IS IT TIME TO ABOLISH THE 130 FSW DEPTH LIMIT?

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This paper was published in the Proceedings of the International Conference on Underwater Education (1992) sponsored by the National Association of Underwater Instructors. Technical diving was emerging. Diving depth issues were being debated. Many diving related issues had to be "brought to the surface" for discussion. Today (2002), most national recreational diver training agencies sponsor courses in extended range diving and the use of alternative gas mixtures. Physiologists and divers now have a better understanding of human response to breathing air and various mixed gases at depth. Diving training, equipment and techniques have improved. Consequently, some information in this paper may no longer be valid. This paper is presented here as a historical information document. It is not the author's or University's intent to promote extended range diving. This paper does identify recreational diving issues at the beginning of the 1990's. Neither the author nor the University of Michigan will accept responsibility for accidents or injuries resulting from use of the materials contained herein or the activity of diving. Please see Disclaimer on the last page of this document.

ABSTRACT

Recreational scuba diving instructional agencies in the United States have embraced the 130 FSW depth limit since the early days of modern scuba diving. Currently, the U.S. Navy and the American Academy of Underwater Sciences approves the use of compressed air scuba to depths of 190 FSW. It is common knowledge that thousands of recreational scuba divers exceed this depth limit annually, many diving to depths exceeding 200 FSW. The 130 FSW value has become as much of a depth goal as a depth limit. Propagating a fixed value also creates a liability factor for instructors, agencies, dive operators, and equipment manufacturers. Realistically, a diver's depth limit must be based on the diver's motivation, acceptance of responsibility, emotional status, health, fitness, training, experience, self-discipline, diving companion, environment, equipment, emergency ascent options, support vessel, underwater task, and geographic location, not a fixed numerical value. A properly trained diver will have the knowledge and self-discipline to determine his/her personal depth limitation for any given dive. For some recreational divers an appropriate limit will be 30 FSW in warm, clear water. For others it may be 190 feet in cold, dark waters. Prudent divers desiring to exceed 190 FSW will advance to the use of safer alternative gas mixtures. Abolition of the 130 FSW depth limit would require significant improvement in the quality of recreational diver education.

INTRODUCTION

Human nature inspires individuals to explore the unknown and achieve the impossible. To the underwater adventurer depth seems to be one of the most potent attractions -- almost seductive! Since the dawn of modern recreational scuba diving, humans have challenged diving's physiological limits. On the other hand, physiologists, educators, bureaucrats, and conservative diving authorities have advocated stringent limits for recreational scuba divers. The 130-foot depth limit has prevailed since it was published in early editions of the *U.S. Navy Diving Manual* and *The Science of Skin and Scuba Diving*. Today, instructors indoctrinate their students with the 130-foot absolute depth limit and encourage adherence to an even shallower 100-foot limit. Any scuba dive beyond a depth of 60 feet is considered to be a deep dive. Many dive boat captains and resort guides rigidly enforce these limits, often through threat and intimidation. At some resorts, exceeding a depth of 100 feet is an established premise for revocation of diving privileges.

Nevertheless, each day of the year it appears that countless certified recreational scuba divers exceed sanctioned depth limits without notable adversity. [Note: It must be acknowledged that DAN statistics suggest that divers incur higher risk of decompression sickness when diving to depths in excess of 80 feet.] Since there is no mandatory recordkeeping and reporting requirement for recreational divers, accurate documentation is very difficult. However, in one study, an analysis of 77,680 recreational dives made by clients on a diving cruise ship suggested that 25% of the dives documented were to depths in excess of 100 feet [5]. Forty percent of the divers using computers in this study (accounting for more than 44,000 dives) admitted to exceeding the 130-foot depth limit, and some dived in excess of 200 feet. During this same study, the professional staff of the cruise ship made more than 600 air dives to depths of 250 feet. Fifty-four percent of questionnaire respondees at a recent University of Michigan workshop indicated that they had exceed 130 feet, with maximum depths ranging from 140 to 300 feet. [Note: Based on 85 respondents at the Dynamics of Decompression Workshop , 16 November 1991.] For many divers, the opportunity to make a deep dive is the highlight of their tropical holiday. To some adventurous scuba divers, cave diving, shipwreck diving, and deep diving are synonymous.

During the last decade, the recreational diving community demonstrated a renewed interest in deep scuba diving. Unfortunately, today's educational programs do not satisfactorily address the true nature and limiting factors of breathing gases at high pressures. This is so even though a deep dive is one of the required dives in an advanced recreational scuba diving course and most instructional agencies market a deep diving specialty course. Although most recreational divers learn of nitrogen narcosis during deep diving specialty training, the potential problems associated with carbon dioxide and oxygen are seldom addressed. In addition, nitrogen-carbon dioxide synergism and elevated partial pressure of oxygen pose potential risks in deep air diving.

Today, we stand on the threshold of modern high-technology recreational diving with mixed gases and computerized closed-circuit mixed-gas scuba. New technologies and improved training will soon enable recreational divers to venture to depths far beyond those recognized today. Individuals who choose to challenge the depths of our aquatic environment and extend beyond conventional limits must recognize their responsibilities to families, friends, and themselves. Diver education organizations must be prepared to meet the challenges of high technology diving.

In this paper I will primarily address diving with compressed air and open-circuit scuba. This is the breathing gas and apparatus currently recognized by the recreational diving training agencies and most commonly associated with scientific diving. However, I will include an historical overview of deep diving, including the use of various gas mixtures.

HISTORICAL OVERVIEW

Depth has been an allurement since humans first ventured into the underwater world. In 1943, soon after development of the first modern Aqua Lung, Frederic Dumas dived to 203 feet breathing compressed air. In 1947, Cousteau's team (formed in 1943) made experimental compressed air scuba dives to 297 feet [4]. In more recent years, Andrea Doria dives have become popular. As I recall, it was July of 1956, when Peter Gimbel and Dumas made the first dive to the sunken luxury liner. Two weeks later, Ramsey Parks, Earl Murray, Bob Dill, and Peter Gimbel filmed the sunken vessel for *Life* magazine. These pioneer scuba divers used compressed air scuba at a depth of about 240 feet for these dives.

In 1967, Hal Watts made a record compressed air scuba dive to 390 feet, and in 1968, Neil Watson and John Gruener reached 437 feet [9]. More recently (1989), Brent Gilliam completed a series of air dives in excess of 300 feet with an unofficial record dive to 452 feet [5]. In Lake Superior, at least 19 divers have dived to a particular shipwreck at a depth of approximately 250 feet. Apparently, two have died while diving on that wreck and two others from this group died while diving on other deep

shipwrecks. The popular appeal and machismo associated with deep dives tends to lure unsuspecting novice divers to depths beyond the capacity of their equipment, knowledge, skill, and physiology.

Deep air diving has become quite fashionable in the recreational diving community particularly among shipwreck and cave divers. Published and unpublished accounts of recreational dives using compressed air scuba to depths of 200 to 300 feet are not uncommon. Many recreational divers, including prominent certification agency instructor trainers, openly exceed the limits specified for recreational scuba diving. Unfortunately, some do get hurt. For example, during a five-day period in August of 1989, three Great Lakes shipwreck divers experienced decompression sickness, one experienced severe air embolism and decompression sickness, and one diver died. All were using compressed air scuba at depths of 190 to 250 feet.

Today, an increasing number of recreational divers are seeking the advantages of alternative gas mixtures. Historically, alternative gas mixtures have been attractive to dives since before the turn of the century. However, it was not until 1937 when Max Gene Nohl dived to 420 feet in Lake Michigan using a self-contained helmet diving system and a mixture of helium and oxygen under the direction of Dr. Edgar End of Marquette University, that alternative gas mixtures truly opened the door to deeper diving [4]. In the late 1930's, the U.S. Navy conducted experimental dives to 500 feet in a chamber at the Experimental Diving Unit in Washington, D.C. The U.S. Navy conducted its first deep, operational heliox dives to a depth of 240 feet in 1938 during the rescue and salvage of the *Squalus*. Bollard of the Royal Navy completed a helmet dive to a depth of 540 feet breathing helium-oxygen in 1948. In 1954, Jean Clarke-Samazan made a 350 foot helium-oxygen scuba dive [4].

By the late 1950s, heliox had caught the attention of an expanding commercial diving industry [10]. In 1962, Dan Wilson dived to 420 feet, and in 1967 Nic Zinkowski made a record dive in the Gulf of Mexico to 600 feet. The first commercial saturation diving job in the United States was conducted in the summer of 1965 (Smith Mountain Dam), and heliox saturation diving soon emerged as the dominate mode of deep diving. As commercial divers pushed beyond depths of 1,000 feet, they encountered new physiological problems -- high-pressure nervous syndrome (HPNS) and articular joint pain. In the mid-1980s Comex divers (French) successfully used hydrox (hydrogen-oxygen) during chamber dives to 520 meters to overcome HPNS and breathing resistance problems. In 1988 Comex divers saturated at 500 meters on hydreliox (hydrogen-helium-oxygen) dived to 531 meters (1742 feet) for 4-hour works shifts in the open sea [2].

The use of nitrogen-oxygen breathing mixtures [7] (other than compressed air) was recognized as early as 1912 in Germany [6] and was used by the U.S. Navy with semi-closed circuit scuba beginning in the late 1950s. Enriched air nitrox diving was introduced to the scientific diving community in the early 1970s and is currently used for operational diving by several research groups. Enriched air nitrox was introduced to the recreational diving community in the mid-1980s and is currently gaining considerable popularity. Enriched air nitrox is most advantageous in extending no-decompression dive time in the depth range of 40 to 130 feet. However, today an increasing number of divers are using enriched air nitrox as a conservative alternative to air when diving with air tables and computers. Enriched air nitrox or technical nitrox mixtures have also prove advantageous for diving depths up to 180 feet.

Mixtures of helium-nitrogen-oxygen (trimix) have been used to varying degrees in commercial diving since the 1960s. However, it wasn't until the 1980's that adventurous recreational divers began serious experimentation with trimix. Deeper diving with gases other than compressed air has always been limited by the volume of gas that a self-contained diver can carry, facilities for lengthy decompression, and the availability of safe dive tables. The gas volume problem has been addressed by over-pressurizing scuba cylinders, multiple-cylinder scuba, staging techniques, and oxygen supplied from the surface for decompression. Bill Hamilton pioneered an effort to design special trimix dive tables for the recreational

diving community. In 1988 Sheck Exley used staging techniques and Hamilton's trimix tables in his record dive to 780 feet [3]. One year later Exley completed a deeper dive to 881 feet [9].

The cave and wreck diving communities have maintained the "cutting edge" of advancement in recreational diving technique and technology. In an effort to market scuba diving to a mass population, national training agencies have, in many respects, stifled the advancement of diving. While the major recreational diving training agencies have been terrified by the perception of legal liability associated with training a large population of mediocre divers, the so called "technical divers" have established their own standards. The national training agencies currently advocate no-decompression diving only, air diving only, open-circuit scuba only, and a depth limit of 130 feet (ideally 100 feet). The recreational diving equipment manufacturers promote color coordinated diving equipment, high-performance regulators, and dive computers (some designed for air dives to 300 feet or deeper). In contrast, the cave and wreck diving communities have embraced compressed air diving depths commonly exceeding 200 feet, mixed gas diving, decompression diving, closed-circuit scuba, and a host of other advances in diving technology and techniques.

Today, we stand on the threshold of modern, deep, high technology recreational diving. The commercial diving community was there in the early 1960s. Using diving bells, deck chambers, umbilical-supplied recirculating breathing equipment, active thermal protection, mixed gases, and millions of dollars, they have extended their in-water diver working capability to nearly 2,000 feet. However, as they extended their depth, they recognized major logistical, economical, and physiological limitations. Today, almost 30 years later, atmospheric diving systems (ADS) and remotely operated vehicles (ROV) with force-feedback manipulators enable commercial divers to perform safe and productive work at great depths. Where will the recreational and scientific diving communities be in 2020 AD?

DEPTH LIMITS

A depth of 130 feet is the absolute maximum depth that may be achieved in any training program sanctioned by the major recreational diver training agencies. Agencies and instructors encourage divers to observe a 100-foot depth limit and they address any dive beyond a 60 feet as a deep dive. Many dive resorts and dive boats specify that divers may not exceed 100 feet and some operators will revoke the individual diving privileges of violators. Most dive operators universally apply the same rule to all divers.

For purposes of discussion, lets examine two hypothetical vacationing scuba divers:

> **Diver A** is a veteran diver who has been actively involved in diving for more than 20 years. He has worked as a commercial diver, saturation diver, and military diver. He has been an active recreational diving instructor for at least 15 years and has made an average of 80 dives annually for the past 5 years He is in excellent physical condition. With regard to depth, he has made 400 foot saturation dives and mixed-gas closed-circuit scuba dives to 320 feet as well as many compressed air scuba dives in excess of 150 feet.
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> **Diver B** is a middle aged executive who learned to scuba dive in a special weekend course last year. At that time he completed 4 open water scuba dives for certification during a second weekend at a tropical resort. He has not been diving for approximately 14 months. He is a bit overweight.

Both Diver A and Diver B complete a shallow shore based orientation dive on their day of arrival at the resort. The next morning both divers are taken to a popular wall dive site where they are allowed to make

a 20-minute dive to 100 feet. Later in the week, Diver A's diving privileges are revoked because he descended to 130 feet to photograph a black-capped basslet. It appears that experience and training are no longer acceptable factors in addressing the qualifications of a diver.

On the other hand, some dive charter boats on the U.S. East Coast and in Florida routinely support diving to depths exceeding 200 feet. Great Lakes recreational shipwreck divers routinely dive to depths between 130 and 250 feet breathing compressed air. All of this leaves the average scuba diver in somewhat of an emotional dilemma. A diver might say,

> *My scuba instructor and textbook specified that I must limit my diving depth to 130 feet or less. They say that this is the limit for my equipment, my body, and my training. Yet, many recreational divers appear to be diving to much greater depths, even beyond 200 feet. Many movies and videos show divers at deep depths. I read accounts of dives to the Andrea Doria and deep cave dives. These divers appear to be using the same equipment and breathing gas that I use. Why shouldn't I be able to dive to depths greater than 130 feet?*

Present day high-quality and properly maintained open-circuit scuba will generally function satisfactorily well beyond a depth of 130 feet. Humans experience physiological limitations to breathing compressed air at great depths, but individual tolerances can elevated oxygen and nitrogen pressures can vary significantly. The recreational and scientific diver's greatest limitation is their training. Today, the average recreational and scientific divers simply do not receive the necessary theory or skill training necessary for deep diving. They are not trained in the techniques, proper use of dive tables/computers, and decompression procedures associated with deep diving.

The deep diving specialty courses of the recreational diving agencies appear to be designed to provide a diver with some additional knowledge and skill useful in no-decompression diving between depths of 60 and 130 feet and to discourage divers from venturing beyond 130 feet. Unfortunately, many of these courses are more profit-oriented than content-oriented. One of my greatest concerns is that fact that many novice divers develop a false sense of confidence and ability when they are handed a deep diver specialty certification card. Plastic cards have little to do with true safety underwater.

Today, recreational divers are instructed to observe conservative no-decompression limits. Furthermore, required decompression is considered an emergency by the Professional Association of Diving Instructors(PADI); the Recreational Dive Planner only allows for no-decompression diving. Decompression diving is one of the community's taboos. Keep in mind that a diver decompresses during any ascent, even form a no-stop dive, and continues to decompress for some time after surfacing.

The depth of 130 feet has become a magic number in the civilian diving world. Early U.S. Navy diving manuals and publications did specify this as the maximum depth for operational use of open-circuit scuba, although the normal surface-supplied air diving limit was 190 feet and the absolute air limit was designated at 300 feet. The 130-foot limit was probably based, at least in part, on knowledge of diving physiology at that time, concerns with the breathing limitations (mechanical performance) of early open-circuit scuba, working capability of the diver using this new diving apparatus (as compared to continuously ventilated surface-supplied helmets), air volume limitations of scuba cylinders, military diver mission requirements, training protocol, and so on. It is likely that the military decision-makers saw little need to send a scuba diver with limited work capability beyond a depth of 130 feet when a surface-supplied deep sea diver could stay longer and perform the task better.

The recreational diving community has embraced this numerical value (130 feet) with such enthusiasm that law suits have been filed on behalf of recreational divers who have been injured or died at

a depth of only 10 feet deeper. To many divers the 130 foot depth value has imparted a false sense of security -- "I'm safe as long as I do not exceed 130 feet!" Let me assure you that a numerical value is only a minor factor in the realm of diving safety. Some divers are at far greater risk at a depth of 50 feet than other would be at a depth of 150 feet.

Currently the U.S. Navy limits on open-circuit air diving are 100 feet using a single cylinder scuba, 130 feet for normal working limit, and 190 feet for the maximum limit [15]. Compressed air diving is allowed to 285 feet using surface-supplied deep sea diving equipment. Federal occupational safety and health standards that govern commercial diving operations are far more restrictive. For example, diving with scuba is limited to a maximum depth of 130 feet and a hyperbaric chamber must be ready for use if the diver exceeds 100 feet or the no-decompression limits. Standards published by the American Academy of Underwater Sciences (AAUS) specify 190 feet as the limit for compressed air diving [1]. However, divers authorized under AAUS standards must meet more rigid training requirements that recreational divers, requalify annually, follow a prescribed experience acquisition track, and must be approved by a Diving Control Board.

The bottom line is that establishment of a universal depth limit is a less than satisfactory mechanism of "controlling" recreational divers. Based on trends in diving instruction and activity today, I suggest that most recreational divers are trained for diving in warm, clear water to depths not exceeding 60 feet under the supervision of a dive master or dive guide. Most courses do not provided the diver with sufficient information to make an informed decision relative to personal capability and limitation.

PERSONAL LIMITATION

Throughout my diving manuals and in my courses I emphasize the concept of personal limitation. A prudent diver will continuously evaluate himself/herself and establish reasonable limitations. Depth is certainly one of these limitations. It is easy for an agency or dive master to specify a given limit, be it 50 feet or 130 feet. Based on observations of recreational divers in the field, I suggest that most divers will dive close to the limit designated for a given dive or by a resort/boat operator. If the limit for the morning dive is 120 feet you can generally find divers, some with only 5 to 10 prior dives, near or at the limit, especially in tropical waters. For many divers, I suggest that the stated depth limit becomes the □depth goal!

How deep is reasonable for a recreational diver's depth limit? First of all, I will not assign a specific depth. A reasonable and prudent depth depends on many factors including, but not necessarily limited to, the diver, environmental conditions, equipment, and accompanying divers. The following 15 factors are ones that I would consider in assessing personal limitations with regard to diving depth. Keep in mind that other factors many come into play based on individuals, diving conditions, and circumstances.

Motivation. Why do you wish to dive? Why do you wish to dive to a specific depth? Each individual must explore his/her personal motivation for making a given dive. By nature, the human being is an adventurer. Some find adventure in reading great books and others in challenging technological, physiological, and psychological limits. Some are true explorers who accept the fact that they might be seriously injured or die in the quest of a goal -- to be the first! Every individual has the right to seek personal adventure and goals. However, diving with reckless abandon in order to cultivate an image for others is questionable motivation.

Responsibility. Every diver, regardless of depth achieved, has a responsibility to themselves, their diving buddies, their loved ones, and the diving community. Do you understand that your actions as a diver

could lead to personal injury, disability, loss of sexual function, or death? Do your loved ones understand these facts? Are you prepared to accept the responsibility for your actions and the possible consequences of your actions? If not, I encourage you to seek alternative activities and leave the oceans to responsible divers.

Emotional Status. Diving is not an activity for an emotionally unstable person. Individuals who tend to lose control or to panic in times of crisis may well find occasion to do so in diving. Although panic and subsequent actions may be life-threatening at even very shallow depths, the consequences can be quite dramatic at deeper depths. Recklessness and emotional instability in a diver is a serious liability for both the individual and companion divers. These traits may be further amplified by the narcotic affects of nitrogen at depth. Outwardly, some deep divers do appear emotionally unstable and reckless; some people have even said they are brain-dead. [Note: For purposes of this paper, a deep diver is defined as an individual who plans and executes dives to depths exceeding those currently recognized by the major recreational diver training agencies.] A good deep diver is, in reality, an extremely stable and disciplined individual. Like race car drivers, many seem to thrive on living on the edge. The bottom line is that you must be completely at ease and in control if you intend to extend your diving depth.

Health and Fitness. Persons in poor health and/or poor physical condition are generally considered to be more susceptible to the emotional and physical stress associated with diving. It has been documented that such individuals are also more susceptible to decompression sickness. Persons in poor health should seek the advice of a qualified physician and consider imposing significant limitations on themselves or foregoing scuba diving all together. Individuals who are in generally poor physical condition, but have no serious health problems, should embark on a fitness improvement program under the guidance of a physician or professional health/fitness counselor.

Training. Certification procedures published by the American Academy of Underwater Sciences require completion of at least 32 supervised dives and approval of the organization's Diving Control Board in order to qualify for dives to 130 feet. However, most recreational diver training courses, including deep diving specialty courses, do not adequately prepare divers to dive to depths exceeding 60 or 80 feet. A diver can become a certified deep diver with as few as 11 open water dives (total diving experience). Many training programs fail to provide to the diver with the necessary information required to make an informed decision about whether it is wise for them participate in deep diving.

The training program must provide the diver with an comprehensive insight into the physiological and psychological factors associated with extending diving depths. The diver must be schooled in personal assessment, dive companion assessment, and environmental assessment so that he/she may make an informed risk-benefit analysis. Greater emphasis must be placed on dive organization and planning. Trainees must develop high proficiency in the use of dive tables and computers. The diver must then participate in a series of supervised training experiences designed to progressively advance diving skill, demonstrate proper procedure and technique, and solve potential problems that might be encountered on deeper dives. Supervised problems solving should actually be practiced at depth. For example, a diver may have previously demonstrated adequate proficiency in alternate air source breathing during ascent from a depth of 20 or 30 feet. However, the emotional stress associated with performing this procedure from deeper depths may be significant in some individuals. Ideally, a diver should be capable of providing air to another diver for ascent from the maximum depth of certification (or diving).

Today, many authorities feel that the deep diving specialty courses sanctioned by the major training organizations are marginal in content and product. Graduates of many courses have only learned additional information that should have been presented in a basic course and had an opportunity to experience a few more supervised dives. I suggest that it is time for the major training organizations to re-evaluate course content at all levels.

Fortunately, new courses designed to address the needs of divers who are seeking training in deep diving and the use of alternative gas mixtures been developed by the International Association of Nitrox and Technical Divers. The Technical Nitrox Diver Course provides training in the use of enriched air nitrox to depths of 180 feet, decompression procedures, and use of oxygen for decompression. The Trimix Diver Course extend the divers capabilities to the use of oxygen-helium-nitrogen with training dives to 280 feet. [Note: For additional information, contact the International Association of Nitrox and Technical Divers, 1545 NE 104 Street, Miami Shores, Florida 33138.]

Experience. To be a good diver you must dive! Experience is often the best teacher. Unfortunately, far too many individuals "want it now" and are not willing to pay their dues in the acquisition of experience. For nearly 40 years the scientific diving community has used a dive and depth progression procedure to qualify divers for extending their depth rating [1]. In accord with American Academy of Underwater Sciences, a diver must satisfactorily complete 12 dives and receive the approval of the institution's Diving Control Board before they may dive to depths between 30 and 60 feet when accompanied by a diver already authorized to 60 feet or greater. For authorization to 100 and 130 feet, a diver must hold a 60-foot authorization, complete four supervised dives near the maximum depth of each respective category, and be approved by the organization's Diving Control Board. To obtain a 130-foot authorization, the diver must have completed at total of at least 32 supervised dives. [Note: This requirement has recently been changed. Previously, a diver had to complete 12 dives (rather than 4 dives) to advance to the next higher depth rating. Consequently, a total of 48 dives was ultimately required for authorization to 130 feet.]

By the way, these scientific divers must also meet requirements for requalification annually by making 12 dives in the previous year, completing a periodic medical examination, and being approved by a Diving Control Board. Another bottom line!

If you intend to extend your diving depth beyond the shallows of a coral reef, you had better acquire lots of shallow water experience first and work up to the deep depths through a series of progressively deeper dives. In addition to progressive acquisition of experience, a prudent diver will always do a series of "buildup" dives prior to making deep dives. For example, many individuals are seasonal divers. At the beginning of each diving season a prudent diver will begin with shallow and simple dives and progressively work up to deeper, more complicated dives.

Self-Discipline. Any form of diving, be it recreational, scientific, public safety, military, or commercial, requires a certain degree of self-discipline. And, the deeper the depth, the greater the need for self-discipline. One might observe a group of experienced good deep divers casually preparing for a dive. Their mannerisms may appear to be just that -- casual! However, I can assure you that each individual has mentally rehearsed or visualized the entire dive, checked and rechecked their equipment, verified dive table calculations, taken a very close look at their fellow divers, and given proper attention to even the most minor details. If the diver senses problems associated with the dive, the dive is aborted.

Underwater these divers will monitor their breathing rate, cylinder pressure, time, depth, position (relative to the ascent line), and a host of other status indicators while completing a task. They know through progressively acquired experience when things are going right or wrong. They know their limits -- physical, emotional, air supply, thermal, depth, distance. The deeper the depth, the smaller the margin for error. They know when to turn back or abort the dive. Self-discipline is acquired through training, experience, and emotional conditioning. You can't buy it and you can't learn it in a two-day specialty course. Whether you are diving to 10 feet (in a pool), 30 feet, 60 feet, 130 feet, or ???, it is never too soon to start developing the self-discipline necessary for safe diving.

Environment. The nature of the environment dictates both depth and personal limitations. Thousands of divers casually swim at 100-foot depths in clear, warm tropical waters every week wearing only a thin, nonrestrictive dive skin. For an experienced diver such a dive can be exhilarating and rewarding. However, for the same diver, a dive to the deck of a sunken ship in the dark, icy waters of the Great Lakes encased in a dry suit could be "a dive to hell!" When planning deep dives one must consider wave conditions (producing adverse conditions at decompression or safety stop depth), current, visibility, water temperature, and so on. If the environmental conditions are unsatisfactory or too demanding on the diver, a prudent individual will cancel the dive. And, only through a progressive acquisition of environmental experiences will an individual develop the necessary skill and knowledge required to make such decisions.

Diving Companion. Solving a problem and safely ascending back to the surface from deep depths can be extremely complicated, especially if you do not have a capable companion. First of all, when selecting a diving companion for a deep dive, or any dive, try to select someone who is not going to be a problem. If the diver exhibits evidence of inadequate training, lack of experience, nervousness, overconfidence (cockiness), carelessness, or other undesirable traits, find another buddy or postpone the dive. Don't dive with a heavy breather who has a reputation for running out of air. Ideally, dive with an individual who you know to be properly trained, experienced, equipped, and that you have dived with before. Buddy selection is seldom discussed in traditional recreational diving courses.

Keep in mind that your diving buddies are persons with whom you have elected to share the enjoyment and exhilaration of the dive. A buddy team is two or more divers functioning as a single unit, but not in a dependent manner. [Note: The topic of non-dependent diving and the psychological aspects of deep diving are addressed in a new book on mixed gas diving written by Tom Mount and other selected contributors. This book is being published by Watersports Publishing, Inc. and should be released in late 1992.] Your buddy is not your underwater lifeguard. All divers must be trained for self-sufficiency. Good divers will be able to assist each other if the need arises. However, a good buddy will never enter the water relying on the presence and skill of another diver. That diver cannot think for you or breathe for you. If you must rely on your buddy, I suggest that your should not make the dive. The abilities of the least experienced or capable diver will determine the limits of the dive team.

Leadership. Today, more and more scuba dives are conducted under the leadership of a dive master, dive guide, or instructor. The leader generally selects the dive site, plans the dive, designates the procedures and depth limit, and, in many cases, accompanies the divers underwater. Unfortunately, most scuba divers are conditioned in training to accept the directions of the leader without question. Too often such acceptance is carried to extremes. For example, would you blindly accept the lead of individuals who you observed partying, drinking, and smoking pot until the wee hours of the morning before your 10 AM planned deep dive. Not too long ago seven divers did just that. Of the seven divers and two leaders who entered the water, one bent, one embolized, and three died! Get to know your leaders. If the leader seems to be directing you down an uncomfortable path or acts in a manner which you feel is inconsistent with prudent behavior or proper diving procedure, seriously consider "sitting this one out!"

Emergency Ascent Options. As you dive deeper and deeper you will find that your emergency ascent options become more limited and complicated. Today, the most popular emergency air supply option is "octopus" breathing. However, let's assume that you carelessly deplete your air supply at a deep depth. How much air do you think that your buddy still has? If you are out of air, your buddy's air supply is probably very low also. Will that remaining air support two divers with elevated breathing rates (stress induced even in the best divers in such situations)? Will the regulator deliver sufficient air volume at low cylinder pressure and high demand? If one diver's scuba malfunctions early in the dive, an "octopus" ascent would probably be quite easily accomplished by a team of experienced divers. However,based on today's training, can you imagine single regulator buddy breathing from a depth of 100 feet or greater?

There are several schools of thought relative to emergency ascent options for deeper dives. Some old-time divers feel that you should not dive to a depth deeper that from which you can make a independent controlled emergency swimming (exhaling) ascent. In fact, in some early scientific diving programs divers had to demonstrate this ability before an authorization was issued for diving to a given depth. Although the concept is valid and such ascents were made for many years, this practice is no longer observed because of changing trends in diving and potential liability complications in the even of an injury. Please do not attempt unsupervised practice of emergency exhaling ascents.

Other authorities suggest that at deeper depths divers must be equipped with redundant scuba for total self-sufficiency. The use of auxiliary scuba is common among deep cave and shipwreck divers. Keep in mind that the compact "tiny scuba" may not be sufficient for ascending from deeper depths (greater than 60 feet), especially if the diver is stressed and breathing rapidly. So, as you can see, you had better evaluate your emergency ascent capability and options before committing to any dive, especially a deep dive.

Equipment. For dives up to, but not exceeding, 130 feet, conventional recreational scuba diving equipment will generally be adequate. However, depending on the environment, dive profile, underwater task, and diver's air consumption, the volume of air contained in a conventional scuba cylinder may be marginal to insufficient for safe diving. Divers are encouraged to maintain about 30 percent of their air supply in reserve for unexpected or increased air demands that might be associated with ascent (i.e., difficulty locating ascent line, extended decompression, sharing air with another diver, and so on). [Note: Most authorities suggest that divers use the "rule of thirds" commonly associated with cave diving and shipwreck penetration diving for deep open water diving.] Furthermore, ideally the diver should plan to complete the entire dive with the air in his/her scuba and not rely on "emergency" scuba placed at the decompression stop on the ascent line. Interestingly, many recreational divers cannot mathematically compute air supply requirements for a dive. Naturally, the above rule may be modified for special condition diving such as cave penetrations and extremely deep shipwreck diving activities that are beyond the scope of this paper and the diving population for which it is intended.

Divers must take into consideration that added thermal protection may be necessary at deeper depth, especially in northern waters. Many cold water divers now use dry suits even in the summer months. Wet suits compress considerably at depth reducing both thermal protection and buoyancy. A buoyancy control device is mandatory, even when using a dry suit. When diving from a vessel it is imperative that divers maintain orientation and return to the surface via the ascent line. Precise compass navigation may be required. Ideally, the ascent line is clearly marked, especially if there is more that one descent line in the area (as found on some popular shipwrecks). For some locations, especially if visibility is limited, divers will use a guideline dispensed from a small reel. The guideline (tag line or distance line) is attached to the ascent line and played out as the diver moves away. Divers will also carry a lift bag that, when attached to a line reel, may be floated to the surface to provide the diver with stability during decompression in the open sea should the need arise.

Obviously, divers will need instrumentation for determining depth and dive time. The increased popularity of dive computers has greatly simplified deep diving. However, complete dependence on these computers has also led to decompression sickness for some divers.

As you can see, you must be properly equipped for deep diving and some special equipment must be considered. You are far more dependent on properly functioning equipment at deeper depths. Some divers prefer complete self-sufficiency. This implies the use of auxiliary scuba (a pony), more than one computer, and so one. Lack of proper equipment should impose significant limits on the diver's safe depth.

Vessel. At some locations (some islands, inland caves, etc.) deep water can be accessed directly from shore. However in many cases, a vessel of some sort will be required to transport divers to a deep dive site and serve as a support platform. In order to properly support a deep dive, the vessel must be of sufficient size to provide space for divers, equipment, and surface personnel. Onboard equipment must include an oxygen delivery system. The vessel must have sufficient propulsion for rapid return to shore in the event of an emergency or injury. The vessel must be capable of being securely moored at the dive site. Prudent divers will carefully evaluate available vessels. If an adequate vessel is not available, the dive site, plan, and depth may have to be modified.

Underwater Task. High work levels must be avoided at deep depths when using scuba. Not only is the diver limited by the increased air consumption associated with heavy exertion, but also by the performance capability of some scuba regulators at greater depths. Consequently, work load becomes a controlling factor in determining maximum dive depth. The prudent diver will avoid heavy exertion.

Geographic Location. In planning deep dives one must take into consideration the distance and time between the dive site and professional medical assistance and a hyperbaric chamber. Although a diver can be seriously injured in 10 feet of water, I feel that most experienced divers consider that the risk increases with depth. Of course, in deep diving our major fear is decompression sickness. When diving in remote areas prudent divers will plan their dives conservatively, both in time and depth.

So, what is your diving depth limitation? As you can see, depth limit cannot be a standardized numerical value. The community figure of 130 feet imposes an unreasonable limit on some divers and establishes a dangerous goal for others. Depth limit is dependent on the individual diver, environment, and situation. However, based on training available from the primary agencies today, the prudent diver will think very seriously before exceeding a depth of 60 feet even in the best of environments and circumstances. For those individuals who have acquired sufficient training and experience, the depth limit should be a matter of individual capability and choice. Each diver must be capable of properly assessing both personal capabilities as well as limitations.

CONCLUSIONS

Depth seems to be an allurement for recreational divers. Depth limits often become depth goals. In spite of aggressive promotion of the 130-foot depth limit and no-decompression dive times, recreational divers are routinely exceeding these limits. Unfortunately, most diver training programs do not provide students with sufficient insights into the deep diving techniques and associated risks. Thus, considering the present level of diver education, it is very wise for a diver to observe conservative limits. However, I suggest that it is time for diver training agencies to re-evaluate course content and diver training.

In nearly every sport trainees and participants are encouraged to swim faster, jump higher, or run further. Coaches and instructors inspire athletes to perform to their physiological and psychological limits -- to achieve the impossible. Athletes do get hurt and some even die in their pursuit of excellence. They accept the risk and the responsibility. I truly feel that nearly every coach and athletic instructor views each beginner as an Olympic hopeful.

With some exceptions, this is not the case in modern scuba diving. In fact, the opposite is true. During the first scuba diving class instructors begin to impose limits. Throughout subsequent classes, courses, and diving activities, these limits are reinforced by instructors, dive guides, boat operators, dive organization representatives, and so on. Limits are even written into bylaws of dive clubs. Individuals aspiring to exceed the limits are ridiculed and even threatened. If an athlete is injured in the pursuit of

achievement, he is generally praised by his peer group for the attempt. If a diver is injured, he is often maligned by fellow divers, instructors, and agencies. In diving, one who does dive to greater depths (for example) must often hide their accomplishments to avoid ridicule. The diving community has, in my opinion, cultivated a condition in which the individual diver no longer has freedom of thought, expression, and action. Divers are shaped as clients destine to wallow in mediocrity while they fuel the economic furnaces of manufacturing, retailing, and tourism.

All divers must understand their personal limitations and those of there fellow divers. The depth limit for a given dive is dictated by the least experienced or capable member of the team. Some recreational divers would be prudent to limit their dive depth to 30 feet in warm, clear water. Others possess the training, experience, emotional stability, and self-discipline to exceed 150 feet in cold, dark water. Prudent divers electing to exceed 190 feet will use safer alternative gas mixtures. In all, there are at least 15 factors that must be considered in determining the depth for any given individual on any given dive.

In recent years, the major recreational training agencies, well-meaning dive operators, and leaders in diving have stifled much of the freedom and adventure that was once associated with recreational diving. Many recreational divers are capable of diving beyond a depth of 130 feet. Others should never consider exceeding a depth of 60 feet. A deep dive can be conducted with relative safety provided that the divers are well-trained, experienced, and properly equipped. Such dives must be planned meticulously and divers must completely understand the added risk associated with diving to deeper depths. We have entered the decade where the use of alternative gas mixtures will enable properly trained recreational divers to routinely dive to depths in excess of 300 feet. At the same time conventional market-oriented scuba diving instruction leaves many individuals ill-prepared for even shallow coral reef depths. Recreational diver depth limit can no longer be a fixed value. It is time to re-evaluate the 130-foot depth limit (or goal)!

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DISCLAIMER

Neither the author nor the University of Michigan will accept responsibility for accidents or injuries resulting from use of the materials contained herein or the activity of diving. All diving activities have inherent risks. An individual may experience injury or disease that can result in disability or death. Variations in individual physiology and medical fitness can lead to serious injury even with adherence to accepted standards of performance and the correct use of dive tables. All persons who wish to engage in any form of diving must receive instruction from a qualified instructor and complete nationally recognized requirements. Trained and certified divers are informed of the risks associated with deep and alternative gas mixture diving and ultimately bear responsibility for their own actions. Any individual has the right to refuse to dive. Persons should not engage in any form of diving if they are unwilling to complete a course of instruction, pass certifying examinations and evaluations, maintain their skill/knowledge through active participation in diving activities, and accept responsibility for their own actions when participating in diving activities.