liters needed} \div \text{tank volume} \]
\[ = 1400 \text{ L} \div 12 \text{ L} \]
\[ = 117 \text{ bar (120 bar)} \]

Drift dive, so use All Usable

Minimum Fill pressure: \[ = \text{bar needed} + \text{Minimum Gas} \]
\[ = 120 \text{ bar} + 50 \text{ bar} \]
\[ = 170 \text{ bar} \]
Student exercises

1. Determine the minimum amount of gas (in liters) that is needed for 2 divers to safely ascend from 30 m to the surface sharing gas? Assume the following and complete the table shown below:
   - An SCR of 30 L/min for each diver. [60 L/min for both divers]
   - Assume one minute to manage the emergency; in practice more may be appropriate
   - An ascent rate of 9 m/min to the first deco stop
   - Recreational diving deep stops begin at 50% of max depth. [0.50 x 30 m = 15 m]
   - Minimum deco, i.e. 30 second stops at 9 m, 6 m & 3 m.
   - 30 second slide/ascent between minimum deco stops.

<table>
<thead>
<tr>
<th>Depth</th>
<th>Time</th>
<th>SCR</th>
<th>$D_{ata}$</th>
<th>Liters</th>
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Minimum gas

2. Suppose 2 divers are planning a drift dive with max depth of 30m and an average depth of 21 m. Diver A’s single 12 L is filled to 220 bar and Diver B’s single 12 L is filled to 210 bar. Assume an SCR of 20 L/min for both divers.
   (a) What is the minimum gas that both divers need to reserve for this dive?
   (b) What are the turn pressures for both divers?
   (c) Approximately how long will it take each diver to hit his/her turn pressure?

3. Suppose 2 divers are planning a dive with an average depth of 27 m and they must return to the ascent line. Diver A’s twin 12’s are filled to 230 bar and Diver B’s twin 15’s are filled to 210 bar. Assume an SCR of 20 L/min for both divers.
(a) What is the minimum gas that both divers need to reserve for this dive?

(b) What are the turn pressures for both divers?

(c) Approximately how long will it take each diver to hit his/her turn pressure?

4. If a diver must return to the ascent line, what is the minimum pressure that his/her twin 15’s need to be filled in order to do a 40 minute dive (20 minutes out and 20 minutes to return) at an average depth of 27 m? Assume a SCR of 20 L/min.

5. If a diver prefers to return to the ascent line, what is the minimum pressure that his/her twin 12’s need to be filled in order to do a 50 minute dive (25 minutes out and 25 minutes to return) at an average depth of 21 m? [Assume a SCR of 20 L/min.]
Gas planning

Cave divers were among the first to establish precise gas management rules; this is because their environment demanded greater care as well as a reasonable safety margin. In cave diving the ‘Rule of thirds’ is used to determine the pressure at which a diver must turn the dive. The ‘Rule of thirds’ theoretically reserves enough gas for a cave diver to exit the system sharing gas with a buddy who has had a catastrophic gas failure at the point of greatest penetration. Once the first diver hits thirds, (s)he calls the dive and both divers begin their exit. This thirds rule is useful anytime a diver MUST return to their starting point. Certain scenarios might require that divers reserve even greater gas supplies to account for delays in reaching the starting point; these scenarios include a prolonged ascent (such as with decompression), environmental conditions (such as current) and loss of visibility. Other gas rules such as “½ useable” and “all usable” can be used in other forms of diving where return to the starting point is either less important (diving from an anchored boat) or not relevant (drift diving).

Thirds for similar tanks

Divers in a team must reserve sufficient gas to account for differences in gas consumption; this ensures that the diver with the greatest consumption can be brought to the starting point with the supply of gas reserved in a team members cylinders. Divers using the same cylinders have little trouble calculating this required supply because the same pressure among team members with the same size cylinders equates to an equivalent total gas supply in liters.

Step #1: Determine which tanks have the least pressure. By using the diver with the least pressure (and therefore volume) we ensure that the team will not deplete the available supply before reaching the surface.

Step #2: Round the lesser pressure down to the first number divisible by 3 (for example 220 bar would round down to 210 bar) and divide by 3. Divers use intervals of 10 bar because these can be easily read on a pressure gauge.

Step #3: Subtract the pressure found in Step #2 from both tanks’ starting pressures to determine the turn pressures. It is important to subtract from the fill pressure; otherwise divers inadvertently use more gas than permissible.

Example: Using twin 16 liter cylinders rated at 230 bar

Suppose Diver A’s twin 16 liter tanks are filled to 220 bar and Diver B’s twin 16’s are filled to 230 bar. Determine the turn pressures for both divers using the rule of thirds.

Step #1: Determine which tanks have the least content.
Diver A’s 16’s have the least pressure. (220 bar vs. 230 bar)

**Step #2:** Round the lesser pressure down to the first number divisible by 3 and divide by 3.

\[220 \text{ bar} \approx \frac{210 \text{ bar}}{3} = 70 \text{ bar}\]

**Step #3:** Subtract the pressure found in Step #2 from both tanks’ starting pressures to determine the turn pressures.

Turn pressure for Diver A: \[220 \text{ bar} - 70 \text{ bar} = 150 \text{ bar}\]

Turn pressure for Diver B: \[230 \text{ bar} - 70 \text{ bar} = 160 \text{ bar}\]

**Student Exercises**

1. Suppose Diver A’s twin AL 80’s are filled to 210 bar and Diver B’s twin AL 80’s are filled to 180 bar. Determine the turn pressures for both divers using the rule of thirds.

2. Suppose Diver A’s twin 12’s are filled to 200 bar and Diver B’s twin 12’s are filled to 230 bar. Determine the turn pressures for both divers using the rule of thirds.

3. Suppose Diver A’s twin 15’s are filled to 230 bar and Diver B’s twin 15’s are filled to 220 bar. Determine the turn pressures for both divers using the rule of thirds.

**Thirds for dissimilar tanks**

Different sized cylinders carry different volumes of gas when under the same pressure. Therefore, when determining thirds for dissimilar tanks we CANNOT compare starting pressures. For example, 50 bar in twin 16’s is NOT the same volume as a 50 bar pressure drop in twin 12’s. In some cases this difference in volume is significant. For example, the 50 bar in the twin 16’s is about 1600 L and the 50 bar in the twin 12’s is about 1200 L for a difference of 400 L.

The diver with the larger tanks CANNOT use more than one third of the gas volume of the smaller tanks. If the diver with the larger tanks is allowed to use equal pressure they would use more volume; this would mean that the diver with the smaller cylinders would not have sufficient volume to properly assist the diver with larger tanks.

To determine thirds for dissimilar tanks requires additional steps as in the following:

**Step #1:** Determine which tanks have the smaller quantity of gas. This quantity is represented in liters.
Step #2: Determine the thirds for the tank with the smaller quantity of gas in bar and liters. This determines the bar that may be consumed by the diver with smaller cylinders; converting this bar to liters allows a comparison to the other sized cylinders.

Step #3: Determine the equivalent bar in the larger tanks, rounding down for a conservative calculation.

Step #4: Determine turn pressures for both tanks.

Example: Consider double 15’s with a rated pressure of 200 bar and 12’s rated to 230 bar. Suppose Diver A’s twin 15’s are filled to 180 bar and Diver B’s twin 12’s are filled to 240 bar. Determine the turn pressures for both divers using the rule of thirds.

Step #1: Determine which tanks have the smaller quantity of gas.

In order to establish the tanks with the smaller quantity of gas we must convert the bar in these cylinders to liters which relates the volume contained in each cylinder. This is accomplished by multiplying the volume of the cylinder by the pressure found in the cylinder.

15’s filled to 180 bar

\[2 \times 15 \text{ L} \times 180 \text{ bar} = 5400 \text{ L}\]

12’s filled to 240 bar

\[2 \times 12 \text{ L} \times 240 \text{ bar} = 5760 \text{ L}\]

Step #2: Determine the thirds for the tank containing the smaller quantity of gas in bar and liters.

One third of the twin 15’s is calculated thus.

\[2 \times 15 \text{ L} \times 180 \text{ bar} = 5400 \text{ L} \div 3 = 1800 \text{ L}\]

\[180 \text{ bar} \div 3 = 60 \text{ bar}\]

Step #3: Determine equivalent bar in the tanks which offer the most gas.

1800 liters in 12’s = 1800 ÷ 24 L = 75 bar

Step #4: Determine turn pressures for both tanks.

Turn pressure for Diver A: 180 bar – 60 bar = 120 bar

Turn pressure for Diver B: 240 bar – 75 bar = 165 bar.

Round this to 170 bar

Note:
Gas planning

- One can determine intuitively that a tank of greater volume which contains a similar pressure will hold a greater volume. However, there are situations in which this is less obvious and where smaller tanks may contain a greater volume such as in example #3 in the exercises below.

- If Diver B was allowed to use a third of the gas in his/her tanks (i.e. 80 bar), (s)he would use $80 \text{ bar} \times 24 \text{ L} = 1920 \text{ L}$ (vs. 1800 L) for penetration. That would be 1020 L MORE than thirds of the 15’s! In the event that Diver B had a catastrophic gas failure and had to share gas with Diver B from the most distant point the gas carried would be insufficient to allow a safe return.

Student exercises

1. Suppose Diver A’s twin 12’s are filled to 210 bar. Diver B’s twin 15’s are filled to 200 bar. Determine the turn pressures for both divers using the rule of thirds.

2. Suppose Diver A’s twin 15 are filled to 230 bar and Diver B’s twin 16’s filled to 220 bar. Determine the turn pressures for both divers using the rule of thirds.

3. Suppose Diver A’s twin 12 are filled to 220 bar and Diver B’s twin 16’s filled to 180 bar. Determine the turn pressures for both divers using the rule of thirds.
Introduction

The information in this appendix is designed as a personal study guide to be used in preparation for GUE Fundamentals. Students with no previous Nitrox training should carefully study this material; those with previous Nitrox training should review this material to acquaint themselves with GUE Nitrox training. This appendix contains a simplified set of guidelines outlining the safe and efficient use of Nitrox within the realm of recreational diving (maximum depth 30 m and within the GUE Minimum Deco schedule). Included in this appendix are the basic physics, physiology, safety concerns and practical aspects of Nitrox diving. This material should not be considered a substitute for Nitrox training; instead it must be combined with the GUE Recreational Diver level 1 or GUE Fundamentals training. Participants should study this appendix, fill out the included quizzes and take the final GUE Nitrox Examination. Participants successfully completing this training will be accredited as a certified Nitrox user, allowing them to use the GUE standardized bottom gas: 32% Nitrox. This information will be printed on the GUE Fundamentals certification card.

The air we breathe at surface

Surface air consists of 21% oxygen (O₂), 78% nitrogen (N₂), and 1% of other gases such as argon. To make things easier to remember, air is usually referred to as 21% oxygen and 79% nitrogen. Enriching air with additional oxygen produces a Nitrox gas mix. The primary constituents of a Nitrox mix are oxygen and nitrogen, but the amount of oxygen will now be higher; thus, it is often called oxygen-enriched air, or enriched-air Nitrox.

What is nitrox?

Nitrox is a gas with elevated oxygen content; the Nitrox designation is clarified by specifying the percentage of enriched oxygen. For example, EAN32 is a Nitrox gas mix containing 32% oxygen and 68% nitrogen. In GUE, an EAN32 Nitrox gas mix is commonly referred to as 32% Nitrox, and is one of the organizations standard bottom gases for recreational use to a maximum depth of 30 m.

History of nitrox usage and applications

Although Nitrox was first used as a diving gas during the early 1900s, it was not used commercially until 1950, when the US Navy and the NOAA implemented the use of Nitrox in their manuals. The recreational community started using Nitrox in the early 1990’s albeit with limited acceptance among
recreational organizations. Cave and technical divers had been using Nitrox for more than a decade, sharing their experiences with the general diving community. With the growth of Nitrox, air diving is becoming largely obsolete. GUE is the first organization to completely forgo the use of air, establishing a set of standard breathing gases to maximize safety and efficiency for recreational and advanced cave and technical divers.

Advantages

The advantages gained by using Nitrox are not derived from the raised levels of oxygen in the gas mix. More relevant is the reduced amount of nitrogen, since the demand for decompression is related to the amount of nitrogen and/or helium being dissolved into tissues (commonly called on-gassing) during a dive. Both the tissues’ on-gassing time and the total amount of nitrogen dissolved in the diver’s body are governed by the “partial pressure” of nitrogen in the breathing gas. In other words, high levels of nitrogen in the breathing mix (79% N₂ in air) give the recreational diver shorter Minimum Deco bottom times as well as additional decompression stress. A 32% Nitrox mix will extend the allowed Minimum Deco bottom time to almost double that of air.

Concerns

Most of the problems found in air diving are equally relevant for diving Nitrox; a small collection of problems discussed below create unique concerns for diving Nitrox. As with all diving, Nitrox must be treated with respect; dives should be executed in a mature and conservative manner. Barotraumas, gas emboli, DCI, etc., are as relevant when using Nitrox as when using air. Diving Nitrox can create some additional risk. For example, the risk for oxygen toxicity may be elevated when using Nitrox due to the increased oxygen content, requiring caution while preparing, analyzing and using the gas.

Oxygen toxicity (pulmonary and central nervous system - CNS)

CNS oxygen toxicity results from breathing mixtures in which the percentage of oxygen is excessive. Toxicity may also develop when breathing elevated oxygen mixes for long periods of time. Maladies brought about by breathing elevated oxygen percentages are referred to as Hyperoxia. Hyperoxia can affect the body in two primary ways; these are referred to as 1) Central Nervous System Oxygen Toxicity (CNS) and 2) Pulmonary Oxygen toxicity (also known as Whole Body Oxygen Toxicity). CNS Toxicity can lead to convulsions that are similar to an epileptic seizure. This effect may occur when the pressure

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7 Partial Pressure Defined:
In a mixture of gases, each gas has a partial pressure; this is the pressure which the gas would have if it alone occupied the volume. The partial pressure of a gas is a measure of the activity of the gas's molecules. Gases will always flow from a region of higher pressure to one of lower pressure; the larger this difference, the faster the flow. Gases react according to their partial pressures, and not necessarily according to their concentrations in a gas mixture.
of oxygen becomes too great; for example, when diving too deep on Air, Nitrox, or Timix. Pulmonary Toxicity may occur when using an elevated Oxygen mixture over a long period of time; this condition primarily affects the lungs. Due to relatively short bottom times during a recreational dive, this condition is not especially relevant as a risk factor; this is true until divers engage in aggressive technical diving (long and/or deep diving).

**Gas laws and principles**

Due to the increased risk of oxygen toxicity while diving Nitrox, the user should be familiar with the procedure for calculating Nitrox limits. However, limited reliance on calculations is one of many benefits found in GUE standard gasses. This is because a GUE Standard gas nearly eliminates these risks within its prescribed range. Understanding gas laws facilitates the calculation of breathing gas parameters; this is an important aspect to evaluating the safety limits for a particular mixture.

**Pressure and depth**

Water is 800 times more dense than air. As we descend deeper on a dive, the surrounding pressure increases. The term ATA, atmosphere absolute, is commonly used to describe surrounding pressure. At the surface, the surrounding pressure is 1 ATA; at 10 m depth, the pressure is 2 ATA, and at 20 m, 3 ATA. At 30 m, the GUE recreational depth limit, the pressure is elevated to 4 ATA. Some organizations use bar to describe surrounding pressure as well as tank pressure. One bar is equal to 1 ATA.

As you read this appendix, you are being exposed to a surrounding atmospheric pressure of one ATA. Because the atmosphere consists of approximately 21% oxygen, the oxygen partial pressure is 0.21 ATA. In diving terms, this is referred to as a PPO2 of 0.21 ATA. You might remember that roughly 79% of air consists of nitrogen; therefore, the partial pressure of nitrogen must be 0.79 ATA or PPN2 of 0.79 ATA. In any gas mixture like air or Nitrox, each gas takes up its own part in the total gas mixture pressure, called partial pressure. Summing the partial pressures of all gases in any gas mixture gives the mixture’s total pressure. For example, 32% Nitrox at the surface consists of 32% oxygen and 68% nitrogen. The PPO2 is 0.32 ATA and the PPN2 is 0.68 ATA; at the surface the total pressure of the gas mixture is 1.0 ATA. This principle is based on the Dalton gas law. As we descend, the surrounding pressure increases, resulting in an increase in the partial pressure of the constituent gases. For example, diving to 20 m using 32% Nitrox results in a surrounding pressure of 3 ATA where the PPO2 will be .96 (.32 x 3 = 0.96 ATA) and the PPN2 increases to 2.04 (.68 x 3 = 2.04 ATA). Together, the sum of pressures of the individual gases will be identical to the surrounding pressure (PPO2 0.96 + PPN2 2.04 = 3 ATA). Pressure is often expressed as P (pressure). The surrounding pressure is referred to as Pata. Therefore, the following rule
applies to both air and Nitrox: \( P_{\text{ata}} = P_{O_2} + P_{N_2} \). To express the percentages of individual gases in a gas mixture, the letter F is used (fraction). Regarding air, oxygen makes up 21%, and thus, the fraction of oxygen (\( F_{O_2} \)) is 0.21 while the fraction of Nitrogen (\( F_{N_2} \)) in air is 0.79.

The formula for calculating the partial pressure of any gas is:

\[
P_{\text{gas}} = \text{Fraction} \times P_{\text{ata}}
\]

Question: What is the PPO\(_2\) diving 32% Nitrox to 30 m?
Solution: \( 0.32 \times 4 = 1.28 \)
Answer: PO\(_2\) 1.28 ATA

Using this formula, we can also calculate the depth of a given PO\(_2\):

Question: At what depth will the PPO\(_2\) be 1.1 ATA using 32% Nitrox?
Solution: \( 1.1 = 0.32 \times P_{\text{ata}} \)
\( P_{\text{ata}} = 1.1 \div 0.32 \approx 3.44 \text{ ATA} \)
\( (3.44 \text{ ATA} - 1) \times 10 = 24 \text{ m} \)
Answer: 24 m depth

**Oxygen and the diver**

Most people are aware that oxygen is needed to sustain life, but few understand the ways in which oxygen can be dangerous. For example, many people believe that nitrogen narcosis is the primary limit for the depth at which air or Nitrox can safely be used. However, seizures caused by CNS Oxygen Toxicity present a notable danger to every diver using mixed gases or diving deep on air. A diver exposing him or herself to an elevated PPO\(_2\) increases the risk for hyperoxia, or oxygen toxicity. GUE recommends that a maximum PPO\(_2\) of 1.4 ATA should be used while diving. For longer, colder or more demanding dives, GUE recommends PPO\(_2\) 1.2 or less.

Using the table below we establish a 210 minute limit while at a PPO\(_2\) of 1.2 ATA. If the diver spends 210 minutes under this oxygen partial pressure they will use 100% of his or her allowed time. If the dive lasted only 35 minutes the diver would have used 17% of the safe oxygen dose for a single exposure (35 ÷ 210 = 0.166).
Table 1: Dr. Bill Hamilton Oxygen tolerance limits.

<table>
<thead>
<tr>
<th>PO2</th>
<th>Single Exposure</th>
<th>24 hour Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6</td>
<td>45</td>
<td>150</td>
</tr>
<tr>
<td>1.5</td>
<td>120</td>
<td>180</td>
</tr>
<tr>
<td>1.4</td>
<td>150</td>
<td>180</td>
</tr>
<tr>
<td>1.3</td>
<td>180</td>
<td>210</td>
</tr>
<tr>
<td>1.2</td>
<td>210</td>
<td>240</td>
</tr>
<tr>
<td>1.1</td>
<td>240</td>
<td>270</td>
</tr>
<tr>
<td>1.0</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>0.9</td>
<td>360</td>
<td>360</td>
</tr>
<tr>
<td>0.8</td>
<td>450</td>
<td>450</td>
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</tbody>
</table>

Two disorders are caused by Hyperoxia; these include CNS Oxygen Toxicity and Pulmonary Oxygen Toxicity. CNS Oxygen Toxicity is the most relevant to recreational divers and by far the more dangerous disorder. Pulmonary Oxygen Toxicity only becomes a problem if the diver exposes him or herself to PPO2 0.5 ATA or higher for a prolonged time; it is very difficult to do this within the realm of recreational diving. Extreme technical and cave explorers track their pulmonary oxygen exposures using OTU calculations (Oxygen Toxicity Units). Hypoxia (inadequate supply of oxygen) is unlikely in open-circuit recreational diving; nonetheless divers should be familiar with this condition. Inadequate levels of oxygen can cause unconsciousness without warning. As the PPO2 drops below 0.16 ATA, the risk of Hypoxia increases. The use of rebreathers or Hypoxic Trimix or Heliox gas mixtures elevates the risk of Hypoxia.

The following guidelines will make your Nitrox diving safer:

- Always keep PPO2 within 0.21 and 1.4 ATA while diving
- A PPO2 below 1.2 ATA further reduces risk for long, cold or demanding dives
- Always analyze your breathing gas and properly mark and label your tanks accordingly
- Use GUE standard mixes to ensure utility and safety
CNS oxygen toxicity

Humans can temporarily withstand a PPO₂ above 2.0 ATA; however, such an elevated PO₂ is only reasonable while at rest in a comfortable and controlled environment. Levels such as these are normally only used in recompression treatments where risk is reduced through the use of a dry environment where patients are monitored by medical personnel. Dr. Kenneth Donald accumulated years of research studying CNS Oxygen Toxicity with the U.S. Navy; he discovered that Oxygen tolerance at high pressures highly variable.

As partial pressures escalate the risk of toxicity becomes more pronounced. A PPO₂ higher than 1.4 ATA is especially dangerous while diving; this is because exertion predisposes one toward toxicity. Oxygen levels as high as 1.6 should only be used by experienced technical divers during resting decompression. Symptoms of CNS Oxygen Toxicity include: Convulsions, visual disturbances, euphoria nausea, twitching, irritability, dizziness, etc. It is important to understand that these symptoms, among others, may indicate an oncoming seizure; however, these symptoms may not occur or may not be noticed. The acronym CON-VENTID will help you remember these possible symptoms.

<table>
<thead>
<tr>
<th>Con</th>
<th>Convulsions</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>Vision</td>
</tr>
<tr>
<td>E</td>
<td>Ear</td>
</tr>
<tr>
<td>N</td>
<td>Nausea</td>
</tr>
<tr>
<td>T</td>
<td>Twitching</td>
</tr>
<tr>
<td>I</td>
<td>Irritability</td>
</tr>
<tr>
<td>D</td>
<td>Dizziness</td>
</tr>
</tbody>
</table>

Maximum Operational Depth - MOD

The maximum safe diving depth is often referred to as the MOD (Maximum Operational Depth). A gas with an MOD of 21 m cannot be used deeper than this depth without incurring significant risk of CNS Oxygen Toxicity.

The MOD formula is used to calculate the maximum safe operational depth of a given breathing gas. The formula is as follows:

MOD (ATA) = \( \frac{PO₂}{1.4 ÷ FO₂} \)

Calculate the MOD for a recreational 32% Nitrox dive in warm and relaxed conditions.

MOD = 1.4 ÷ 0.32 = 4.37 or 33 m depth (GUE’s limit is 30 m)

Calculate the MOD for a recreational 32% Nitrox dive in current with cold conditions.

MOD = 1.2 ÷ 0.32 = 3.75 or 28 m depth
Equivalent Air Depth - EAD

The previous review demonstrated ways to calculate the operational range of a breathing gas as well as the maximum operational depth. The following review outlines strategies for adjusting decompression tables while breathing Nitrox. Diving Nitrox may be done using specially designed Nitrox tables or by modifying existing air decompression tables. Using the Equivalent Air Depth formula (EAD), you can convert any planned Nitrox dive to an equivalent air depth; this allows the use of a standard air table. This is possible because Nitrogen is the primary agent resulting in decompression. Therefore, the EAD relates the Nitrogen pressure of a given Nitrox mix to the equivalent Nitrogen pressure that would be found in air.

Example:  Comparison between 32% Nitrox and air used at 24 m depth

32% Nitrox

Question: If we dive 32% Nitrox to a depth of 24 meters, what is our PPN₂?

Solution: PPN₂ = 0.68 x 3.4 ATA = 2.312 ATA

Answer: PPN₂ = 2.312 ATA

Air

Question: If we dive air to a depth of 24 meters, what is our PPN₂?

Solution: PPN₂ = 0.79 x 3.4 ATA = 2.69 ATA

Answer: PPN₂ = 2.69 ATA

The EAD while using Nitrox will always be less than the actual depth of the dive; this is because the pressure of the Nitrogen (PPN₂) is reduced while using Nitrox when compared to air. EAD Formula: EAD = [(FN₂ / 0.79) x (Depth + 10)] - 10

Question: If we dive 32% Nitrox to a depth of 27 m, what is our EAD?

Solution: [(0.68 / 0.79) x (27+10)] – 10 = 21.8

GUE Guesstimate: For 32% Nitrox, reduce depth by 20% to find EAD (EAD = 0.8 x depth)

Question: If we dive 32% Nitrox to a depth of 27 m, what is our EAD?

Solution: 0.8 x 27 m = 21.6 m

Answer: 22 m is our EAD. We use this depth in the standard air table.
Practical considerations

Rather than utilize numerous calculations to establish the proper breathing mixtures GUE has established standard gases; this insulates divers from several risks inherent in Nitrox diving. GUE promotes the use of 32% Nitrox for recreational diving to a depth of 30 m. This strategy reduces confusion and increases team unity while simplifying dive planning.

Equipment

In most cases divers may use their conventional equipment when diving Nitrox; however, some preparation may be necessary. Diving regulators can be oxygen cleaned and assembled with parts that are oxygen compatible. Oxygen cleaning removes hydrocarbons or other contaminants that can increase the risk of combustion; Oxygen compatible parts also reduce this risk. According to the recommendations drawn from NOAA, any regulator can be exposed to 40% oxygen without modifications. Oxygen servicing is accomplished by removing all hydrocarbons and grease; Viton or other Oxygen compatible O-rings are used with Christolube or another oxygen-compatible grease.

An Oxygen serviced regulator is safe to use in a 100% Oxygen environment. For a recreational Nitrox user, the only dive equipment that will be exposed to pure oxygen is the tank and its valve. This is because some forms of blending Nitrox require that 100% Oxygen be directed into the tank. Today, almost all regulator manufacturers offer oxygen-compatible products; these are normally included without additional charges. In addition to proper equipment maintenance it is important to fill one’s tanks at a reputable facility with cleanest possible air; this reduces the risk of contamination. All service or modification of your equipment should be performed by a professional service technician.

Nitrox mixing, analyzing and marking

There are several methods for producing a Nitrox mixture. The most common is called partial pressure filling. The process usually starts with the diver’s empty, oxygen-cleaned tank. A specified amount of pure oxygen is diverted to the tank; air is filled over the top of the oxygen mixture. Nitrox should only be filled by a trained and certified technician. However, the formula for producing a Nitrox mixture is straightforward. The Nitrox blending formula is as follows:

\[
\text{Pressure of } O_2 \text{ to add} = \left(\frac{F_{O_2} - 0.21}{0.79}\right) \times \text{Desired fill pressure}
\]

**Question:** The diver wants a 32% Nitrox filled to 230 bar. How many bar O2 should be added?

**Solution:** \[
\left(\frac{0.32 - 0.21}{0.79}\right) \times 230 \text{ bar} = 32.02 \text{ bar}
\]

**Answer:** 32 bar oxygen are first filled into the tank. The mix is finalized by topping off with air to the desired fill pressure.
The most efficient method of producing Nitrox is through the use of continuous blending. During this process the compressor is fed a predetermined mix of air and oxygen, delivering the correct Nitrox mixture directly into the diver’s tank. This method reduces the importance of oxygen-clean tanks and valves.

Divers must always verify that his or her tanks contain the correct Nitrox mixture; personally analyzing the gas content is best way to verify this is done properly. The Nitrox mixture’s oxygen content is analyzed using an Oxygen Analyzer and the result is immediately written on the tank’s label. Analysis is recorded to one decimal point to highlight that the analysis was completed; the person doing the analysis also notes the date and their personal initials. The breathing mixture in a cylinder is not ready to use until the tank content has been analyzed by the user; the MOD label must also be personally verified. Verifying proper gas mixtures and cylinder marking is a team responsibility. If any doubt exists about the contents of a cylinder the breathing gas should not be used.

GUE requires that every cylinder be permanently marked it with the **Maximum Operational Depth of the breathing mixture**. This procedure ensures that a gas will not be breathed beyond its safe operational range. The MOD marking should be on both sides of the tank; in this way serves as identification for the diver and their team. Divers living in a country using Imperial measurements should use these for identification; those using the metric system should label their tanks accordingly.
Knowledge quiz

1. What are the percentages of the gases in the air you are breathing?
2. What two gasses are found in 32% Nitrox? What are their percentages?
3. What is a Normoxic gas?
4. At what depth does GUE recommend that divers breathe air?
5. Compared to using air what is the major advantage of using Nitrox?
6. While diving in the ocean what is the surrounding pressure at 26 m?
7. At what depth is the pressure equal to 2.6 ATA?
8. While diving to 26 m what is the PPO₂ of a 32% Nitrox?
9. At what depth will the PPO₂ reach 1.28 ATA while using 32% Nitrox?
10. When diving 32% Nitrox, at what depth is the same PPN₂ reached as when using air to 25 m?
11. Name the two different oxygen toxicity disorders.
12. What does the acronym CON-VENTID stand for?
13. How can you as a Nitrox user avoid CNS Oxygen Toxicity?
14. Calculate MOD for a 32% Nitrox using PPO₂ 1.2 ATA.
15. What is the difference between oxygen-clean and oxygen-compatible?
16. When mixing a 32% Nitrox mixture to 200 bar how many bar of oxygen do you need to add?
17. Who is responsible for the gas content in a tank?
18. Why does GUE require content and MOD markings on every tank?
Knowledge quiz - solutions and answers

1. 21% oxygen and 79% nitrogen
2. 32% oxygen and 68% nitrogen
3. 21% oxygen content
4. No! Air is not a GUE standardized breathing gas, and NOT recommended for diving
5. Longer Minimum Deco times allowed due to reduced nitrogen on-gas into tissues
6. \((26 \text{ m} \div 10) + 1 = 3.6 \text{ ATA}\)
7. \((2.6 \text{ ATA} - 1) \times 10 = 16 \text{ m}\)
8. \(0.32 \times 3.6 \approx 1.15\)
9. \(1.28 \div 0.32 = 4 \text{ ATA equals to 30 m}\)
10. Step 1: PPN\(_2\) using air to 25 m = 0.79 x 3.5 \(
\approx 2.76 \text{ ATA}
\)
    Step 2: 2.76 ATA \(\div 0.68 \approx 4.1\) or 31 m
11. CNS and Pulmonary Oxygen Toxicity
12. Vision, Ear, Nausea, Twitching, Irritability and Dizziness
13. Limit PPO2 to 1.4 ATA or less. Analyze and label with MOD. Be responsible
14. \(1.2 \div 0.32 = 3.75\) or 27 m depth
15. Oxygen-clean = cleaned for hydrocarbons. Oxygen-compatible = components such as O-rings and compatible grease
16. \(((0.32 - 0.21) \div 0.79) \times 200 \text{ bar} = 27.8 \text{ O}_2\)
17. The user and the team
18. To minimize the risk of confusion, which could lead to oxygen-toxicity accident.
Deep stops

by Bob Sherwood

When breathing at depth, gasses are dissolved in a diver’s tissues and these gasses may bubble when the pressure is relieved during ascent. The bubbles are thought to be a major component in what we know as Decompression Sickness. Therefore, it is reasonable to assume that controlling the size and frequency of bubbles is likely to reduce the risk of DCS and improves the safety of diving.

While some bubbling is likely to be inevitable, minimizing bubbles is accomplished by slowing one’s ascent before significant bubbles can form and grow. The speed of one’s ascent and the depth at which decompression stops should be initiated are modeled partly on empirical evidence (such as the dives done by GUE’s WKPP project) and also, more recently, from calculations that anticipate bubble formation and growth.

Generally speaking, dives with mandatory decompression stops (long and/or deep) require divers to begin stops at 80% of the diver’s maximum depth as measured in atmospheres absolute (75% of max depth is a reasonable approximation).

However, during recreational diving (dives with no mandatory decompression stops) notably less gas is dissolved in a diver’s tissues and the reduced gas allows greater progress to be made in the early stage of the ascent without bubble formation getting out of control.

During these dives GUE recommends stopping at 65% of the diver’s maximum depth as measured in atmospheres absolute (50% of the diver’s max depth is a reasonable approximation). Once a diver has reached this level they are encouraged to break the ascent with stops every 3 meters.

Example: During a 24m ocean dive at what depth should a diver perform his/her first deep stop?

0.5 × 24 m = 12 m

Student exercises

1. During a 36 m ocean dive at what depth should a diver perform his/her first deep stop?

2. During a 30 m ocean dive at what depth should a diver perform his/her first deep stop?
Partial pressure

by Bob Sherwood

Understanding the concept of partial pressure is an important component toward appreciating the effect of various breathing gases at different pressures. Therefore, the partial pressure of a gas is determined by the concentration of the gas and the ambient pressure. For example, the concentration of O₂ in air is about 21% and the partial pressure of O₂ in air at surface is about 0.21 ata as a component of the one atmosphere total pressure. The concentration of O₂ in air remains the same at depth but the partial pressure reflects the increasing pressure and compression of the gas. At two atmospheres absolute the number of O₂ molecules per unit volume is twice what it is at the surface and the partial pressure is double or equivalent to .42 partial pressure.

Dalton’s law

According to Dalton’s Law, the total pressure exerted by a gas equals the sum of the partial pressures of all the gases that compose the gas, i.e.

\[ P_{\text{total}} = P_1 + P_2 + \ldots + P_3 \]

In the case of air, the total pressure exerted on our bodies equals the sum of the ‘partial pressures’ exerted on us by the individual gases that constitute the air we are breathing, i.e. nitrogen, oxygen, Argon, Carbon Dioxide, … and Xenon, i.e.

\[ P_{\text{total}} = P_{N_2} + P_{O_2} + P_{Ar} + P_{CO_2} + \ldots + P_{Xe} \]

Partial pressures of nitrogen and oxygen

Since the air we breathe is primarily composed of nitrogen (78.084%) and oxygen (20.946%), the total pressure exerted on us by the air we breathe primarily equals the partial pressure exerted by nitrogen and the partial pressure exerted by oxygen, i.e.

\[ P_{\text{total}} = P_{N_2} + P_{O_2} \]

The partial pressure of a gas equals the fraction of the gas multiplied by the total pressure, i.e.

\[ P_{\text{gas}} = F_{\text{gas}} \times D_{\text{ata}} \]

So the partial pressures of nitrogen and oxygen are:

\[ P_{N_2} = 0.781 \times D_{\text{ata}} \quad \text{and} \quad P_{O_2} = 0.209 \times D_{\text{ata}} \]
Partial pressure

So…

$$P_{N_2} = 0.781 \times D_{\text{ata}} + P_{O_2} = 0.209 \times D_{\text{ata}} \approx D_{\text{ata}}$$

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>$P_{N_2}$</th>
<th>$P_{O_2}$</th>
<th>Total $P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$0.781 \times 1$ ata = 0.781 ata</td>
<td>$0.209 \times 1$ ata = 0.209 ata</td>
<td>$1$ ata</td>
</tr>
<tr>
<td>10</td>
<td>$0.781 \times 2$ ata = 1.562 ata</td>
<td>$0.209 \times 2$ ata = 0.418 ata</td>
<td>$2$ ata</td>
</tr>
<tr>
<td>20</td>
<td>$0.781 \times 3$ ata = 2.343 ata</td>
<td>$0.209 \times 3$ ata = 0.627 ata</td>
<td>$3$ ata</td>
</tr>
<tr>
<td>30</td>
<td>$0.781 \times 4$ ata = 3.124 ata</td>
<td>$0.209 \times 4$ ata = 0.836 ata</td>
<td>$4$ ata</td>
</tr>
</tbody>
</table>

From the table above, we can see that as our depth increases so do the partial pressures of nitrogen and oxygen; this would be true of any constituent in our breathing mixture.

Concerns with high partial pressures

Nitrogen narcosis

When the partial pressure of nitrogen approaches 3 ata one can measure increasing levels diver impairment. This nitrogen induced impairment is call ‘nitrogen narcosis’. When planning your dives, ensure that the partial pressure of nitrogen does NOT exceed 3 ata. It is likely that oxygen also impacts the feeling of narcosis although oxygen levels are normally constrained by other physiologic factors.

Central Nervous System (CNS) toxicity

High partial pressure of oxygen increase the likelihood of a physiological response known as central nervous system toxicity (CNS toxicity). During such a reaction the diver may convulse and is at risk for drowning. In order to reduce the risk of this malady it is recommended that divers not exceeding a 1.4 ata partial pressure of oxygen during the working part of the dive; a 1.6 ata partial pressure of oxygen during decompression is considered permissible by experienced technical divers. In order to insulate against the risk of oxygen, divers should be conservative about the oxygen pressures utilized; they should also be careful to analyze their cylinders the day they dive. A measurement known as CNS% is used to track oxygen exposure and to decrease the risk of this malady.

Pulmonary oxygen toxicity

Breathing moderate partial pressures of oxygen (greater than 0.5) for long periods of time can also result in pulmonary toxicity. Although this usually not a concern for recreational divers it can be a concern for technical divers. A measurement known as an oxygen tolerance unit (OTU) is used to track oxygen exposure and to decrease the risk of this malady.
I would like to start this discussion by leveling the playing field, so to speak, and explaining what these terms mean. Once I do so, I will then discuss techniques for their use and deployment.

Although the terms “lift bag” and “SMB” are, at times, used interchangeably, such a use is not entirely accurate; this inaccuracy is similar to the one that collapses the distinction between a “decompression” and “stage” bottle. We will begin by looking at the two different uses these devices can have, because both can lift and mark. But as with most things in life, if we use the correct tool, the job becomes a great deal easier.

The primary function of lift bags is to lift objects from the water; they serve a secondary function as a surface marker. In order to lift an object from a body of water, we need to obtain positive buoyancy to offset the negative buoyancy of the object. In the commercial world, divers use lift bags to raise everything from anchors to ships. Generally, it’s best to use several smaller lift bags to gain as much control as possible over the object. That way, the object can be raised to the surface without danger to the diver. It also maximizes the chance of a successful lift the first time because the diver can keep complete control throughout the lift, rather than simply filling a bag as much as possible and hoping it will arrive on the surface in one piece and stay there. We will return to this point in great detail later. Most lift bags come in a pillow design with a somewhat smaller opening at the filling end. However, some – such as those used for prop removal and other specialty uses – come in a vast range of shapes and sizes, with models available in the 10,000s-of-pounds range.

Attaching the object correctly is of the utmost importance. With this in mind, it is always a good idea to think of the object going toward the surface without the diver. By this, I mean it is important to make sure that all items of the diver’s gear are out of the way, and that the object has no appendages that could catch the unwary diver and drag him or her to the surface.

In contrast to a lift bag, the sole purpose of an SMB is to supply team members on the surface with a marker by which to fix the relative position of a submerged diver. Once the diver commits to the water, there are a number of possible problems to consider, many of which we have little to no control over: possible mechanical trouble with the dive vessel, deteriorating weather, changing conditions with regard to current sheer, etc. Such variables make using an SMB a critical skill that a diver should develop over time with practice.
As we said, the sole purpose of an SMB is to notify our surface support where we are. Once the SMB is on the surface, it’s doing its job as long as it stays there. As a result, we must make certain that we are using an SMB that is as noticeable as possible to the surface vessel. This does not always mean that we have to select the largest SMB we can carry – in fact, a number of factors come into play when deciding which SMB to take. Some of the deciding factors are the kind of dive site we are on, our distance from shore, the color of the SMB, and the exposure protection we are using.

During GUE Fundamentals training, divers are shown the nuts and bolts of how to send an SMB to the surface. Safe deployment of an SMB, however, takes a lot of practice. Before one can do this while multi-tasking toward the surface on time, divers should not incorporate sending an SMB to the surface as part of the dive plan.

When selecting an SMB, one important consideration is how to fill the device. There are three basic kinds of devices: closed, semi-closed and open. As the name implies, a closed system acts in much the same manner as a buoyancy compensator. It has a fill nipple that cannot lock onto the inflator hose, and an overpressure relief valve. Once the diver fills the device, Boyle’s law takes over, and as the marker rises to the surface, the excess air is vented from the OPV. This kind of SMB has many advantages, given that it all but eliminates the possibility that air will spill out of the device once it hits the surface. Even so, there are some issues that confront the wetsuit diver. Though smaller, closed SMBs, such as the 3.3 ft, can be orally inflated, the 4.5 ft and larger SMBs require an LP inflator hose to be effectively filled. This means that the wetsuit diver is forced into carrying an extra LP hose, or worse, disconnecting his/her BC inflator – never a good idea. Semi-closed bags are gaining in popularity because they are filled with a second stage (much like a traditional open bag), but employ a baffle that allows gas to enter but not escape by sealing once the gas enters. It also uses an overpressure relief valve that allows excess gas to escape during ascent. The most traditional in design is the open circuit bag. As the name suggests, these have a pillow shape and an open end for filling; excess gas leaves the bag through the filling end during ascent. The biggest disadvantage of using an open-circuit bag is that when tension is not kept as the SMB approaches the surface, the diver is faced with the possibility that the gas in the SMB will spill out, leaving it ineffective at best, or that it will sink back down to the diver at worst.

Once you choose a filling method, it’s time to decide on the size and shape of your SMB. There are two basic shapes to choose from: a sausage or a bag. In choosing, several parameters must be kept in mind, the first being inflation size. Trying to get a full 100 pound bag to the surface will require a large amount of gas to be added at depth, which might cause major problems with the diver’s buoyancy. On the other hand, trying to fill this bag at a shallow depth could result in a very ineffective marker for the boat. A small 3.3 ft sausage with approximately 5 lbs of lift can be shot from any depth with ease, with little or
no effect on diver’s buoyancy. Only a small sausage can stand several feet above the surface, making it a very effective marker for the support vessel. This is maintained by keeping a small amount of tension on the line. It is surprising just how little tension is needed to keep the sausage standing upright; one finger tapping on the line will have the desired effect. If a larger SMB is needed, then using a 4.5 ft’ or 6 ft sausage will create a larger surface target for the vessel to see without needing to add massive amounts of gas. With an OPV fitted enclosed or semi-closed SMB, divers have the best options in nearly all conditions.

Since the ocean is a dynamic place and has a habit of changing rapidly, divers’ plans need to be as flexible as possible. By looking out into the distance from shore, and by noting typical weather, currents, tides and boat traffic, one can start to identify patterns that can help structure a sound dive plan. During any dive offshore, weather still in sight of land, or 150 miles from the nearest safe harbor that is seen and picked up by the dive vessel, is of utmost importance. This is why SMBs are used in the first place. For a boat to find a diver, the captain must make decisions based on known information; this is why the captain is a key member of any ocean dive. If a dive is undertaken in a tidal area, the captain will have a good idea of where the dive teams are as long as the time frame of the dive is within the plan. If a dive is undertaken in an area marked by strong currents, this may make the captain’s life a great deal harder, because currents can be very different within the water column. In fact, it is not uncommon to have currents going in completely different directions at different depths. In a case like this, shooting the SMB becomes a critical element of the dive plan. During a dive where divers are out of sight of land, and with little or no chance of a different vessel picking them up, it is imperative that the vessel knows where divers are at all times. This is one of the largest dangers facing the ocean diver, if not the greatest danger.

It is common practice to mark a wreck site with a down line, sometimes called a shot line. Divers use this technique to find the wreck; boats use it to know where divers are at the beginning of the dive. It is during the start of the ascent when several choices are to be made. One can choose to use the shot line as a marker by bringing the grapple up and tying it to the line. The advantage of this is that it allows all the divers to be in one place, making the job of surface support a great deal easier. The disadvantages of this technique are that it requires all divers to come back to the line to complete their ascent; it requires that everyone keeps to their planned bottom time, or the line may be released prematurely; and it requires divers to work at depth (having to bring grapple and chain up when gas supply could be getting low, and each extra minute spent could mean extended decompression beyond that of the planned gas supply).
Nonetheless, at some point divers will have to send an SMB to the surface. The question is, from what depth should it be sent? One can shoot it from the bottom, from mid-water or from very shallow. Conditions of environment and time of day will determine from where in the water column a diver will shoot their bag; one must be flexible. For example, on a day where there is no current and there is great visibility both on the surface and below, there is no need to send an SMB from the bottom or mid-water. Because both the diver and the boat will not move far from the wreck site, sending an SMB up from a shallow depth will be adequate. On the other hand, if the dive site is in a location that suffers from fog and currents, it will be necessary to shoot an SMB from depth and keep the teams together. As can be seen from these examples, there is no one right way to do this. Many variables have to be taken into account when deciding when to shoot a bag, and divers and captains must be on the same page and work together to create and implement the safest plan.

In closing, it is important to keep several things in mind. First, a great deal of practice is required to maintain the skill needed to safely use and deploy a lift bag or SMB. Second, learning to decide when to shoot an SMB is extremely important, and making the correct decision at the right time will come from experience and by talking with the vessel captain and crew, because they are the ones looking out for you! Third, having all the dive team members, support vessel members and staff on the same page regarding bottom times, etc., will make all the difference between an easy, safe dive and a complete nightmare. Lastly, once the SMB is on the surface, it is doing its job. At this point, it is more important for divers to watch each other and keep time than it is to reel in the spool or reel.
Student study guide

The Fundamentals of Better Diving

Course Overview

- Welcome
- Course Overview
- Paperwork Collection
GUE Fundamentals

Overview

- Course Objectives
  - How to evaluate personal skill level
  - How to assess what I know
  - How to make sound equipment choices
- Learning Outcomes
  - Comfort, competence, confidence
- Means of Realizing Objectives
  - Education, practice, experience
- Fundamentals Skills and Drills
- Grading and Performance Criteria

Course Overview

Overview

- Lectures
  - GUE overview
  - Why SCUBA dive?
  - Evaluating capacity
  - GUE Fundamentals
  - Buoyancy and weighting
  - Balance and trim
  - Propulsion techniques
  - Developing diving capacity
  - Summary of in-water skills
  - Equipment overview (DIR)
  - Decompression overview
  - Gas properties
  - Dive planning
  - Situational awareness

- Field Exercises
  - Equipment configuration
  - Analyze/mark cylinders
  - Propulsion & maneuver techniques
  - Basic 5
  - Valve drill
  - S-drill
  - Reserve light deployment
  - SMB deployment
  - Unconscious diver recovery

- Five Scuba Dives

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Course Overview

Dive 1

Surface preparation led by instructor or team captain.

- GUE EDGE
- Mod Valve and Mod S
- Bubble Check
- Application:
  - Buoyancy and trim practice
  - Frog kick
  - Modified frog kick
  - Proper flutter kick
  - Modified flutter kick
  - Slow ascent with at least one stop for one minute
  - Team skills (awareness, communication, sequence, team captain)
- Post-Dive Debrief

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Course Overview

Dive 2

Surface preparation led by instructor or team captain.

- GUE EDGE
- Mod Valve and Mod S
- Bubble Check
- Application:
  - Backward kick
  - Helicopter turn
  - Basic 5 skills
    - regulator remove and replace, regulator exchange, full hose deploy, mask clear, mask removal
  - Slow ascent with at least one stop for one minute
  - Team skills (awareness, communication, sequence, team captain)
- Post-Dive Debrief

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Dive 3

Surface preparation led by instructor or team captain.

- GUE EDGE
- Mod Valve and Mod S
- Bubble Check
- Application:
  - Descent drill
  - Valve drill
  - S-drill
  - Propulsion practice
  - OOG ascent drill (two stops for one minute each)
  - Team skills (awareness, communication, sequence, team captain)
- Post-Dive Debrief

Dive 4

Surface preparation led by team captain.

- GUE EDGE
- Mod Valve and Mod S
- Bubble Check
- Application:
  - Practice previous skills
  - Reserve light deployment (cave/tech)
  - No-mask swim
  - SMB demo/practice/ascent
  - Unconscious diver recovery
- Post-Dive Debrief
Course Overview

Dive 5

Surface preparation led by team captain.

- GUE EDGE
- Mod Valve and Mod S
- Bubble Check
- Application:
  - Descent drill
  - Valve drill
  - S-drill
  - Propulsion (helicopter left, right)
  - SMB deployment
  - OOG ascent with min-deco stops
- Concluding Remarks
- Course Completion Forms
- QC Forms

GUE Fundamentals

Grading Criteria

Diver Assessment Categories:

- Full Qualification
- Provisional Qualification
- Failure

*Grade 1*: Unsafe diver.
*Grade 2*: Cannot complete the required skill/task satisfactorily.
*Grade 3*: Completed the task satisfactorily (passed) but needs improvement.
*Grade 4*: Indicates that the student has completed the task well.
*Grade 5*: Completed the task extremely well.
Required Skills and Drills

1. Demonstrate proficiency in safe diving techniques.
2. Demonstrate awareness of team-member location and a concern for safety.
3. Efficiently and comfortably demonstrate how to deco an out-of-gas diver.
4. Safely demonstrate a gas sharing ascent with minimum deco ascent.
5. Demonstrate at least three propulsion techniques appropriate for silty environments.
6. Demonstrate the techniques needed for a successful backward kick.
7. Demonstrate a safe and responsible demeanor throughout all training.
8. Demonstrate proficiency in the ability to deploy a surface marker while using a spool.
9. Demonstrate proficiency in underwater communication.
10. Demonstrate basic equipment proficiency and an understanding of the DIR equipment configuration.
11. Demonstrate dive-rescue techniques, including effective management of an unconscious diver.
12. Demonstrate a comfortable demeanor while swimming without a mask.
13. Trim should remain within 30 degrees of horizontal.
14. Buoyancy should remain within 1.5m of target depth.
15. Demonstrate aptitude in the following open-water skills: Mask clearing, mask removal and replacement, regulator removal and exchange, long-hose deployment.
16. Demonstrate safe ascent and descent procedures.
17. Demonstrate proficiency in executing a valve drill.

All skills require a grade of 3 or above to qualify for full qualification.

* Skills and drills 18-24 apply only to students seeking admittance into Tech or Cave training. All skills require a grade of 4 or above to qualify for registration into the Tech or Cave curriculum.

18) Demonstrate proficiency with a primary light by using it during all skills except SMB deployment.*
19) Demonstrate efficient deployment and stowage of a reserve light.*
20) Demonstrate an efficient valve drill with double tanks.*
21) Demonstrate a comfortable demeanor while swimming without a mask.*
22) Trim should remain within 20 degrees of horizontal.*
23) Buoyancy should remain within 3 feet of target depth.*
24) Demonstrate proficiency in the backward kick.*
Global Underwater Explorers
GUE was created to increase the quality and diversity of aquatic education. Founded by conservationists, explorers and educators, Global Underwater Explorers is prepared to redefine the nature of aquatic activity in three specific areas: education, research and exploration.

Paradigm Shift
• Ending the Disconnect Between Training and Passion
  - Historically, dive training has been entirely disconnected from diving research, exploration and conservation; moreover, no broad educational platform exists to further long-term understanding and protection of our global aquatic resources.
GUE Overview

Short and Long Term Aspirations

- Develop global standards and procedures capable of supporting the world's most aggressive diving
- Develop the world's most robust diver training
- Build an international base of capable divers, educators, and researchers
- Develop ongoing exploration, research, and conservation initiatives

Structure of GUE Training

- Recreational
  - GUE Fundamentals (rec and tec)
  - GUE Recreational Triox
  - Recreational Diver Level 1
  - Recreational Diver Level 2
- Cave
  - Cave Diver Level 1
  - Cave Diver Level 2
  - Cave Diver Level 3
- Technical
  - Technical Diver Level 1
  - Technical Diver Level 2
  - Technical Diver Level 3
  - Rebreather
GUE Overview

Distinguishing Features of GUE Training

- GUE Standards and Procedures
- Mandatory re-qualification every three years for both GUE divers and Instructors
  - GUE divers must perform twenty-five dives at their highest level of certification
  - GUE instructors must requalify every three years; they must also conduct at least 25 non-teaching dives yearly
- Experience between courses allows divers a chance to gain proficiency
- Quality control evaluations to 100% of students
- No Smoking
  - General health as well as pulmonary fitness are important components of safe diving
  - Lung damage and chemicals from smoking are unhealthy and addictive, affecting individual and team safety
- Fitness Requirement
  - Fitness is a lifestyle choice that can safeguard individual health and greatly enhance diver safety
  - Parameters from decompression to stress management promote fitness as the only sensible option

Why Scuba Dive?

Diving for Fun

Some dive because they find happiness in **adventure**; others dive because they find happiness in **relaxation**; still others find happiness in **exploring** the limits of their abilities.
Establishing Capacity

A diver’s capacity plays a critical role in the ability to effectively pursue his or her goals.

Buoyancy and Weighting

Proper Buoyancy

- Foundation of Sound Diving
  - All skills should be performed while neutral
  - Fixed position
  - Requires practice
- Define good buoyancy: what is it?
Buoyancy and Weighting

Measuring Buoyancy Control

- Recreational Diver
  - Buoyancy should not vary by more than 1.5 meters
  - The 1.5 meter variation is measured from a specified depth
- Technical Diver
  - Buoyancy should not vary by more than 1 meter
  - Divers must always be in control of their ascents/descents
  - Divers must be able to complete simulated decompression stops

Proper Buoyancy

- Problems encouraging lack of control
  - Overweighting
  - Poor breathing control
  - Lack of practice and/or emphasis
**Buoyancy and Weighting**

**Properly Weighted Configuration**

- Properly weighted configuration i.e. "Balanced Rig"
  - Ideal configuration allows comfortable ascent with a BC failure and full tanks; this weighting should also allow a diver to hold a safety stop with nearly empty cylinders

Can you swim to the surface with a failed wing? Can you hold a stop with near empty tank?

---

**Buoyancy and Weighting**

**Weighting Variables**

<table>
<thead>
<tr>
<th>Negative</th>
<th>Positive</th>
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<tbody>
<tr>
<td>Diving Light</td>
<td>Buoyancy Compensator</td>
</tr>
<tr>
<td>Hardware</td>
<td>Dry Suit/Undergarments*</td>
</tr>
<tr>
<td>Weight Belt</td>
<td>Wet Suit*</td>
</tr>
<tr>
<td>Diving Cylinders*</td>
<td></td>
</tr>
<tr>
<td>Breathing Gas*</td>
<td></td>
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</tbody>
</table>

Neutral:

Human Body

*Note: Certain objects can change buoyancy over time/depth*
### Buoyancy and Weighting

#### Equipment Weighting

<table>
<thead>
<tr>
<th></th>
<th>Aluminum Tank</th>
<th>Steel Tank</th>
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<tr>
<td></td>
<td>30m (full tank)</td>
<td>3m (empty tank)</td>
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<tr>
<td>Regs</td>
<td>-1.4kg</td>
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<td>Tank</td>
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<td>Wetsuit</td>
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<td><strong>Drop wt. belt?</strong></td>
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### Buoyancy and Weighting

#### Equipment Weighting

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### Buoyancy and Weighting

#### Equipment Weighting

<table>
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<tr>
<th></th>
<th>Aluminum Tank</th>
<th>Steel Tank</th>
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<tr>
<td></td>
<td>30m (full tank)</td>
<td>3m (empty tank)</td>
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<tr>
<td>Regs</td>
<td>-1.4kg</td>
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<tr>
<td>Tank</td>
<td>-1.8kg</td>
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<tr>
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<td>-2.7kg</td>
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<tr>
<td>Light</td>
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## Buoyancy and Weighting

### Equipment Weighting

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Balance and Trim

Proper Trim Position

- Head back
- Flat from chest to knees
- Feet flat to assist stability
- Skill substitutes, i.e. ankle weights lead to greater problems
- Proper trim facilitates efficiency and environmental responsibility
  - Reduced drag in the water
  - Reduced risk of entanglement/damage to environments
  - Improved visibility
- Define proper trim: what is it?
- Proper Trim Position

Measuring Proper Trim

- Recreational Diver
  - Divers should be able to remain within approximately 30 degrees of horizontal
- Technical Diver
  - Divers should be able to remain within approximately 20 degrees of horizontal

Note:
- Figure 1 shows a diver with relaxed trim but the knees are bent to limit bottom contact.
- Divers who relax their trim must remain aware of their surroundings and the position of their feet.
- Divers must be capable of maintaining proper trim even while under duress.
Balance and Trim

Developing Proper Trim

- Adjust Position in Water
  - Raise or lower head
  - Lower or raise fins
  - Adjust breathing

Developing Proper Balance

- Equilibrium of diver’s position (i.e., right and left side)
- Equipment affects balance
- Shift body weight to adjust

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Propulsion Techniques

Kicks

- Different kicks for different circumstances
- Wide range of intensities
- Variety reduces risk of cramping
  - Flutter Kick (proper and modified)
  - Frog Kick (proper and modified)
  - Frog-Flutter comparison
  - Backward Kick
  - Helicopter Turns

Developing Diving Capacity

Cultivating Proper Skills

- Practice with Proper Form
  - No extraneous movement
  - Remain horizontal and neutral

- Beginning with the Basics
  - Basic 5
    1) Regulator removal and replacement
    2) Regulator exchange
    3) Long hose deployment
    4) Mask flood and clear
    5) Mask removal and replacement

- Proficiency Requires Practice
  - These skills must ultimately be performed under duress while maintaining proper form, good buoyancy and limited movement
Developing Diving Capacity

Going Beyond the Basics

- Integrating fundamental skills into life-preserving techniques
- Valve Drills
  - Single and Double
- Gas-Sharing Drills
  - S-drill
    - S-drill details
- Surface Marker
  - SMB deploy
- Miscellaneous Skills
  - Pressure check
  - Deploy reserve light

Developing Diving Capacity

A Solid Foundation – Crawl, Walk, Run

- Progressive learning process, building upon previously developed skills
- Difficult to overcome bad habits
- Repetition of correct action necessary
Developing Diving Capacity

Refined Fundamental Skills

- Efficient response to stressful scenarios
- Expanded scope of awareness
- Maintain control despite escalating difficulty

Summary of In-Water Skills

Summary of Skills and Drills

The following outline provides an overview of the skills to be accomplished, along with an estimate of the dive upon which they are likely practiced.

Dive One:
- Buoyancy and trim practice (fixed position)
- Frog kick
- Modified frog kick
- Proper flutter kick
- Modified flutter kick
- Slow ascent with at least one stop for one minute

Dive Two:
- Backward kick
- Helicopter turn
- Basic skills (regulator removal, exchange, hose deploy, mask clear, mask removal)
- Slow ascent with at least one stop for one minute

Dive Three:
- Descent drill (controlled with stops)
- Valve drill
- S-drill
- Propulsion practice
- OOG ascent drill with at least two stops

Dive Four:
- Practice previous skills
- Reserve light deployment (Cave/Tech)
- No mask swim
- SMB deployment demo/practice/ascent
- Unconscious diver demo/practice/ascent

Dive Five:
- Descent drill
- Valve drill
- S-drill
- Propulsion (helicopter left, right)
- SMB deployment
- OOG ascent drill with at least two stops
Preventing to Dive

Prior to Diving

- Pre-Dive Sequence
  - GUE EDGE
  - Modified valve drill (full version during training dives)
  - Modified S-drill/full long hose deployment (full version during training dives)
  - Bubble check

Dive Overview  GUE EDGE

GUE EDGE

- G – Goal, dive objectives
- U – Unified team, team strategies
- E – Equipment match
- E – Exposure, depth/time
- D – Decompression strategies
- G – Gas strategies
- E – Environmental issues
Equipment Configuration

History

- Developed by leading explorers
- Evolved for use in all environments
- Key platform for all GUE training

Equipment Configuration

Overview

- Minimalism and streamlining
- System and accessories chosen for utility
- Core components similar in all diving
- Configuration designed to minimize drag
Equipment Configuration

Backplate and Harness

- Rigid plate with one-piece harness
- No quick-release buckle
- Two chest, one hip, and two crotch strap D-rings
- Waist buckle with second retaining buckle for light
- Fit should be snug but unrestrictive
- Crotch strap should be easily removable (one piece)
- D-rings positioned at proper height
- Removal of Backplate
  - Important for getting into small boats and/or for emergencies
  - Harness should be snug but not inhibit in-water removal
  - Gas should be removed from the BC to facilitate easy removal
  - Divers should practice this skill to ensure capacity

Wing Style Buoyancy Compensator

- Durable construction
- Circular or elliptical design
- No “bungee-style” retaining bands
- Lift capacity appropriate for system

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Equipment Configuration

Regulators

- Quality construction
- Downstream design
- Removable second stage cover
- Facilitate streamlined hose routing and reduce gas trapping in wing

Hoses

- Quality construction
- Proper-length hoses reduce drag and entanglement potential
- Hose length varies, primarily according to first stage used
  - Primary second stage
    - 1.5m - 2m
  - Reserve second stage
    - 60cm
  - Pressure gauge hose
    - 55cm - 60cm
  - Inflator hose
    - 55cm
  - Dry suit hose
    - 55cm - 60cm
Equipment Configuration

Lights

- One primary light; two reserve lights; quality design
- Primary mounted to right hip; reserve lights on chest harness
- Reserve light: in-line design with no switch; do not overdrive bulb

Equipment Configuration

Dry Suit

- Tri-laminate construction
- Telescoping, self-donning design (no shoulder zippers)
- Pockets on each leg (side of leg); loop in pocket for accessories
- Turbo soles
- Shoulder dump
- P-valve
- Good flexibility and range of motion
Decompression Overview

Decompression

- Gas under pressure is absorbed by tissues
- Ascending creates a gradient for gas elimination (dissolved gas)
- Slow ascents control bubbles, likely reducing injury (free phase)

Decompression Overview

Decompression Sickness Defined

- DCS is a diving injury that leads to pain, numbness and possibly paralysis or death
  - Can result from dives in which bubbles are formed, such as during a rapid ascent
  - Bubbles may cause mechanical and/or biological reactions

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Decompression Overview

Dissolved Gas

- Dissolved Gas Paradigm
  - John Scott Haldane developed modern dissolved gas decompression theory
  - "Decompression must be started through a great ambient pressure reduction"
  - Albert Buhlmann translated theory into popular decompression models and tables

- Bubble Model Paradigms
  - Address free phase gas (bubbles) as well as dissolved gas (tissues)
  - Limit bubble formation and growth while allowing gas elimination from the tissues
  - Brian Hills and David Yoont (varying permeability model - VPM)
  - VPM is used in GUE’s DecoPlanner

Minimum Decompression

Minimum Deco

- Any dive may result in bubbling
  - Slow ascents reduce bubbling
  - Slow ascent to a first "deep" stop; additional stops of one minute are continued every 3m thereafter

- Deep Stops
  - Stop depth/duration depend upon the longevity and max depth of dive
  - Must be shallow enough to allow gas elimination, but deep enough to reduce bubbling
  - Can be calculated in programs such as GUE’s DecoPlanner
Minimum Decompression

Deep Stop Details

- Long and/or deep dives require deeper stops
- First deep stop generally occurs at 80% of the atmospheres absolute
- 75% of one’s max depth is a useful estimate for 80% of the ATA’s

Minimum Decompression

Deep Stops During Recreational Diving

- Less gas loading during recreational dives
- Start one-minute stops at 65% of total atmospheres (50% of depth)
- One minute stops are actually 30 seconds with a 30-second ascent
Minimum Decompression Dive

- “Minimum deco” dive to 30m
- Slow ascent to first deep stop
- One minute across each 3m interval

9 m/min ascent = 2 min

30 m

Diving Nitrox

Breathing Gases

- Breathing gases carry oxygen to the tissues
- These constituents create varying results
- Effect depends upon the gas and the partial pressure

- Partial Pressure
  - Part of pressure represented by individual gas
  - Fraction of gas x ATA

- Partial pressure examples:
  - Standard breathing gas from 0 - 30m (32% Nitrox)
  - Surface pressure = 1 atmosphere = .32PO₂ and .68PN₂
  - 10 m = 2 ATA = .64PO₂ and 1.36 PN₂
  - 20 m = 3 ATA = .96PO₂ and 2.04 PN₂
  - 30 m = 4 ATA = 1.28PO₂ and 2.72 PN₂
Diving Nitrox

Breathing Gas Mixes

- Evaluating Mixes
  - Partial pressure
  - Max depth

- Calculating Partial Pressure
  - Convert the depth (meters) to ATA's
  - Multiply the fraction × ATA's = Partial Pressure
  - Example:
    - What is the PPO₂ of 30/30 Triox mixture at 30m?
    - (30m / 30) + 1 = 4 ATA's × .30 = 1.2

- Maximum Operating Depth (M.O.D.)
  - PP / FO₂ = ATA's
  - Convert MOD from ATA to meters: ATA = 1 × 10
  - Example:
    - What is the MOD of 30/30 Triox mixture?
    - 1.2 / .30 = 4 ATA
    - 4 ATA = 1surface × 10 = 30 meters

Hypoxia vs. Hyperoxia

- Hypoxia
  - May compromise mental capacity and/or consciousness (PPO₂ < 0.16 ATA)
  - Loss of consciousness and death can occur with PPO₂ below 0.10 ATA

- Hyperoxia
  - Excessive oxygen may result in pulmonary damage or seizures
  - Two forms of O₂ toxicity
    - Pulmonary
    - Central nervous system (CNS)

Hypoxia 0.16 ATA 0.21 ATA 0.5 ATA Hyperoxia Normal
Diving Nitrox

CNS Oxygen Toxicity

- Central Nervous System Oxygen Toxicity
  - May cause seizures, which can result in drowning
  - Kenneth Donald - most notable of researchers to chronicle oxygen limits
  - Donald’s book “Oxygen and the Diver” analyzes thousands of trials
  - Results are inconclusive with extreme variability over time

- Variables Affecting Oxygen Toxicity
  - Depth
  - Time of exposure
  - Drugs and medications
  - Increased CO₂ concentration
  - History of prior seizures
  - Cold
  - Physical exertion

  Symptoms are unreliable, but include:
  - Convulsions
  - Visual disturbances
  - Ears (audible disturbances)
  - Nausea
  - Twitching
  - Irritability
  - Dizziness

---

Diving Nitrox

CNS Toxicity

- Oxygen Toxicity Complications
  - Highly variable among and between individuals
  - Limited predictability and low survivability
  - Poor understanding of oxygen toxicity mechanisms
  - Requires conservative parameters

- Operational Parameters
  - Operational range of PO₂ = 0.8 - 1.2 PO₂
  - Maximum working partial pressure = 1.4 PO₂
  - Max resting PO₂ = 1.6 (planned decompression)
Diving Nitrox

CNS Toxicity

- CNS Oxygen Toxicity Mechanisms
  - During the metabolism of oxygen, hydrogen peroxide is produced
  - Increased levels of $\text{H}_2\text{O}_2$ appear to trigger seizures
  - $\text{H}_2\text{O}_2$ production also increased from physiological stresses including:
    - Hyperoxia
    - Thermal stress, either hypothermia or hyperthermia
    - Physical exertion
    - Fatigue or lack of sleep
    - Dehydration

CO$_2$ accumulation creates significant physiological stress, it has long been known to accelerate the onset of hyperoxic seizure

Estimating CNS Toxicity Risk

- Traditional CNS Calculations
  - Divide PO$_2$ time exposure by the established limit
  - 90 minutes at surface assumed to reduce exposure by 50%

- GUE Guesstimate
  - Where bottom PO$_2$ averages 1.2
    - max CNS = 210 minutes
    - quick calc estimate BT/2

<table>
<thead>
<tr>
<th>PO$_2$</th>
<th>Exposure</th>
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<tbody>
<tr>
<td>0.6</td>
<td>720</td>
</tr>
<tr>
<td>0.8</td>
<td>450</td>
</tr>
<tr>
<td>1.0</td>
<td>300</td>
</tr>
<tr>
<td>1.2</td>
<td>210</td>
</tr>
<tr>
<td>1.4</td>
<td>150</td>
</tr>
<tr>
<td>1.6</td>
<td>45</td>
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</tbody>
</table>
Diving Nitrox

Pulmonary Toxicity

- Pulmonary or whole-body toxicity risk develops after extended periods of usage
- Coughing, labored breathing, irritated lungs, reduced vital capacity, edema
- OTU’s are units used to track pulmonary toxicity
- One minute of oxygen at 1 ATA = 1 OTU
- OTU accumulation clock resets every 24 hours

<table>
<thead>
<tr>
<th>PO2 (ATA)</th>
<th>OTU / Min</th>
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<tbody>
<tr>
<td>1.0 PO2</td>
<td>1.0</td>
</tr>
<tr>
<td>1.2 PO2</td>
<td>1.32</td>
</tr>
<tr>
<td>1.4 PO2</td>
<td>1.63</td>
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OTU Allowable Exposure

<table>
<thead>
<tr>
<th>Exposure</th>
<th>Daily Dose</th>
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<tbody>
<tr>
<td>1 Day</td>
<td>850</td>
</tr>
<tr>
<td>After 9 Days</td>
<td>310</td>
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Conservative Estimate: Run Time x 1.5 OTU

Diving Nitrox

Narcosis

- Narcosis (nitrogen, oxygen, carbon dioxide)
  - Impairment of intellectual capacity
  - Degradation of neuromuscular performance
  - Compromised response
  - True “adaptation” is not possible
- Narcosis Limits
  - Recommended maximum 30m
  - Reduced narcotic agents with increased difficulty
Diving Nitrox

Narcosis

- Narcosis (nitrogen, oxygen, carbon dioxide)
  - Caused by a wide variety of agents
  - *Meyer-Overton rule* - lipid solubility predicts narcotic response

<table>
<thead>
<tr>
<th>Gas</th>
<th>Solubility: Partition Coefficient</th>
<th>Narcotic Potency</th>
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<tbody>
<tr>
<td>Helium</td>
<td>0.015</td>
<td>4.26</td>
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<tr>
<td>Nitrogen</td>
<td>0.052</td>
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<tr>
<td>Oxygen</td>
<td>0.110</td>
<td>0.45</td>
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<tr>
<td>Carbon Dioxide</td>
<td>1.340</td>
<td>0</td>
</tr>
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</table>

Note: CO₂ lipid solubility is 25 times that of Nitrogen

Carbon Dioxide

- CO₂ Toxicity
  - Nausea, vomiting, dizziness, headache, rapid breathing, confusion, convulsions, unconsciousness
  - Toxicity levels begin at about 15,000 parts per million or 1.5%
  - Fit person generates about half the CO₂ present in unfit individuals

- Causes of CO₂ Accumulation
  - Heavy exertion
  - Poor ventilation
  - Inefficient equipment
  - Poor technique/limited control
  - Poor fitness
  - Increased depth
  - Improper gas selection

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Diving Nitrox

Gas Density

- Gas density is the primary limit to proper ventilation
- Heliox at 300m is similar to air at a depth of 33m
- Increases risk of carbon dioxide poisoning and oxygen toxicity
- CO₂ increases stress and is very narcotic

Density increases proportional to pressure

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Air (% of normal)</th>
<th>Oxygen-helium (% of normal)</th>
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</thead>
<tbody>
<tr>
<td>30</td>
<td>50</td>
<td>86</td>
</tr>
<tr>
<td>60</td>
<td>35</td>
<td>63</td>
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<tr>
<td>120</td>
<td>24</td>
<td>48</td>
</tr>
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</table>

The resistance to air flow through the respiratory passageways increases directly in proportion to the density of the breathing mixture. Therefore, one can readily see that the increased density of the air will increase the work of breathing, and as a corollary, will decrease the maximum breathing capacity (the amount of air that one can breathe each minute).

---

GUE Standard Mixes

- Safety, Efficiency, Familiarity, Consistency
- Dive Planning
- Gas Mixing
- Decompression

<table>
<thead>
<tr>
<th>Depth (Meters)</th>
<th>Mixture (O₂/He)</th>
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<tr>
<td>0 – 30</td>
<td>Nitrox 32 or Triox 30/30</td>
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<tr>
<td>30 – 45</td>
<td>Trimix 21/35</td>
</tr>
<tr>
<td>45 – 60</td>
<td>18/45</td>
</tr>
<tr>
<td>60 – 75</td>
<td>15/55</td>
</tr>
<tr>
<td>75 – 90</td>
<td>10/70</td>
</tr>
<tr>
<td>90 +</td>
<td>Appropriate O₂/Helium (Heliox)</td>
</tr>
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</table>

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Diving Nitrox

Bottle Marking Examples

EAD

- EAD relates adjusted N₂ to that found in air
- Air tables can be used while planning dives on Nitrox

<table>
<thead>
<tr>
<th>20</th>
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<th>30</th>
<th>35</th>
<th>40</th>
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Diving Nitrox

**EAD**

- EAD Formula
  \[ EAD = \frac{(1 - fO_2)(d + 10)}{0.79} - 10 \]
  - Example:
    - What is the EAD if we use Nitrox 32 at 30m?
      \[ \frac{(1 - 0.32)(30 + 10)}{0.79} - 10 = 24.4 \text{m} \]

- GUE Guessimate
<table>
<thead>
<tr>
<th>Mix</th>
<th>EAD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>less 20%</td>
<td>0-30m</td>
</tr>
</tbody>
</table>

  - Example:
    - 30m x 20% = 6m
    - 30m - 6m = 24m

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Diving Nitrox

**Oxygen Handling**

- Reasonable care necessary during handling
- Fire triangle: fuel, oxygen and ignition
- Elevated oxygen pressures require oxygen-cleaned components and oxygen-compatible materials (such as viton o-rings and oxygen grease)

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Diving Nitrox

Partial Pressure Method

1 - Separator
2 - Dryer
3 - Active charcoal
4 - Sieve 13x

Precision pressure gauge

Air Air OXYGEN OXYGEN

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Dive Planning

Unified Team

• Dive Buddy
  – Team-centered focus with similar individual goals
  – Planning should account for experience and training
  – Communication:
    • light (active vs. passive)
    • hand
    • wet notes

• Support
  – Boat captain/crew
  – Surface support
  – Emergency protocol

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Dive Planning

Preparation

- Pre-Dive Preparation
  - Mental focus
  - Physical fitness
  - Dive experience
  - Dive planning

Building a Dive Plan

- Define Objectives
- Define Risk
- Diving Logistics
- Parameters
- Responsibility
- Contingency
- Equipment
- Nutritional Requirements
 Dive Planning

GUE EDGE

- G – Goal, dive objectives
- U – Unified team, team strategies
- E – Equipment match
- E – Exposure, depth/time
- D – Decompression strategies
- G – Gas strategies
- E – Environmental issues

Preparing to Dive

- Pre-Dive Sequence
  - GUE EDGE
  - Modified valve drill (full version during training dives)
  - Modified S-drill/full long hose deployment (full version during training dives)
  - Bubble check
Dive Planning

Comparing Cylinder Capacities

- Divers must account for tank particulars
  - Cylinder size
  - Cylinder pressure

Dive Planning

GUE Tank Factors

- Relating Pressure and Volume
  - BAR x cylinder size = Volume
  - Example: 12 Litre tank
    - 100 BAR in tank
    - 1200 free Litres
Dive Planning

Evaluating Breathing Gas Supply

- Surface Consumption Rate (SCR)
  - \( \text{SCR} = \frac{\text{Litres consumed}}{\text{average ATA's}} \times \text{time (min)} \)

- Converting BAR to Litres
  - \( \text{BAR} \times \text{Volume} = \text{Litres} \)
  - 50\(\text{BAR}\) consumed out of a 12 liter tank = 50\(\text{BAR}\) x 12\(\text{L}\) = 600 Litres

- Converting Litres to BAR
  - \( \frac{\text{Litres}}{\text{Volume}} \)
  - 600 Litres consumed out of a 12 liter tank = 600 Litres / 12\(\text{L}\) = 50\(\text{BAR}\)

- Common Gas Consumption Rates
  - Deco consumption = 15L / min
  - Bottom consumption = 20L / min
  - Consumption during emergencies = 30L / min

Minimum Decompression

Deep Stops During Recreational Diving

- Less gas loading during recreational dives
- Start one-minute stops at 65% of total atmospheres (50% of depth)
- One minute stops are actually 30 seconds with a 30-second ascent
Minimum Decompression

- “Minimum deco” dive to 30m
- Slow ascent to first deep stop
- One minute across each 3m interval

9m/min ascent = 2min

Diving Nitrox

Breathing Gases

- Breathing gases carry oxygen to the tissues
- These constituents create varying results
- Effect depends upon the gas and the partial pressure
- Partial Pressure
  - Part of pressure represented by individual gas
  - Fraction of gas x ATA

Partial pressure examples:
- Standard breathing gas from 0 - 30m (32% Nitrox)
- Surface pressure = 1 atmosphere = .32PO₂ and .68PN₂
- 10m = 2 ATA = .64PO₂ and 1.36 PN₂
- 20m = 3 ATA = .96PO₂ and 2.04 PN₂
- 30m = 4 ATA = 1.28PO₂ and 2.72 PN₂
Dive Planning

Minimum Gas Calculation

Minimum gas calculations must be adjusted to account for the following:
- Diver capacity
- Diver training
- Diving environment
- Diving equipment
- Don’t use minimum gas less than 40 BAR

Common Minimum Gas Values

<table>
<thead>
<tr>
<th>Depth</th>
<th>10th</th>
<th>12th</th>
<th>24th</th>
<th>30th</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 18m</td>
<td>60BAR</td>
<td>50BAR</td>
<td>40BAR</td>
<td>40BAR</td>
</tr>
<tr>
<td>18m - 30m</td>
<td>120BAR</td>
<td>100BAR</td>
<td>50BAR</td>
<td>40BAR</td>
</tr>
</tbody>
</table>

Dive Planning

Minimum Gas

- Minimum Gas Considerations
  - Used as a tool but not a crutch
  - Complex dives/problems should be considered
  - Slow ascent from 80% ATA’s
    - Stops at 55% ATA’s, i.e. 50% depth
    - One minute each 3m

- Minimum Requirements
  - Gas for two divers
  - Stress and consumption (i.e. SCR ≥ 30 Litres per min)
  - Consumption at depth vs. ascent
  - Average consumption over ascent
Dive Planning

GUE Minimum Deco Ascent

- **3m 1min**
  - Considering a SCR of 30 Litres per min at an average depth of 2.5 ATA = 75 Litres per min

- **6m 1min**
  - 8 min of gas x 2 divers = 16 min required gas supply

- **9m 1min**
  - 16 min x 75 Litres per min = 1200 Litres total gas required

- **12m 1min**
  - 1200 Litres / 12l = 100BAR

- **15m 1min**

9m/min ascent = 2min

AT LEAST 1 min for emergency

---

Dive Planning

Establishing Breathing Gas Rules

- All gas can be considered usable
  - Wall/drift diving where return to the boat/departure is unnecessary

- 1/2 of available gas can be considered usable
  - Returning to boat/entry is not important but potentially easier

- No more than 1/3 of available gas is considered usable
  - Required any time diver MUST return to starting point
  - Cave/wreck penetration; offshore diving with return to upline/boat

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### Dive Planning

#### All Gas Usable

- Diving a 12th at 200 BAR
- "Minimum Deco" dive to 30m
- Minimum gas = 100 BAR (see gas management)
- Usable gas = fill pressure - minimum gas
- $200\text{BAR} - 100\text{BAR} = 100\text{BAR}$ turn pressure

![Diagram](image1)

#### 1/2 Gas Usable

- Diving a 12th at 200 BAR
- "Minimum Deco" dive to 30m
- Minimum gas = 100 BAR (see gas management)
- Usable gas = fill pressure - minimum gas / 2 (two directions of travel)
- $200\text{BAR} - 100\text{BAR} = 100\text{BAR}$ rounded down to number divisible by 2
- 100 BAR for dive and return
- $100 / 2 = 50\text{BAR}$ for dive and $50\text{BAR}$ for return + $100\text{BAR}$ for ascent
- Turn pressure = $150\text{BAR}$ ($200\text{BAR} - 50\text{BAR}$)

![Diagram](image2)
Dive Planning

1/3 Gas Usable

- Diving a 12m at 200BAR
- "Minimum Deco" dive to 30m
- Minimum gas = 100BAR (see gas management)
- Usable gas = fill pressure - minimum gas / 3 (1/3 out, 1/3 back, 1/3 emergency)
- 200BAR - 100BAR = 100BAR rounded down to number divisible by 3
- 90BAR for dive and return
- 90/3 = 30BAR for dive and 30BAR for return + 30BAR for emergency + 100BAR min gas (+ 10BAR from rounding)

100BAR minimum gas + 10BAR from rounding

Situational Awareness

Overview

During every minute of every dive, you manage tasks and decisions within three primary arenas. Learning to divide your attention and simultaneously manage an array of sensory input is paramount to successful diving operations.

- Environment
- Equipment
- Team
Situational Awareness

Environmental Awareness

- Depth
  - Current, max, average
- Dive Times
  - Bottom time, deep stop, deco, contingency
- Gas Management
  - Required breathing supply, reserve, minimum gas
- Decompression Management
  - Minimum deco, planned deco, contingency
- Navigation
  - Exit, compass, natural navigation, guideline management
- Environment
  - Weather, current, visibility, temperature
- Entanglements
  - Guideline, anchor line, lift bag, debris

Equipment Awareness

- Team Resource
  - Divers must remain aware of personal and team equipment; these items remain a team resource
- Verification
  - Operation, capacity, reserve
- Malfunction
  - Failure, management, resolution
- Location
  - Proper storage, accessibility, streamlined, entanglement-free
Situational Awareness

Team Awareness

- Capacity
  - Team limited by individual training and experience
- Responsibility
  - Navigation, lighting, surface marker, deco
- Dive Plan
  - Individual and team responsibility; clarity is essential to team efficiency and safety
- Protocol
  - Among divers, with surface and dive support, between boat crew
- Communication
  - Active and passive, hand signals, light signals (active and passive), touch contact, written
- Team Formation
  - Proximity, awareness, position
- Problem Resolution
  - Team assistance, awareness, communication, team formation
- Awareness
  - Narcosis, toxicity, team member difficulty

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Situational Awareness

Diving Accidents

In order to prevent accidents, divers must manage three distinct areas, each with a wide range of variables; these stresses need to be prioritized and managed in order of their relative importance.

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Situational Awareness

Incident Pit

- Minor problems occur easily resolved
- Serious problems, more complex to resolve
- Emergency, rapid and correct responses needed
- Un-resolvable problems, un-survivable situation

Normal operational region
- Increasing stress levels, ability to think required
- Danger of panic, automatic responses required (training)

The incident pit concept is a way of illustrating that we constantly come across minor problems over the course of a dive. If we fail to resolve these problems, then we take a step into the pit. Continued failure to rectify problems as they occur takes us further down the "hole." The further we get into the pit, the steeper the sides become, making recovery more and more difficult and making survival less and less likely.

Situational Awareness

Diving Accidents

- Fatalities rarely result from a single unique problem
  - Problems usually involve multiple events
  - Poorly-managed events generally escalate
  - Escalating difficulty creates stress
  - Stress exacerbates problems, straining resources

- Stress management is the cornerstone to safe diving
  - Divers must recognize personal and team stress
  - Stress must be controlled to prevent panic
  - Panic is essentially uncontrollable
Situational Awareness

Problem Resolution

- Divers should plan carefully, operate as a team and monitor their environment
- Teams that operate effectively rarely encounter serious problems
- Problems encountered by a well-focused team rarely result in serious accidents

Conclusion

- Diving should be fun with challenges that are selected responsibly
- Risk occurs through a lack of preparation or through careless attention to detail
- Committed divers reduce risk while preparing for unforeseen difficulties
- These individuals dive with greater safety and enjoy themselves considerably more
Summary

- Education, Conservation, Exploration
- Course Overview
  - Lectures
    - GUE overview
    - Why SCUBA dive?
    - Evaluating capacity
    - GUE Fundamentals
    - Buoyancy and weighting
    - Balance and trim
    - Propulsion techniques
    - Developing diving capacity
    - Summary of in-water Skills
    - Equipment overview (DIR)
    - Decompression overview
    - Gas properties
    - Dive planning
    - Situational awareness
- Quality Assurance Form
  - GUE continual improvement
  - Mandatory for certification

Field Exercises
- Equipment configuration
- Analyze/Mark cylinders
- Propulsion & maneuver techniques
- Basic 5
- Valve drill
- S-drill
- Reserve light deployment
- SMB deployment
- Unconscious diver recovery

Credits

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