MICHU-H-90-001

THE UNIVERSITY OF MICHIGAN DIVING MANUAL

VOLUME I: DIVING THEORY

LEE H. SOMERS, PhD

THE UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

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DISCLAIMER

Neither the author or The University of Michigan will accept responsibility for accidents or injuries resulting from use of the materials contained herein or the activity of scuba diving.

Scuba diving is an activity that has inherent risks. An individual may experience injury 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 scuba diving must receive instruction for a certified instructor and complete nationally recognized requirements in order to be certified as a scuba diver.

Trained and certified divers are informed of the risks associated with scuba diving and ultimately bear responsibility of their own actions. Persons should not engage in scuba 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 scuba diving activities.

THE UNIVERSITY OF MICHIGAN DIVING MANUAL

Revised Edition

Printed in the United States of America.

PREFACE

This manual has been prepared for use in the training of scientific and recreational scuba divers at the University of Michigan. It contains the basic information and discussion of applied diving technology needed to participate in safe scuba diving using compressed air at depths of less than 130 feet in tropical and temperate climate environments.

This manual contains no beautiful pictures or stunning illustrations. The current edition of the manual is divided into two volumes — Volume I: Diving Theory and Volume II: Underwater Research Methods. This manual was designed to be used *only* in conjunction with illustrated lectures at the University of Michigan. This manual in itself is not to be used as a substitute for lectures by an instructor or as a self-training manual. All persons intending to scuba dive *must be trained* in an accredited course. Furthermore, the manual does not include dive tables. Dive tables are distributed in class with other support materials.

The information presented in my lectures and in this manual evolved from scuba diving courses I have taught over the past twenty years to an audience drawn from virtually all disciplines at the University of Michigan including oceanography, physical education, biological sciences, geological sciences, art, education, music, law, medicine, and business administration as well as members of the local community. With such a diverse audience, this manual and my course are not focused on a particular discipline, but rather on general principles and practices of safe diving. The course and this maunal also represent a departure from the modern trends of scuba diver education.

Although this course is aimed at undergraduate university students, it is applicable advanced high school students, university graduate students, faculty, and any individual with the desire to learn safe scuba diving. Persons who have been overawed by the course and the breadth of this manual have not suffered from a lack of intellectual skill, but lack of sophistication and, in some respects, maturity. Most students simply fail to appreciate or respect the gravity of the subject matter.

During my more than 30 years of diving I have seen many changes in diving course content and instructional methods. In order to appreciate the evolution of undersea exploration and recreation in the United States, one must return to the early years of the late 1940s. Cousteau and Gagnan had developed the *aqualung* in 1943. However, first compressed air aqualung was brought to the United States by Commander Francis Douglas Fane of the U.S. Navy's famed World War II Underwater Demolition Teams in about 1947.

In 1949 a young marine biology graduate student at Scripps Institution of Oceanography, Conrad Limbaugh, acquired an aqualung from Commander Fane and the modern era of scientific and recreational scuba diving begin. A scientific diving program and training course was established at Scripps in 1950. Concurrently, a young man at Woods Hole Institution of Oceanography named David Owen with inspiration from Oceanographer Allyn Vine guided the development on the East Coast. In 1955, David published *A Manual for Free-Divers Using Compressed Air*, one of the nations first scuba diving manuals and considered to be a classic today.

Meanwhile, on the West Coast spearfishermen and Los Angeles County lifeguards ventured into the depths of the Pacific with mask, fins, and spears and *no* thermal protection — a hardy group to say the least. I am told that Bev Morgan, Ramsy Parks, and Al Tillman were among the first to be trained as scuba divers in the new Scripps program. In 1951 these men lead the development of the Los Angeles County Underwater Program and American recreational scuba diving was born.

The aqualungs were made available to the U.S. public for the first time by Rene Bussoz in his Westwood Village, California store, *Rene Sports*. In about 1950 (plus or minus a year or two) Cousteau was futilely trying to get someone in the U.S. interested in handling his new Aqua

Lung. Rene contacted him and Cousteau agreed to sell him 20 Aqua Lungs. Rene soon discovered that no one would fill the French cylinders because they were not ICC rated. Fortunately, they did get them filled on the sly at an unnamed university. In one year Rene had sold only 20 Aqua Lungs. When Cousteau inquired about a reorder Rene's associates apparently advised against it — declaring: "The U.S. market is saturated."

Shortly thereafter the U.S. Navy begin buying Aqua Lungs and training Underwater Demolition Teams (UDT) in their use. Next, the motion picture "The Frogmen" starring Richard Widmark made the nation Aqua Lung conscious. Aqua Lung popularity and Navy orders soon lead to the formation of U.S. Divers Company (by Rene Bussoz).

During the 1950s a number of clubs, diving councils, and local organizations begin teaching scuba diving and even certifying instructors. The first nationally accredited scuba instructor certification course was conducted by the YMCA in 1959 and that National Association of Underwater Instructors (NAUI) held their first instructor training program in 1960. The Professional Association of Diving Instructors begin issuing instructor certifications in about 1968.

Many, if not most, of the names that will appear in this manual will be meaningless to the beginning scuba diver. Even experienced divers and most diving instructors will not recognize these names. This is unfortunate! These names are part of our American diving heritage and, along with many others, should take a place with world figures such as Cousteau, Hass, and Davis. The list could be endless — Bussoz, Empelton, Bond, Lamphier, Scalli, Goff, Lambertsen, Hughes, Cahill, Wilson, Stewart, Egstrom, Earle, Anderson. People preceded PADI and NAUI! Diving is people, not acronyms!

The pioneers of American scuba diving were swimmers, lifeguards, and people of the sea. Most were as at home in and on the water as on land. Although they lacked the sophisticated equipment of the present scuba diver, they more than make up for it in watermanship, skill, and knowledge. The early knowledge base for recreational diving was drawn from the U.S. Navy Diving Manual and other publications, mainly prepared by persons influenced by Navy concepts and philosophy. A *basic scuba diver* was generally considered to be quite knowledgeable in such subjects as diving physic and medicine. For example, it was not uncommon for the beginning diving student's written examination to include essay questions such as, *"List the cause, prevention, signs, symptoms, first aid, and medical treatment for the major injuries that might result from both direct and indirect effects of pressure and pressure changes on the human body."*

Most divers could readily apply Boyle's and Charles' Laws to compute pressure-temperature-volume change problems. The dive manuals were simplistic by some standards, but the knowledge was complete. The US Navy Diving Manual was often a required text for instructor candidates. Instructors were schooled in preparing lectures and designing their own courses.

Confined water training was long and complete, often with extensive surface swimming and skin diving prior to using scuba In some cases the student did not use scuba until the fifth or sixth session. On the other hand, many of the early diving courses, especially in middle America, included *no* formal open water diver training program. Once training was completed in the classroom and confined water, a beginning diver would join a dive club or team up with others divers or classmates for the first open water experiences. Yet there was a comradery in the diving community — an *esprit de corps*. People became divers because of a love for water and the sea. Divers became instructors because of a love for diving. *One was proud to be a diver!*

In contrast, today recreational scuba diving is big business. For many people it is a career. Beginning diving students often use scuba during the first pool session. Skin diving is often completely ignored during the training program. Most of today's diving courses are *prepackaged* for instuctors! Textbooks, workbooks, and training aids are geared for rapid learning of minimum knowledge. Formal lectures are generally replaced by video or tape recording synchronized slides presentations. Pool training that once required 25 or more hours is completed in 12 or less hours. New three-lesson courses which include video lectures that may be viewed in the comfort of your home are now taught in Michigan.

More recently a highly praised innovative home study course has been introduced. The student receives a module instructional package that may be studied at home. An 800 telephone number allows the student to discuss course information and problems with an instructor as (and if) needed. You may then complete your training by traveling to a participating dive resort and completing an written examination, so sheltered water training with diving equipment, and four ocean dives. This can be accomplished in a long weekend.

Under the shroud of modern concepts in education scuba diving has become the fast-food of the recreational world. The instructor may only have a year of diving experience and may have never been to the ocean. Aggressive national training agencies compete for students. In some areas you can certify as a basic diver on a long weekend. Volume and profit — the American way — is the driving force of modern recreational scuba diving.

The beginning student is advanced rapidly to open water training which generally includes no less than four supervised scuba dives. In this respect, we have come along ways. Yet, the modern certified diver is quite often an minimal swimmer who may depend heavily on scuba diving equipment, especially elaborate buoyancy systems, for both pleasurable diving and survival in the sea. This diver often lacks true insight into the degree of risk that might be associated with scuba diving. During the past decade, for example, death became the "D-word" that an instructor was advised never to mention in a diving course. Words like air embolism were replaced with softened, less threatening statements. On the other hand, we are entering a new decade when the recreational scuba diver will savor the benefits of modern technology and enter the sea with greater ease that ever before.

In sad contrast, I see far too many divers who are *"at-risk"* in the ocean. They can neither survive without their special equipment nor even comprehend that they might be at risk. They blindly accept dive computers and devise means of fooling or exceeding the limits of the computer. Many depend completely on a dive guide to select a dive location and direct them through a safe dive rather that developing their personal knowledge and understanding of the environment.

The diving industry relies on the *concept of continuing education* today. What a diver might have learned in one or two courses in the past is now often spread over eight or nine courses. The principle is sound provided that all divers embrace continuing education. Unfortunately, far too many divers receive their only formal instruction in one initial course and fail to understand or appreciate the fact that their education for safe diving only *begins* at the end of this course. Safe diving isn't a course, or even a series of courses. It is a *state of mind* — an attitude. And this attitude is strengthened by knowledge!

Thus, this *beginning scuba diving manual* represents a return to the old days where knowledge and truth were considered precious. It is a basic diver's manual, not an advanced manual.

And for those critics who will read this manual, surely it has many typographical and grammatical errors. For this I apologize in advance. The reader is warned to check formulas and calculations before using them. I will be most appreciative if readers will list misspellings, unclear explanations, and errors on the sheet provided in the back of this manual and submit it to me in class.

In this book, I have been uninhibited in expressing my opinions. Some will no doubt be outdated; some will be open to challenge. Some individuals in diving will scorn my opinions as those of an aging diving dinosaur who is unable to accept progress. I would rather be scorned than to wallow in the mediocrity that embraces diving today. Besides, the worst sin of a writer is to have no opinions. And, I have not been sufficiently programmed to leave the direction of modern recreational scuba diving education unchallenged.

If you wish to be a modern equipment and divemaster dependent diver who cannot read dive tables or plan a dive, you are in the wrong course and reading the wrong manual. If you plan to complain everytime you get a bit cold in the pool, you are in the wrong course. If you plan to miss classes because of conflicting social activities, laziness, or lack of interest in the lecture topic, you are in the wrong course. If you have enrolled for an easy grade and the grade is your bottom line, you are in the wrong course.

My bottom line is a skilled, knowledgeable, safe diver. I will accept no less!

Manuscript revised: 23 December 1989
Manuscript revised: 13 June 1990
Manuscript revised: 14 August 1990

VOLUME I

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INTRODUCTION TO SCUBA DIVING

SCUBA DIVING

Scuba diving is most often referred to as a *recreational sport*. However, the term *sport* sometimes implies erroneous connotations and limits understanding. Scuba diving can also be an avocation or a vocation. It is a pastime, a pursuit, or even a life-style, which can be as limited or extensive as you make it. Your level of commitment, degree of skill, and types of equipment all depend on what you want out of scuba diving.

You may choose to dive only once or twice a year during your Florida or Caribbean vacation. In such cases you will often rent most of your equipment and rely on the knowledge and skill of a *dive guide* for selecting an appropriate dive site and safety. On the other hand, you may find that scuba diving fills the *need* in your life for adventure and challenge. You will acquire the finest equipment and dive throughout the world's oceans. You will progressively develop your skills and knowledge to embrace all diving environments. You may even seek vocational diving involvement as a educational, scientific, search and rescue, commercial, or military diver.

At this point you are preparing for your initial diving training experience. You feel both anticipation and apprehension as you enter your training experience. Many textbooks and diving publications present a glorified impression of scuba diving and the underwater world. DIVING IS FUN! ANYONE CAN DIVE! THERE ARE NO RISKS IN DIVING! On the other hand, some instructors will relate tales of terror and superhuman feats. You are overwhelmed with both conceptions and misconceptions.

In the following pages I will attempt to sort some of these things out for you. I will neither glamorize nor demean scuba diving. However, I will do my best to provide you with the factor as I see them. I simply ask you to remember one thing. *I care about your personal health and safety as well as the quality of experience that scuba diving will be for you.*

ENVIRONMENTAL CONSIDERATIONS

Initial diver training takes place in a swimming pool or shallow, protected open water. This enables the student to develop skill competence and general comfort in a non-threatening environment. Once confined water (and theory) instruction is completed, the diver advances to open water training in a lake, quarry, or ocean setting. Initial open water experiences are generally limited to a location with mild environmental conditions. The diver may have to cope with thermal protection problems as well as minor wave and current conditions. Visibility is often more restricted than in swimming pools. These initial experiences include equipment familiarization (especially thermal protection), skill learning and evaluation, and environmental orientation.

Once the diver has completed initial open water training, he/she is assumed to be competent for diving under similar environmental conditions. *However, beginning divers are encouraged to dive with experienced divers, instructors, or dive guides until they are very comfortable with the equipment and the environment.* The first 10 to 15 dives are *learning* and *confidence-building* dives for the beginner.

As a diver gains experience he/she will generally wish to extend environmental diving capability. Divers trained in northern lakes and quarries may wish to extend their diving to include year around activities and more adventurous aspects of diving. Shipwreck diving is very popular in the Great Lakes and generally involves exposure to more active surface conditions (waves), diving from boats, and deeper depths. Others will wish to advance to winter and under ice diving. Scientific divers may venture into polar waters. Most cold water divers will soon purchase a dry suit. Many Michigan divers explore the bottom of the St. Clair River. River diving is a highly specialized activity that requires special training and equipment to be done properly and safely. Specialty courses are available in shipwreck, deep, under ice, and dry suit diving.

Most northern fresh water divers will soon hear the *call of the sea* and travel to tropical oceans where the water is warm and clear. Tropical resort and live-aboard boat diving is one of the major aspects of diving in the Americas. Here, in addition to unsurpassed beauty, one is likely to experience his/her first encounters with potentially hazardous marine life, strong ocean currents, and tropical sun. The greatest risks these divers will no doubt face are decompression sickness resulting from a desire to dive many times day after day, tropical sunburn, motorbike-related trauma, and party overload. Since there are no official tropical diving specialty courses, divers traveling to tropical oceans for the first time are encouraged to dive with experienced tropical divers and under the supervision of a dive guide. Many divers now travel to Hawaii, South Pacific Islands, and the Great Barrier Reef each year.

Many divers also turn to the unique clear springs, caverns, and caves of northern Florida. Cavern and cave diving is a highly specialized activity requiring special equipment and training. *Cave diving is considered one of the highest risk of all recreational diving activities.*

Some divers travel west with our Rose Bowl teams to the waters of southern California and the Channel Islands. Here they encounter waves, surf, currents, marine animals, kelp, and varying diving conditions. Surf entry requires special training that can only be accomplished on a surf beach. Diving in a kelp forest is a unique experience that requires special techniques and understanding of the environment.

Each environment is unique and requires some special diving skills and/or equipment. Beginning divers are encouraged to advance skill and environmental range in a logical and progressive fashion. *The major cause of diver injury and fatality is exceeding limitations of training, experience, and equipment.*

HEALTH CONSIDERATIONS

One question often asked by my students is, **"Do I really need a medical examination before beginning my scuba diving training?"** It is true that many instructors and instructional agencies accept students into courses without requiring a medical examination. The student is requested to complete a medical history or health status form which the instructor will review. If the instructor feels that there are medical conditions that may be inconsistent with safety in diving, the student is advised to see a physician before beginning training. Is this a satisfactory screening system? Not necessarily!

In my opinion, all students should complete a medical examination from a qualified physician prior to entering scuba diving training. Why? First, some individuals will not feel comfortable about providing personal health information to a scuba instructor. Second, in most diving courses the student is unaware of the specific physiological risks associated with diving at the time they complete a medical history form for the instructor. Consequently, the student may not provide complete information. For example, *asthma is considered to be a disqualification for diving by most authorities.* A student who really wants to learn to scuba dive might have heard that if you mark asthma on the medical history form you will have to see a physician. Maybe the student does not want to risk disqualification or the additional cost of a medical examination. Unaware of the potential risk, the student simply does not mark asthma on the form.

What about the young, healthy individual who exercises regularly? Is there really any risk for this type of person? Do they really need a medical examination? In our university diving program up to 12% of the young, healthy college applicants have been medically disqualified. Generally, about 5% of the applicants are disqualified annually for respiratory, cardiovascular, or other medical reasons. In addition to a routine medical examination, many authorities suggest that all divers, regardless of age, submit to a resting EKG and stress test. Yes, even young, apparently healthy people can have previously undetected serious medical problems.

Some individuals or agencies suggest that a medical examination requirement is invalid because most physicians are not familiar enough with the physiology of diving to administer an appropriate examination. I do not feel that this argument is valid today. You can find physicians with some knowledge of diving in most cities. If your physician appears to lack specific knowledge of diving, have him/her obtain an excellent booklet titled, "Medical Examination of Sport Scuba Divers" by Jefferson C. Davis, M.D. (available from Medical Seminars, Inc., Publishing Division, One Elm Place, Suite 204, 11107 Wurzbach, San Antonio, Texas 78230). Edited by Dr. Davis, this booklet contains the collective opinions of 94 contributing physicians and was reviewed by four outstanding diving physicians.

In order to assist you in assessing your personal medical condition for entry into a diving program, I am including a list of questions that you may ask yourself. *If you answer YES to any question or have any doubt regarding the answers, you may be at some level of potential risk for participation in scuba diving.*

1. Do you have a history of seizure inducing disorder?

2. Do you have a history of dizziness, fainting, or loss of consciousness?

3. Do you experience significant discomfort and major difficulty in equalizing pressure in your ears and sinuses when you fly or dive to the bottom of a swimming pool?

4. Do you have any history of restrictive or obstructive lung disease?

5. Do you currently have active bronchial asthma, have you experienced symptoms suggestive of asthma such as *wheezing* within the past several years, or are you taking asthma control medications? Do you currently experience or do you have a history of exercise or cold air induced asthma?

6. Are you aware of any cardiovascular problems, taking any medications to control cardiovascular problems (presently or in the past), or restricted in your exercise because of *heart/circulatory* problems?

7. Do you have (or have you had) a punctured eardrum, chronic or active (or recurrent) ear infections?

8. Do you have diabetes mellitus?

9. Have you experienced chest radiation treatments, chest surgery, spontaneous pneumothorax (lung collapse), or tuberculosis?

10. Do you currently have any condition requiring continuous medication such as antihistamines, steroids, barbiturates mood altering drugs, or insulin?

11. Do you experience migraine headaches?

12. Are you pregnant?

13. Are you under the care of a physician for any physical or emotional problem?

14. Do you use excesive alcohol or mood altering drugs (recreational; drug dependency; not under supervision of a physician)?

These are only some basic questions that would encompass major contraindications to diving. *Remember that even though you may have been declared physically fit for athletics and exercise programs previously, you might have some condition that would place you at high risk for scuba diving.* For example, a minor obstruction in a small airway might have no significant effect on your ability to participate in strenuous physical activity such as jogging and swimming. However, in scuba diving where you breathe air at higher pressures (ambient underwater pressure), such an obstruction could cause momentary *air trapping* as the air expands when you ascend to the surface, rupturing delicate lung tissue, and allowing entry of air into the circulatory system. These small air bubbles could lodge in the brain with disabling or even life-threatening consequences.

With modern control medications, many persons with diabetes mellitus, seizure disorders (such as epilepsy), and other conditions that might result in loss of consciousness or convulsions do actively participate in exercise and sport activities. *However, momentary impairment of consciousness or a seizure on land is not nearly as life-threatening as the risk of such an episode underwater where near-drowning or drowning is the likely result.*

What is a patent foramen ovale and is this a condition that might cause problems in diving? It is estimated by some authorities that as high as 25% of the normal population may have a patent foramen ovale — a small opening in the wall which separates the right atrium from the left atrium of the heart. The presence of this congenital abnormality has little significance under normal circumstances. However, when the individual performs a valsalva maneuver or induces cardiac engorgement, such as associated with immersion, the foramen ovale may become patent (open) to the point that significant right-to-left shunting (of blood) can occur. Consequently, if venous gas emboli (tiny asymptomatic nitrogen bubbles that may develop in venous circulation during ascent from some dives) are present they may pass directly to systemic circulation and to the brain where they could easily induce cerebral gas embolism or to other sites elsewhere in the body to cause decompression sickness sysmtoms.

Just a word about recreational drugs and drug dependency! If you are drug dependent or even use drugs occasionally, I respectfully request that you do not enroll in this course. If you are enrolled, please drop the course. In my opinion, there is no place in this course, in the ocean, or on earth for even the most casual of drug users. The contraindications for diving associated with mood-altering drugs is too complex to discuss in this introduction. *The word is NO!*

Why is pregnancy disqualifying for shallow water training dives? Most physician and hyperbaric researchers now agree that pregnant women should not dive or be submitted to elevated ambient pressure environments [,1, 2]. Animal studies have shown significantly increased fetal death rates, even when the mother did not experience decompression sickness. One report indicated an 83% death rate. Also, an elevated incidence of birth defects (in research animals) is reported by one researcher to including damage to brain, eyes, jaws, feet, and heart.

A study of 208 women, 136 of whom dived during one or more pregnancies indicated a significant ($p < 0.005$) increase in birth defects among the offspring of women who dived. Shallow diving is no safe guard. The average depth of the women's dives in the study was 43 feet.

Why is the fetus so easily damaged by diving exposures? All unborn are low in oxygen initially due to the exchange mechanism of the placenta. Consequently, any interruption in the supply by even minimal bubble development can cause damage. During early stages of pregnancy when all of the vital organs are developing, bubble formation in a specific tissue location could possibly do major irreversible damage to a developing organ. As you will discover in your diving training, air bubbles can be introduced into circulation as a result of pulmonary barotrauma. Subsequent treatment of a childbearing woman would expose the fetus to high treatment pressure (165 feet) and significantly elevated oxygen partial pressure. Some researchers have suggested that elevated oxygen can be hazards to the fetus.

In addition, during gestation women undergo a number of physiological changes including altered body fluid distribution, increased deposits of body fat, fluid retention, and gastrointestinal dysfunction. In latter stages of pregnancy, equipment placement can be difficult and present potential risk. *In the final analysis, if you are not willing to give up diving for nine months, how can you be a good parent, who must give up so much for at least 18 years! [1] Summarizing all that has been cited and said, pregnant women should not dive! [2]*

After an initial medical examination, divers must also submit to periodic re-examination. The frequency of subsequent medical examination depends on age, medical conditions, and the individuals general state of health. Divers subject to federal or state occupational health and safety regulations must be examined annually. The American Academy of Underwater Sciences requires scientific divers to have an initial medical examination (including chest x-ray, resting EKG, and stress test). Subsequent medical examinations are required every three years to age 40 and every two years thereafter. A chest x-ray is required every three years and a stress test every 5 years. In addition, divers must be specifically authorized to return to diving following any major illness requiring hospitalization, especially if that illness involved the pulmonary or cardiovascular systems. Divers must also be medically requalified for diving following treatment for diving related injuries, especially pulmonary barotrauma/air embolism and decompression sickness.

Is any uncertainty worth such dramatic consequences? Even if your instructor does not require a medical examination, I suggest that you voluntarily submit to examination by a physician.

PHYSICAL FITNESS

Nearly anyone can swim underwater while breathing from scuba regardless of their physical fitness level. I have observed individuals at Caribbean dive resorts who appear *out-of-breath* just from the exertion of walking to the dive boat. Although these individuals appear fairly comfortable underwater, their post-dive *near-exhaustion* level raises doubt in my mind with regard to both safety and quality of experience. How would such an individual respond in a physically or emotionally stressful situation? Research and experience suggest that both the out-of-shape diver and his/her diving companion could be severely compromised in a stressful situation.

Some scuba diving situations, particularly for the unskilled novice, can place serious stress on the entire body, especially the cardiovascular and respiratory systems. Anxiety, skill inefficiency, poorly conditioned heart, hyperventilation, obesity, equipment restrictions, breathing resistance, and heat loss are among the many factors which can cause increased heart rate and onset of fatigue. My experience suggests that a person in reasonably good physical condition is a better learner in a scuba diving course and is more apt to be a safe and comfortable diver. Scuba diving will generally be a higher quality experience for the individual in good physical condition.

To help students evaluate their personal physical fitness level, I administer the Cooper Aerobic 12-Minute Swimming Test early in my training program. Some individuals, especially persons who appear to be poor swimmers, ask if the Cooper 12-Minute Running Test can be substituted. They indicate that they are in exceptional condition and run several miles daily. The swim test is a measure of both aquatic competence as well as physical fitness. A highly conditioned runner who is a poor swimmer may become exhausted very quickly while struggling to remain afloat in water.

The swimming and fitness evaluation is made during the first week of training. Persons failing to swim 400 yards and/or who exhibit signs of poor physical fitness will be expected to improved their swimming ability and physical fitness concurrently with the diver training program. These individuals may enroll in a swimming and/or fitness training course. *Exceptionally poor swimmers and persons in very poor physical condition will be disqualified for diver training.*

The test is age and sex adjusted. I feel that a student diver should be capable of performing at Fitness Category *Fair* and that an active diver should attempt to maintain a fitness level of Category *Good*. This means that a student between the age of 20 and 29 years should be able to swim at least 500 yards (male) or 400 yards (female) in 12 minutes. Complete instructions and fitness charts can be found in "The Aerobics Way" by Kenneth H. Cooper (Bantam Books, New York, 1977). A performance chart for the 12-Minute Swim Test is included in Table 1-1.

I must caution you about fitness testing. Since the heart rate and blood pressure cannot be continuously monitored during this field test, there is a certain degree of risk if one takes the test without having been properly conditioned by previous exercise. If you are over 35 years of age, do not take this type of fitness test prior to beginning an exercise program. Cooper suggests that you postpone testing until you have completed a six-week *starter program*.

CAUTION! Do not exert maximum effort unless you are under 35 years of age, are already conditioned, or have progressed through at least six weeks of an aerobic conditioning program! If, during the swim test, you experience tightness or pain in the chest, severe breathlessness, lightheadedness, dizziness, loss of muscle control, or nausea, stop exercising immediately!

Prior to participation in the swimming evaluation each trainee shall *warmup* by swimming a few easy lengths of the pool and/or a series of stretching and/or light exertion movements of their personal choice. A 7 to 10 minute warmup routine is recommended. Trainees are responsible for their own warmup activities.

Following your swim, *cool down* by walking back and forth on the pool deck or slowly swimming additional lengths for about 5 minutes. Never start or stop exercise abruptly!

TABLE 1-1

12-MINUTE SWIMMING TEST: FITNESS CATEGORY BY AGE
(Distance in Yards in 12 Minutes)

Age in Years		13-19	20-29	30-39	40-49	50-59
VERY POOR	(M)	<500	<400	<350	<300	<250
	(F)	<400	<300	<250	<200	<150
POOR	(M)	500-599	400-499	350-449	300-399	250-349
	(F)	400-499	300-399	250-249	200-299	150-249
FAIR	(M)	600-699	500-599	450-549	400-499	350-499
	(F)	500-599	400-499	350-449	300-399	250-349
GOOD	(M)	700-799	600-699	550-649	500-599	450-549
	(F)	600-699	500-599	450-549	400-499	350-449
EXCELLENT	(M)	>800	>700	>650	>600	>550
	(F)	>700	>600	>550	>500	>450

All divers should participate in an ongoing personal fitness program. If you wish to begin a personal fitness training program, but cannot enter a fitness class, a book titled, *THE AEROBICS WAY* by Kenneth H. Cooper, MD is an excellent introduction to personal fitness training. This book and others on aerobics training programs are available at local book stores.

Physical fitness and good swimming ability are important factors in diving safety and the quality of the diving experience.

As a general rule, average participation in scuba diving activities is not sufficient to develop and maintain a satisfactory level of physical fitness. Diving must be supplemented by a regular exercise program. Persons who participate in diving only on a seasonal or vacation-time basis should exercise regularly or, at least, initiate a conditioning program six to eight weeks prior to active diving.

Hopefully, your participation in scuba diving will motivate you to improve your overall fitness level and, to some degree, your personal life-style. I encourage all students as well as previously trained divers to re-evaluate their current approach toward physical health, stress management, recreation, and general life-style. As previously stated, scuba diving can be a life-style of its own. As part of this new life-style you may wish to initiate a personal health and fitness program. The Cooper aerobic exercise program is a good place to start. Over the past two decades it has been accepted and used by a vast population of average people. Detailed and simplified publications describing the program are sold throughout the world. The exercises and fitness levels are both age and sex adjusted. Your personal exercise program can include a variety of activities ranging from running to volleyball and is adaptable to almost any life-style or living situation. And, most important, it works!

SWIMMING REQUIREMENTS

"How well do I have to swim in order to be a scuba diver? A friend told me that you really do very little swimming without fins and mask and that the flotation equipment makes movement underwater and on the surface almost effortless!" The friend is correct, up to a point! A non-swimmer could scuba dive with the aid of this equipment. However, in the event that the scuba or buoyancy system malfunctions or a fin is lost, the non-swimmer could be in serious difficulty. Please do not let anyone convince you that such things can't happen. During one resort dive I observed a diver lose a fin and the inflation hose off of a buoyancy compensator. Equipment cannot be a substitute for watermanship or physical fitness. A scuba diver must be capable of handling any situation that might involve the loss or malfunction of any or all components of the diving system.

I feel that a person participating in scuba diving should be comfortable in the water. In general, good swimmers are comfortable in the water and poor swimmers are uncomfortable. Furthermore, the more comfortable you are in the water, the "safer" you will be. And, the more comfortable you are the more enjoyable scuba diving will be for you.

"How can I determine if I am comfortable in the water? How will the instructor determine this?" Such determinations are both subjective and objective. First, only you can actually assess your emotional comfort level. If you are experiencing high emotional stress or anxiety when you are asked to swim in the middle of the pool away from the security of the side or if you struggle to stay afloat and move in the water, you are obviously not comfortable.

Some instructors do not include a swimming pre-requisite in their scuba diving program. Some students are only informed that they will be expected to swim 200 to 300 yards without the aid of equipment before they can be certified. For a poor swimmer who is uncomfortable in the water, the training experience can be unpleasant and the *learning experience compromised.* Such individuals may drop out prior to the end of the course, fail to meet the certification requirements, or *sneak through.* I feel such an individual is at high risk, especially the one that sneaks through. A poor swimmer is far better off in a swimming course. This person can then learn to scuba dive later when he/she can both enjoy and gain maximum benefit from the scuba instruction experience.

As an instructor, how do I evaluate comfort level in prospective students? I talk to the students and I ask them to swim. *All candidates for scuba diving training and certification at the University of Michigan must be capable of swimming at least 400 yards (16 lengths of a 25 yard pool) and be in reasonably good physical condition.* I personally feel that a person who can swim at least 400 yards without exhibiting signs of exhaustion or serious emotional/physical stress will *enjoy a more successful learning experience and be a safer diver.* In addition, I ask my students to demonstrate the ability to float or tread water for 15 to 20 minutes, swim 25 yards underwater, and tow a fellow student 25 yards. Other swimming skills will be observed during the course.

Now for the big question, "What if I can't perform these swimming skills during the first pool session? Will I be disqualified for training?" Not necessarily! If you are having difficulty or can't make the swim, we will talk. Is the reason for your difficulty because of poor swimming skill level? Poor physical condition? Out of practice? Could you swim better when you were younger? Sometime I allow poor swimmers to enroll in my scuba course. If you are one of the poor swimmers, I will ask you to make the decision, "Would you rather improve your swimming skill in a swim class and enroll in scuba diving at a future time or make a commitment to me and yourself to concurrently improve your swimming skill?" It works both ways. I had one individual who could only swim 75 yards at the first pool session. Eight weeks later this individual comfortably swam 400 yards in less than 9 minutes and is an excellent scuba diver today. *It's called commitment!* Are you willing to make that commitment to yourself and your instructor? If so, let's go for it! But, remember, you will be a swimmer before I certify you as a scuba diver.

I will not put a scuba diver in the ocean unless he/she can swim at least 400 yards without fins. In fact, I encourage every beginning diver to achieve a level of swimming competency that includes the ability to swim 800 yards or more without undue fatigue. As divers advance to leadership positions, I expect the 400 yard swim to be completed in 8 minutes or less.

"I am an excellent swimmer and was captain of my high school swim team! Will I be a natural scuba diver?" Probably, but not necessarily! A few individuals will not *emotionally* adapt to breathing underwater. Although very rare, such individuals will experience considerable emotional stress and anxiety. They present an unacceptable threat to both themselves and their fellow divers. However, one must not confuse the natural anxiety that might be associated with learning a new activity such as breathing underwater with the deep-seated emotional problem referred to above! If you feel uncomfortable with your first exposures to swimming and breathing underwater, discuss it with your instructor and continue training. Generally, you will be completely at home underwater by the second or third session. Most students will be well adapted by the end of the first session. If your problem is serious, you and your instructor will soon identify it.

SCUBA DIVING COURSES

Recreational scuba diving training courses are sanctioned by one or more of the nationally recognized recreational diver training agencies such as the National Association of Underwater Instructors (NAUI), Professional Association of Diving Instructors (PADI), or Scuba Schools International (SSI). Standards for scientific diver training have been published by the American Academy of Underwater Sciences (AAUS). These agencies have established specific standards for course content and training procedures.

Scuba diving courses include classroom, confined water (generally swimming pool), and open water training sessions. In the classroom you will learn the fundamentals of diving equipment selection, application, and maintenance; marine life and environmental factors; basic diving physics and physiology; dive accident management and first aid for diving related injuries; dive planning and procedures; use of air decompression and repetitive dive tables and so on. The confined water sessions will include basic skin and scuba diving skills; emergency and rescue procedures; buoyancy control; scuba use and maintenance; and other skills fundamental to safe diving. Upon successful completion of this training and upon passing both written and diving skill tests you will advance to open water training.

The open water training program will consist of four to six open water scuba dives (12 dives for scientific diver certification) under the direct supervision of an instructor. You will be expected to demonstrate your ability to perform most of the skills that you learned during confined water training, learn new skills such as underwater navigation, and complete an environmental orientation for your geographic location. For most trainees the open water experience is their first exposure to diving in a thermal protection garment.

Most students complete their open water training within their home geographic area. However, in recent years increasing numbers of students are requesting referral letters/forms so that they may complete open water training during a vacation to the Bahamas or the Caribbean Islands. In fact, many students are now planning their vacations specifically for certification and diving experiences.

"How much does all of this training cost? Will I have to buy my own equipment? How much time will be required?" First, the cost of a complete basic level scuba training course ranges from $120 to $400. Second, for most courses the student was required to purchase (or borrow) mask, fins, and snorkel. The cost of these items ranged from $75 to $150. Third, the amount of training time ranges from 12 to 36 hours plus open water time (generally 2 diving days with one to three dives per day). The amount of time spent in confined water training ranges from 6 to 18 hours.

EQUIPMENT COST

Scuba diving is not an inexpesnive activity and the cost of equipment can be quite high. The type and amount of equipment you purchase depends on the type and amount of diving you expect to do. For example, if you only expect to dive once each year at a Caribbean resort, you could probably get along on the basic mask, fins, and snorkel for $75 to $150 and rent the remainder at the resort. If you expect to do some local diving and make several diving trips, you will want to consider a more complete diving outfit including buoyancy compensator, scuba regulator, exposure suit, and accessories. The following equipment costs are based on approximate retail values of quality equipment:

Regulator including pressure gauge, alternate breathing unit, and console with depth gauge, compass, and timer (the present trend): $550 to $730

Scuba cylinder, backpack, and buoyancy compensator: $500 to $750

Thermal protection garments/suits with boots, hood, and mitts (wet suit) plus weight belt: $300 to $1200

Knife, equipment bag, underwater light, and miscellaneous accessories: $125 to $300

If you dive only in the tropics you may elect to purchase a 1/8-inch foamed neoprene diving suit at a cost of $300 including boots, gloves and hood. On the other hand, if you intend to dive on Great Lakes shipwrecks and extend your activities to four seasons, you will no doubt purchase a good dry suit with thick undergarments at a cost of $700 to $1400. In addition you might want to purchase a wet suit for tropical diving. Thus your equipment investment can range from less than $1000 for the conservative tropical diver to more than

$3000 for the northern four-season diver. This does not include underwater photography equipment.

Please don't let these figures scare you! You can save money by shopping for the best buy and watching for sales. And you may not need a first class dry suit for the limited amount of diving you will do. However, remember that value is not measured in *dollars* alone. *Consider durability, performance, availability of repair/parts on a long term basis, quality of diving experience, and safety.*

RISKS ASSOCIATED WITH DIVING

Many instructors and organizations discourage discussing diving-related risks in basic scuba diving courses. They fear that students will be frightened and drop out of training. This would represent a potential loss of revenue to the diving industry. I disagree with the concept of not informing an individual of the risks associated with any endeavor.

Like any sport or professional activity, scuba diving has inherent risks. However, these risks are minimal for a healthy individual that is comfortable in the aquatic environment and who has received adequate training in scuba diving theory and skills. Each year approximately 500 American divers experience serious ascent-related injuries (air embolism or decompression sickness) and about 80 to 90 lose their lives. Investigation of diving injuries and fatalities suggest that *the vast majority of accidents result from diver's error in judgment and exceeding the level of an individual's training, experience, ability or physical condition.*

Do not let the above figures frighten you! Today there are 1.5 to 2.5 million active scuba divers making an average of about 10 dives annually. These numbers are only subjective estimates. Because the United States has no effective diver data collecting system, the determination of actual diving activity is a highly controversial subject with both inflated and deflated values expressed by special interest groups.

Furthermore, some analysts have suggested that diving is among the safest of sporting activities. For example, it has been determined that the chance of being seriously injured or killed while scuba diving is about one-half as likely as when skiing and 14 times less than participating in hang-gliding.

The scientific diving community does maintain statistics on the diving activities in member organizations. In 1988 the 18 member organizations of the American Academy of Underwater Sciences (AAUS) reported a total of 862 active divers. A total of 15,980 individual dives were reported for these divers. There were no serious diver injuries or fatalities reported from this group of divers. The data collected by the AAUS represents only a portion of the active scientific diving community and does not include statistics for government agency scientific diving. However, through the Academy membership, the Divers Alert Network, the University of Rhode Island Data Center, Scripps Institution of Oceanography, and individuals active in diving accident investigation it is likely that there have been fewer than 10 fatal accidents and less than 20 serious diver injuries in nearly 40 years of organized scientific diving.

The scientific diving community maintains a higher training standard, requires periodic medical evaluations, requires each active diver to log at least 12 dives annually, and requires annual requalification for each diver subject to review by a Diving Office or Diving Control Board. These are some of the reasons for the community's excellent safety record.

Specifically, what types of injury might you encounter as a diver? First, the most serious is death by drowning. Unfortunately, a number of divers lose their lives because they cannot handle themselves in the water — the simply lack basic aquatic skills and comfort or become excessively fatigued.

Each year about 500 divers experience air embolism or decompression sickness. Both of the conditions are associated with ascent. In the case of air embolism injury results from trapping of air in the lung as a consequence of lung abnormality (prior disease or injury), blocking of airway passages by mucus (respiratory infection or cold), or breath-holding by the diver (panicked ascent or carelessness). The air expands, ruptures lung tissue, and enters pulmonary circulation. It is carried to the heart and enters arterial circulation to the brain where it lodges in blood vessels. The blockage deprives the tissue downstream from the blockage of oxygen. The results are not unlike that of a stroke. The diver can experience a variety of neurological deficits including complete paralysis of one side of the body or death. *A scuba diver ascending from a depth of 6 feet in a pool while holding his/her breath can experience serious lung injury with the possibility of subsequent air embolism.*

Although the symptoms of decompression sickness occur during or following ascent, the condition is the result of absorption of inert gas (nitrogen) into body tissues during submergence and failing to allow sufficient time for the gas to be eliminated from the body during ascent. Underwater exposure (depth and time) and subsequent return to the surface is governed by gas absorption-elimination mathematical models of the body which are expressed in the form of dive tables and computers for user groups. Exceeding the time-depth allotments and ascending too rapidly to the surface can result in bubble formation (inert gas coming out of solution) in tissues or body fluids. The results can range from extreme fatigue and mild pain to complete paralysis of lower extremities and, even, death.

All of this can be prevented by proper dive planning, observing time-depth limitations, and good diving practices. Unfortunately, there are a number of variables that influence gas absorption-elimination in the body and individual physiology varies considerably. *All divers must accept the fact that they may experience decompression sickness, even if they follow the values indicated on a dive table or computer.* The chances are minimal if the diver used proper diving procedures and makes accurate depth-time measurements and reads tables or computers correctly. Investigation of diving accidents suggests that the majority of divers experiencing decompression sickness failed to accurately document depth and time and properly read dive tables, pushed or exceeded the limits indicated by the tables or computers, or failed to take into account predisposing factors such as alcohol consumption, fatigue, cold, and so on.

Other parts of the body are subject to barotrauma (pressure-related injury). For example, failure to equalize pressure in ears can result in damage to ear tissues with possibility of subsequent infection, rupture of the ear drum, or injury to other ear structures. Hearing can be affected. Also, attached air spaces such as the mask can cause barotrauma. As the diver descends, he/she must equalize pressure in the face mask. Failure to do so can result in eye injury. Such injuries and adverse consequences are rare if the diver uses proper techniques and common sense precautions.

Scuba air is subject to contamination with oil, carbon monoxide, carbon dioxide, and atmospheric pollutants. The quality of air supplied by diving equipment retailers today is excellent. However, the remote possibility of air supply contamination does exist. High doses of carbon monoxide can cause unconsciousness without warning underwater and breathing oil vapor can cause lung damage.

Today's diving equipment is excellent. Seldom is diver injury or fatality traced to equipment malfunction. And, in the few cases where equipment is determined to be a factor, failure on behalf of the diver to properly maintain and use the equipment has been the underlying factor. Furthermore, a diver should be competent enough to deal with any equipment loss or malfunction within the normal range of diving activity. *Do not become an equipment dependent diver!*

Environmental related injuries are also rare in diving. There are sharks in the ocean and I can not provide you with an absolute assurance that you won't get bitten. However, such incidents are extremely rare in scuba diving. *Generally, environmental related injuries and fatalities are the result of errors in diver judgment — the diver exceeding his/her personal limitations.* During training we will review the environmental factors that influence diver safety and discuss marine life injury prevention and management.

These and other diving-related injuries or conditions will be discussed in detail during training. Great emphasis is placed on how to recognize adverse situations and prevent diver injury or illness. In addition, you will be trained in diver assistance, elementary rescue, and diver injury management (first aid).

The information presented above is intended to provide you with an informed insight into scuba diving risks! It is not intended to frighten you. Whenever you engage in any activity you assume certain risks. We are all aware of the risk associated with driving or riding in automobiles. We assume many risks in everyday life.

CONCLUSIONS

As a scuba diver you can escape the bonds of the earth's gravity and experience the freedom and exhilaration of weightless flight through the underwater world. You will witness the beauty and the reality of nature and behold sights viewed only by those *surface humans* who have chosen to leave the comfort and security of the atmosphere in order to *experience the underwater adventure* rather than to watch others on a television screen.

By nature, man is an explorer. Can you accept the challenge of exploring the earth's last frontier — the sea? The potential for new discoveries are boundless in this underwater world. In the sea you may also discover yourself. You will learn both your capabilities and your limitations. Drifting freely over a coral garden you enter not only another world of physical beauty, but also a world of emotional and spiritual beauty. Beneath the waves there is peace!

To explore the underwater frontier you must accept the challenge, the risk, and the commitment. Each individual will seek their own level of fulfillment. In a basic scuba diving course you will "learn to learn" to dive. This course will provide you with the basic knowledge and fundamental skills necessary to advance to specialty training programs such as ocean diving, river diving, ice diving, underwater photography, research diving, and diver leadership training. With proper training and considerable personal commitment you can be the inner space explorer of the 21st century!

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Manuscript completed: 1 November 1989
Manuscript revised: 23 December 1989
Manuscript revised: 12 June 1990

NOTES:

CHAPTER 1-2

HISTORY OF DIVING

The accumulation of seashell artifacts at prehistoric living cites possibly indicates that food was taken from the sea by divers long before references in recorded history. The earliest records are of Cretan sponge divers (3000 BC) and diving for oyster pearls in China (2200 BC). Military divers were used during the Trojan War (ca. 1194 BC). Reference to military diving activities is made by Herodotus (5th century BC) and in Homer's Iliad (pre-700 BC). Alexander the Great deployed frogmen against the defenses of Tyre (333 BC) and was supposed to have descended in a diving bell himself. Records indicate paid salvors and diving regulatory laws in the 3rd century, BC.

Aristotle (4th century BC) writes of the diving bell. Prior to this time all diving was probably done by breath-holding to depths not exceeding much over 100 ft. The diving bell was the dominant diving apparatus for the next 22 centuries, until about 1800. In the late 1600s the bell was refined and in 1691 a sizable and sophisticated bell was patented by Edmond Halley. This bell was ventilated by lowering barrels of fresh air, and dives were made to 60 ft for 1.5 hr; divers made breath-holding excursions from the bell.

By 1770 the elementary hand-operated air compressor provided the next major advancement in diving. This enabled LeHavre (1774) to develop a moderately successful helmet-hose diving apparatus. Surface-supplied compressed air diving developed as the prevalent diving technique by 1800 and was to maintain a virtually unchallenged position until the mid-1950s. A boosting factor to diving in the 1800s was the salvage of HMS Royal George. For this operation Augustus Siebe developed and perfected the diving helmet and closed dress in 1837. The Siebe helmet and closed dress were the primary diving apparatus for the working diver from 1837 to the 1960s. The present U.S. Navy Mark V Deep-Sea Diving Outfit is only a modification of the 1837 Siebe outfit.

Progress in diving, from 1837 to present, was dependent on two factors: improvement of the air compressor and the study of hyperbaric physiology. The compressor improved rapidly during and following the industrial revolution; however, the study of diving physiology was slow to progress. Paul Bert, in 1878, started to untangle the complexities of nitrogen absorption and elimination, or the bends. The first recompression chamber for treatment of bends was installed to support the cassion workers during construction of the first Hudson River Tunnel in New York (1893). In 1907, based much on Paul Bert's work, John S. Haldane published the first decompression tables for divers.

However, the development of scuba did not begin with Cousteau. In 1680, Borelli developed a scuba based on the theory that the diver's hot, exhaled breath could be rejuvenated by cooling and condensing. Needless to say, this unit was not successful; however, this represents a movement toward freeing the diver. Borelli also experimented with fins and buoyancy-compensating devices. In 1835 Condert published the design of a free-flow scuba, which consisted of a helmet, flexible dress, and a compresses-air reservoir fitted around the diver's waist. This was to have significant influence on the design of future diving apparatus. Rouquayrol (1865) developed a demand regulator system. Although this unit was basically surface-supplied by a hose, it also had significant influence on the development of scuba.

In 1878, Fleuss and Davis designed the closed-circuit oxygen scuba, which utilized a chemical carbon dioxide absorbent. This was the beginning of a long list of closed-circuit oxygen scuba with the eventual development of the semiclosed circuit, mixed-gas scuba by Lambertsen. Yves le Prieur, in 1924, introduced a manual, valved, self-contained, compressed-air breathing apparatus. In 1942, Cousteau and Gagnan developed the demand-type scuba, which is the basic compressed-air scuba used throughout the world today.

Sport diving and spearfishing were being practiced in many European countries during the 1920s and were introduced into the United States in the late 1920s. It wasn't until the early 1950s, with the ready availability of compressed-air scuba, that the popularity of sport diving started to accelerate to its present status. Factors contributing to the growth of sport diving included availability, improvement, and simplification of diving apparatus; an increased number of training programs; publication of the exploits of naval diving groups such as those of the Underwater Demolition Teams (UDT) and SEAL Teams; an increased layman's interest in ecology, oceanography, and related disciplines; and the general increase in need for leisure time and recreational activities.

The first recorded scientific dives were made by H. Milne-Edward (Sicily) in 1844. Over the years, many dives of a scientific nature have probably been made by breath-holding and with helmet or bell-type diving apparatus. Engineering survey dives were also made in the 1800s. Geologists, during the late 1940s, used deep-sea and shallow water surface-supplied diving apparatus for limited underwater observations. However, it wasn't until 1949 that modern scientific diving had its true beginning in the United States. Conrad Limbaugh introduced self-contained scientific diving at Scripps Institution of Oceanography and in 1950 established the first formal scientific diving program and training course. Since 1949, Scripps and the Navy Undersea Warfare Center (formally, U.S. Navy Electronic Laboratory) at LaJolla, California, have had the largest and most active groups of diving scientists in the world. Currently, nearly all research groups studying the freshwater and marine environment utilize divers to various degrees.

Standards for scientific diver training and operational procedures were published by Scripps Institution of Oceanorgraphy in about 1951. These standards were periodically reviewed and updated and served as the foundation of scientific diver training and safety programs at universities and research organizations throughout the country for many years. The National Oceanic and Atmospheric Administration (NOAA) established governmental scientific diver standards and has maintained an active roster of more than 250 scientific divers and technicians since 1970. Two editions of the *NOAA Diving Manual* served the scientific community for nearly two decades.

The American Academy of Underwater Sciences (AAUS) evolved from a group of dedicated scientific divers and diving officers who responded to a 1976 action by the U.S. Occupational Safety and Health Administration to include scientific divers in a federal standard designed to protect commercial divers. The scientific community had operated under the very effective self-imposed Scripps standard for more than two decades with an incident of diver injury far below that of recreational, military, and commercial diving. The AAUS was formally established as a non-profit organization dedicated to the advancement and practice of scientific diving in the early 1980s. Today, the AAUS sponsors an annual meeting on scientific diving and special workshops to address major issues in diving safety and publishes standards for scientific diving certification and operation of scientific diving programs. AAUS scientists from members institutions throughout the county conduct in excess of 20,000 dives annually.

The beginning date of the U.S. Navy diving program is not actually known; however, official records indicate that George Stillson began developing the Navy's program in about 1912. The F-4 submarine disaster of 1915, which somewhat paralleled the more recent Thresher incident in terms of government and public reaction, apparently stimulated interest in diving. The first U.S. Navy diving school was opened in 1915, and the Navy's famous Experimental Diving Unit was originated in 1927. Navy helium-oxygen diving experiments began in the 1930s and were used extensively in the salvage of the submarine Squalus (1939). During World War II, the great potential of military diving became evident.

The famous USN Underwater Demolition Team had its beginning in the summer of 1943. Personnel for this first team came from Navy Construction Battalions, Navy/Marine Scout and Raider Volunteers, and the Office of Strategic Services (OSS). The World War II *Frogman* was primarily a surface swimming reconnaissance and demolition specialist. Diving apparatus was only used on a very limited basis during the war. The first open-circuit scuba was acquired by Commander Francis Douglas Fane in 1947.

Navy UDT personnel saw extensive action in Korea and Vietnam.

U.S. Navy SEAL (Sea, Air, Land) Teams ONE and TWO were commissioned by John F. Kennedy on 1 January 1962. This special warfare group was organized and trained to conduct unconventional warfare, counter-guerrilla, and clandestine operations in maritime areas and riverine environments. Diving is only one of many special activities common to SEAL training. SEALs were involved in the Cuban Crisis in 1962 and the Dominican Republic in 1965. However, it wasn't until their Vietnam involvement that began in 1965-66 that the SEALs would establish their position among the best of the world's elite forces.

Experimentation in living in a hyperbaric environment began in the early 1930s. The concept of saturation diving and living in underwater habitats was introduced by G. Bond, a U.S. Navy submarine medical officer. In 1964, the first U.S. underwater living experiment, SEALAB I, was conducted off Bermuda at a depth of 192 ft. SEALAB II and other projects followed as a part of the continuous Man-in-the-Sea Program. Concurrently, Cousteau (of France) conducted the CONSHELF series of underwater living and work programs with a successful 28-day/330 FSW submergence. More recently, the TEKTITE, HYDROLAB, and AQUARIUS programs have provided an opportunity for scientists to utilize saturation diving techniques.

The first commercial saturation diving job was conducted in the summer of 1965 at Smith Mountain Dam in Virginia. These divers lived and worked at a depth of approximately 200 feet for periods up to five days using the Westinghouse *Cachalot* system. The same system was used the following year for the first saturation dive conducted in the Gulf of Mexico at a depth of 240 feet. In 1967 the working depth was extended to 600 feet. Comex divers (France) extended saturation diving to 840 feet in 1970. In 1988 Comex extended hydrogen-helium-oxygen saturation diving to a storage depth of 1706 feet with excursions to 1742 feet. Although divers are technically and physiologically capable of working to these depths, some authorities suggest that the practical working limit for modern saturation diving is 750 feet.

The diving industry was now pushing to greater depths and staying for longer durations. During the 1970s working dives were made to depths exceeding 1000 FSW and experimental chamber dives tested the diver's ability to function in excess of 2000 FSW. The bell/saturation system was became the mainstay of the diving industry. New self-contained closed-circuit mixed-gas breathing apparatus was capable of sustaining a diver at depths beyond 1000 FSW for up to 6 hr. The increasing demand for the working diver in the oil industry and offshore construction opened a new era of diving. During that decade, the diving industry has made tremendous advancement via commercial, rather than military, influences.

The first Atmospheric Pressure Diving system designs appeared in about 1715. However, it wasn't until the 1920s that Joseph Peress started development of a fluid supported universal joint that would ultimately lead to the development of a successful armored diving suit in 1933. Although successfully used in the 1930s, this suit and concept world lay dormant until the 1960s. In 1968 a British firm recognized the potential significance of this diving system in the offshore petroleum industry and persuaded Peress to assist in the development of a second suit. The suit/system was named JIM after the first diver to used the suit in the 1930s, Jim Jarret. Jarret used the suit at 150 meters in the salvage of the Lusitania. This concept, the One Atmosphere Diving System, played a dominate role in offshore petroleum industry diving throughout the 1970s and 1980s. Dives to more than 1800 feet were now possible without the complex physiological and logistical problems associated with saturation and decompression. Ascent from a dive to 1000 feet now took only a matter of minutes compared to 8 days of decompression previously.

However, increased operational cost, risk factors, insurance, and technological advancement was soon to push saturation diving even a lower priority in operational diving options. The 1980s saw major development in underwater robotics. The Remotely Operated Vehicle (ROV) would challenge both the saturation diver and JIM. As we enter the 1990s, underwater robotics is emerging as the primary underwater work system. Will the diver be replaced? Not completely! However, the role that the diver will play in underwater work will never be the same as it was in the 1960s and 1970s. The immediate future holds many advances in diving apparatus, techniques, and physiology which will influence the expansion of research, commercial, sport, and military diving activities.

The history of diving is far too complex and exciting to summarize in a few brief pages. Little known facts such as the 1 December 1937 helium-oxygen dive in Lake Michigan by Max Gene Nohl to a depth of 420 feet can be extracted from medical journals and notations in early textbooks. Nohl used special self-contained helmet-type diving apparatus developed by himself and John "Danger is My Business" Craig and tables perfected by an American diving physiology pioneer Dr. Edgar End. Any student of diving will find the historical aspects exciting and informative. One must know how we arrived at our present level of knowledge and technology in order to build the future.

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Manuscript completed: 11 January 1990
Manuscript revised: 12 June 1990

SECTION 2

PHYSICS AND PHYSIOLOGY FOR DIVERS

PHYSICS FOR DIVERS

Man naturally exists within a relatively narrow range of environmental parameters. Outside of this narrow range nearly all unusual experiences, both pleasant and unpleasant, encountered in diving stem directly or indirectly from the great differences in physical properties and characteristics which exist between the gaseous and liquid media. Some apparent differences include:

* water has a much higher density and viscosity,
* optical and acoustical properties differ,
* water has a higher degree of heat conductivity than air, and
* gases breathed under increased pressure have distinct physiological effects.

In order to understand the basic principles of diving and to function safely in the underwater environment, the diver must be familiar with certain aspects of physics which deal with pressure and density relative to liquids and gases.

In this section I will not undertake the task of a complete orientation to elementary physics. Rather I will review only the most pertinent physical principles necessary for the study of fundamental air diving theory. Certain aspects such as light and vision underwater, propagation of sound underwater, and thermal factors will be addressed in other parts of this manual.

PRESSURE

Pressure is the amount of force applied per unit area. In diving, units commonly used for pressure are pounds per square inch (psi or lb/in^2), kilograms per square centimeter (kg/cm^2), and atmospheres (atm). One *atmosphere* is the amount of pressure or force exerted on all bodies or structures by the earth's atmosphere. At sea level atmospheric pressure is equal to 14.7 psi or 1.03 kg/cm^2. At higher elevations, the atmospheric pressure is less.

Hydrostatic pressure is the force resulting from the weight of water (or any fluid) acting upon a body or object immersed in the water. Like atmospheric pressure, it is equal in all directions at a specific level or depth. The pressure increases as the diver descends at a rate of 0.445 psi per foot (or 1 kg/cm^2 per 9.75 meters) of descent in sea water and 0.432 psi per foot of descent (or 1 kg/cm^2 per 10 meters) in fresh water.

Absolute pressure exerted on a submerged body is the sum of the atmospheric pressure and the hydrostatic pressure. It is measured in "pounds per square inch absolute" (psia) and "kilograms per square centimeter (kg/cm^2 absolute). Ambient pressure is a synonym for absolute pressure and refers to the pressure surrounding or encompassing the body or object.

Gauge pressure refers to the difference between the pressure being measured and the atmospheric pressure. Most gauges are calibrated to read "zero" at normal atmospheric pressure. Gauge pressure is converted to absolute pressure by adding 14.7 psi (1.03 kg/cm^2).

For every 33 ft that the diver descends in sea water (34 ft in fresh water), there is a pressure increase of 1 atm (14.7 psi or 1 kg/cm^2). Thus, at 99 fsw, the absolute pressure is equal to four atmospheres (58.8 psia or 4 kg/cm^2 absolute).

In a mixture of gases, the proportion of the total pressure contributed by a single gas in the mixture is called the *partial pressure*. The partial pressure contributed by a single gas is in direct proportion to its percentage of the total volume of the mixture.

BUOYANCY

Any object placed in a liquid will either float or sink depending on the density and volume of the object relative to the density of the liquid. The principle of buoyancy was first stated by Archimedes, who established that "any object wholly or partially immersed in a liquid is buoyed up by a force equal to the weight of the liquid displaced by the object." The buoyant force of a fluid depends upon its density (weight per unit volume). Pure water, with a density of 62.4 lb/ft^3 (1 g/cm^3), has slightly less buoyant force than sea water which has a density of 64 lb/ft^3 (1.025 g/cm^3). If an object floats, it is positive buoyant and if it sinks, it is negative buoyant. Neutral buoyancy, or a state of hydrostatic balance, is achieved when the weight of the water displaced equals the weight of the object when totally submerged. An object in a state of neutral buoyancy neither sinks nor floats.

Since a slight density difference exists between fresh water and sea water divers tend to float easier in the ocean. Sea water increases an individual's buoyancy by approximately 1/30 the body weight over what it would be in fresh water. *When a diver properly weighted for fresh water plans to dive in the ocean, the weight belt will have to be increased by several pounds.*

Buoyancy is an extremely important factor in diving. During underwater swimming with scuba, the diver strives to maintain a state of neutral buoyancy. If the diver is negative buoyant, he will have to exert considerable effort to counteract the sinking or downward movement, which can cause unnecessary fatigue and inhibit the diver's ascent. Excessive positive buoyancy is equally undesirable in that the diver must exert a considerable amount of effort to counteract the upward movement and maintain a given depth level. *The scuba diver's buoyancy control situation is further complicated by diving suit compression-expansion, air supply utilization, and breathing characteristics.* Lung inflation-deflation can have a significant effect on the buoyancy of an individual. Buoyancy compensation procedures and equipment are important considerations in diving safety.

AIR

This manual deals primarily with scientific and recreational scuba divers using air as a breathing medium. Air is composed of nitrogen (78.1 percent), oxygen (20.9 percent), carbon dioxide (0.033 percent), and various inert and rare or trace gases. It may also contain water vapor and suspended and dissolved solids.

Nitrogen, the main component of air, is colorless, odorless, tasteless, and inert (in its free state). Under increased pressures, it is selectively soluble in various body tissues and acts as an intoxicant or anesthetic on the central nervous system.

Oxygen, the only gas capable of supporting life, is colorless, odorless, and tasteless in its free state. Under high pressures, oxygen has toxic effects on the body.

Carbon dioxide, a natural waste product of metabolism, is colorless and tasteless (in normal concentration). It is the principal respiratory process stimulant. High concentrations are toxic to the human and will produce unconsciousness with subsequent death.

Other gases important to the diver are carbon monoxide and helium. *Carbon monoxide*, the product of incomplete combustion of fossil fuels, is a highly poisonous, and all possible measures must be taken to prevent its contamination of the diver's air supply. *Helium* is colorless, odorless, tasteless, inert, lightweight, nontoxic, and nonexplosive. During the last two decades, helium has become the major inert gas substituted for nitrogen in deep-diving breathing media. The narcotic effects of helium are relatively limited and the breathing resistance due to lower density is significantly reduced. However, helium does conduct heat about five times as rapidly as air.

Breathing gas mixtures are becoming increasing important for use on selected scientific diving operations. By reducing the amount of nitrogen and increasing the percentage of oxygen in the diver's breathing gas, no-decompression dive time can be significantly increased between depths of 50 and 120 feet. Mixtures of 68%/32% and 64%/36% nitrogen and oxygen (Nitrox) are commonly used. Nitrox diver training and supervised diving activities are available for recreational divers in some areas. Additionly, a few scientists now use mixtures of helium, nitrogen, and oxygen for special extended depth diving operations. Using mixed-gases introduces increased risk of oxygen toxicity and decompression sickness as well as the potential consequences of improperly mixed and analyzed gases.

In comparison to a liquid or solid, gas (air) has a very low density, is highly compressible, and its behavior is governed by laws of physics. Air weighs only about 0.081 lb/ft^3 at 0°C or 0.075 lb/ft^3 at 20°C. Consequently, a diver consuming 70 ft3 of air during a dive will also experience approximately a 5.25 lb change in buoyancy.

GAS LAWS

Gas behavior is subject to three closely interrelated factors – temperature, pressure, and volume. A change in one of these three factors, such as increasing the temperature, must result in measurable change in the other factors. The kinetic behavior of any one gas will be the same for all gases or mixtures of gases. The temperature, pressure, and volume relationship are more conveniently expressed in terms of an imaginary substance called an "ideal gas." In working with gas laws, all pressures are expressed in terms of absolute pressure, all temperatures in terms of absolute temperature, and all units used in the equation should be in one system of measure. The gas laws of direct concern to divers are Boyle's Law, Charles' Law, Dalton's Law, and Henry's Law.

Boyle's Law states that if the temperature of a fixed mass of gas is kept constant, the relationship between the volume and pressure will vary in such a way that the product of the pressure and volume will remain constant. Mathematically,

$$pV = K$$

where p is absolute pressure, V is volume, and K is a constant. The temperature and mass are constant. Thus, at a constant temperature and mass the volume of a gas is inversely proportional to the pressure exerted on that gas. Consequently, when the pressure is doubled, the volume is reduced to one-half of the original volume. Two different states of a gas at the same temperature may be denoted by subscripts 1 and 2. Using this type of notation Boyle's Law may also be written

$$P_1V_1 = P_2V_2.$$

To illustrate Boyle's Law, let us assume that a closed flexible container of air (i.e., rubber balloon) with a volume of 1 cf at the surface is submerged to a depth of 33 fsw. Using the above formula

$$P_1V_1 = P_2V_2$$
$$1 \times 1 = 2\,V_2$$
$$.5 \text{ cf} = V_2$$

where P_1 is atmospheric pressure, V_1 is the volume at P_1 or 1 cf, P_2 is the pressure at 33 fsw in atmospheres, and V_2 is the volume at 33 fsw. Note that the volume is changed by 50%.

In order to illustrate a very important factor in diving, let us now submerge the same flexible container from 33 to 66 fsw. Using the formula

$$P_1V_1 = P_2V_2$$
$$2 \times .5 = 3\,V_2$$
$$.33 \text{ cf} = V_2$$

Observe that the change between 33 fsw and 66 fsw is much less than between the surface and 33 fsw, a change of only 0.17 cf compared to 0.5 cf. Understanding this relationship is important to the diver because it illustrates that ***sudden changes in depth while in shallow water can be far more hazardous than equivalent changes in depth while working in deep water.***

The pressure-volume relationship can be much more dramatically illustrated in terms of an emergency ascent. As a part of a training exercise and, possibly, in actual diving, a diver will have to make an emergency swimming ascent from some given depth. For discussion purposes, let us assume that the diver must ascend from a depth of 66 fsw. While at 66 fsw the diver breathes air from scuba delivered at ambient pressure or 3 ata, so that a pressure balance exists between the body and the surrounding environment. Assuming normal size and capacity lungs, the diver fills them to about 5 liters on each breath. As the diver ascends, the ambient pressure is reduced and the air volume in the lungs increases.

As long as the diver continues to breathe during a normal ascent or continuously exhales during an emergency ascent and maintains a balance with the surrounding environment, there should be no problem. However, if the inexperienced diver holds his breath, the lungs attempt to function like a closed flexible container. During ascent from 66 fsw to 33 fsw, the volume of air in the lungs will increase from 5 liters to 7.5 liters and from 33 fsw to the surface this volume will double. The implications are clear. The lungs will rupture if the diver holds his breath. The serious implications of lung rupture or barotrauma will be discussed later. One can easily see the seriousness of sudden pressure changes in shallow water. ***Improper, rapid ascent from less than 6 fsw can cause serious lung damage with subsequent air embolism, a potentially fatal pressure-related injury.*** Ten feet of sea water is swimming pool depth.

Charles' Law states that if the pressure of a fixed mass of gas is kept constant, ***the volume*** *of the gas will vary directly with the absolute temperature.* Conversely, if the volume is restrained in a rigid container (such as a scuba air cylinder), the pressure will vary directly with the absolute temperature. Algebraically,

$$PV = RT$$

where P is absolute pressure, V is volume, T is absolute temperature and R is a universal constant for all gases.

Boyle's and Charles' Laws demonstrate that for any gas the factors of temperature, volume, and pressure are so interrelated that a change in any of these factors must be balanced by a corresponding change in one or both of the others. The *General Gas Law* is a convenient combination of these two laws in predicting the behavior of a given quantity of gas when changes may be expected in any or all of the variables. These relationships for an ideal gas can be expressed as

$$\frac{PV}{T} = K.$$

where K is a constant. Two states of the gas may be denoted with subscripts,

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

To illustrate gas behavior using the General Gas Law, let us examine the effects of temperature change on a scuba cylinder. A standard 71.2 cf scuba cylinder is filled to 3000 psig in chilled water at 45° F. The cylinder is transported to a tropical beach where it is placed directly in the sun. The cylinder temperature is measured at 140° F following a long exposure to the direct sun. What has happened to the air in the cylinder? Applying the General Gas Law we can compare the cylinder under two conditions – the chilled water tank and the tropical beach. First, the volume of the rigid cylinder remains unchanged so $V_1 = V_2$. This factor can be eliminated from the problem. The variables, therefore, are temperature and pressure. Mathematically,

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

where P_1 equals absolute pressure at the time the cylinder was charged (3000 psig + 14.7 psi = 3015 psia), T_1 equals the absolute temperature of the cylinder when charged (45° F + 460° = 505° R), T_2 equals the absolute temperature of the cylinder on the beach (140° F + 460° = 600° R), and P_2 is the unknown. Substituting the values in the equation,

$$\frac{3015 \text{ psia} \times 600° \text{ R}}{505° \text{ R}} = P_2$$

$$3582 \text{ psia} = P_2$$

or

$$3567 \text{ psig} = p_2$$

Under the new environmental condition, direct sunlight on the beach, the cylinder is significantly over-pressurized.

In diving, one generally works with a mixture of gases rather than a single pure gas. The concept of partial pressure is explained by *Dalton's Law*, which states that *the total pressure exerted by a mixture of gases is the sum of the pressures that would be exerted by each gas if it were present and occupied the total volume.* Partial pressure computations are useful for understanding diving physiology and necessary for mixed-gas diving. The partial pressure (ppA) of a given gas in a mixture may be calculated by the formula,

$$ppA = P_tV_{\%}$$

where P_t is the total pressure of the gas mixture (absolute) and $V_{\%}$ is the percent of gas A by volume in the mixture. Hence, the partial pressure of oxygen in the atmosphere at sea level is

$$ppO_2 = 14.7\ (.21) \text{ or } 3.1 \text{ psi.}$$

Gas is soluble in a liquid. Gas absorption is governed by *Henry's Law*, which states that *the amount of a gas that will be dissolved in a liquid at a given temperature is almost directly proportional to the partial pressure of that gas.* The term "amount" refers to number of molecules or mass of the gas. When gas is in solution, its actual volume is negligible and there is no volumetric increase in the amount of liquid. Henry's Law simply expresses the effect of partial pressure on the amount of gas that will dissolve in a liquid. Solubility is also dependent on temperature and the type of liquid. For example, the solubility of nitrogen in oil or fat is about five times its solubility in water at the same pressure. The lower the temperature, the higher the solubility. This explains why a warm bottle of carbonated beverage forms bubbles more actively than does a cold one.

Gas diffusion refers to the intermingling of gas molecules. In diving, Henry's and Dalton's Laws are considered when dealing with the diffusion of gas in the human body under pressure. The difference between the partial pressure (or tension) of a gas inside of a liquid (or container) and its outside partial pressure will cause the gas to diffuse in or out of the liquid and control the rate of diffusion. This pressure differential is frequently called the gradient. If a gas-free liquid is exposed to a gas, the inward gradient is high and the rate at which gas molecules will migrate into the liquid is high. As the gas tension in the liquid increases, the rate of diffusion decreases and eventually reaches an equilibrium, where the gas tensions in the liquid and outside the liquid are equal. The liquid is then considered saturated for a given pressure and gas. *The subjects of gas solubility and diffusion are important in the study of decompression sickness and nitrogen narcosis.*

Surface equivalent is another notation that frequently appears in the discussion of diving theory. Calculation of surface equivalent (SE) can be expressed algebraically as

$$SE = \frac{pp_D}{1} \times 100\%$$

where pp_D is the partial pressure at depth expressed in atmospheres and 1 is one atmosphere surface pressure. The term surface equivalent and its significance can best be explained by examining a hypothetical air contamination situation. Surface air contaminated with 2% CO_2 ($ppCO_2$ = 0.02 atm) is breathed by a diver at a depth of 132 fsw (ata). The partial pressure of the CO_2 in the inspired gas at depth is therefore 0.1 atm (0.02 atm x 5 atm). This partial pressure converts to a surface equivalent percentage,

$$SE = \frac{0.1 \text{ atm}}{1.0 \text{ atm}} \times 100\%$$

$$= 10\%.$$

Normally, 2% carbon dioxide causes only a slight increase in respiration; however, a diver breathing 10% concentration may exhibit signs of mental confusion, irrationality, drowsiness, and pending unconsciousness.

In this case, the term surface equivalent is used to imply that the concentration and physiological effect of a gas at a given partial pressure at depth is the same as would be experienced at x% breathing on the surface. Although it is a commonly used term, "surface equivalent" is often misinterpreted, it is preferable to use the more exact form for expressing partial pressure in units of pressure (atm, mm Hg, etc.).

LIGHT AND VISION

Underwater vision is of major concern to the diver. In order to complete a task or observe the surrounding environment the diver must be equipped to see as clearly as possible. The human eye needs light in order to see as it creates an image by the reflection of light from the subject being viewed. Underwater light is affected by many factors which directly influence the diver's ability to see and interpret images. The major factors include:

* **turbidity**: particles in the water that obscure vision by obstructing light rays.
* **diffusion**: the scattering of the light rays by the water molecules and particulate matter.
* **absorption**: the property that alters color and intensity of light; light is absorbed and transformed to heat.
* **refraction**: the bending of a light ray as it passes from one medium to another.
* **reflection**: depending on the angle at which the light rays strike the water's surface; some enter the water and others are reflected.

Turbidity is a primary limitation that affects both the diver's safety and performance. Solar light does not penetrate much beyond 1650 feet even under the most ideal conditions of water transparency. Basically, in clear water the luminous energy (or ambient light) is reduced to about one-fourth surface value at 16 feet, one-eighth surface value at 50 feet, and one-thirteenth surface value at 130 feet. In clear water enough light generally remains for vision at up to 400 feet. However, in very turbid waters such as those found near some coastal areas or in many inland lakes underwater visibility may be reduced to "zero." These waters contain large quantities of suspended materials such as sedimentary particles (silts and clays), biological matter (plankton), and/or chemical pollutants. Under these conditions the light rays are partially or totally obstructed.

Anytime there is a significant decrease in the level of ambient light the eye must adapt accordingly. As light level rapidly decreases the eye must transform from a day vision light sensory mode to a night vision light sensory mode. Although most of the dark absorption (or adaptation) occurs within the first 10 minutes, the complete process may require about 30 minutes depending on light level differentials. The diver generally descends much more rapidly than the adaptation process can take place. The process is further changed by absorption of light at greater depths, underwater low light levels in late afternoon or early morning, and turbid water. This adaptation process accounts, in part, for the apparent loss of perceived light as the diver goes deeper. It also accounts for the fact that the diver may sense an increase in ambient light level after remaining on the bottom for 20 to 30 minutes.

The color quality of the light also changes with increasing depth. The color of the water itself is influenced by the color of the sky, the quality and nature of suspended materials in the water and the water depth. Water in the open ocean appears blue for the same reason that the sky is blue. This is caused by scattering of light rays by water molecules and tiny particles suspended in the water. Blue, being of short wave length, is scattered more effectively than light of longer wave length (like red). Although the water is commonly a shade of blue in open ocean, it may appear as various shades of green, brown, or brownish-red near shore as a result of material contained in the water.

Colors underwater are modified with depth because the wave lengths of the visible spectrum are progressively absorbed and filtered out by the water. The process starts almost as soon as the light enters the water. The water acts as a blue filter which intensifies with depth. Although many factors affect the color absorption, in average clear water all red colors are gone at a depth of about 30 feet, yellows at 75 feet, and only blues and greens are visible below 100 feet. At these depths the marine life and submarine features take on a rather drab bluish- gray appearance. Naturally, the color spectrum can be replaced using artificial light.

The angle that the light rays from the sun strike the water significantly affects the light intensity underwater. When the sun is high in the sky, at midday, as much as 97% of the light rays striking the surface of calm clear water may enter the water. As the angle of the sun relative to the water's surface decreases, as in the early morning or late afternoon, more and more light is reflected back into the atmosphere. There is still sufficient light to see underwater even at dusk and dawn since light is scattered back into the water from the atmosphere.

As the sun rises in the morning nearly all of the light rays are reflected off of the water's surface until the sun reaches 48.6° (measured from the vertical), this is the "critical angle of sunlight penetration." As the sun continues to rise a larger percentage of the rays enter the water. The same critical angle applies to internal light. A ray of light directed upward toward the under surface of the water at an angle of greater than 48.6° is totally reflected back into the water instead of being partially reflected into the atmosphere. This makes the surface appear as a mirror when the diver is in the proper position.

The roughness of the water's surface (wave motion) constantly changes the reflective and penetrating angles of the sun's light rays. When the surface is rough and the sun is lower than the critical angle, more light is transmitted in the underwater than on calm surfaces because of excessive diffusion of light at the surface. However, when the sun passes above the critical angle, the rougher the water surface, the greater the reflection back into the atmosphere.

Refraction is another phenomenon associated with light transmission that is significant to the diver. When a light ray is transmitted from a medium of one density into a medium of another, the speed that the ray is traveling changes. This change in speed alters the path of the ray. In air light travels at a speed of 186,000 miles per second; in water the speed is reduced to about 135,000 miles per second. The relative "index of refraction" is then the ratio of the speed of light between the two mediums. The air:water index of refraction is approximately 4:3, varying slightly according to the specific density of a given body of water.

Because of this refraction between air and water, *objects viewed through a face mask underwater appear larger and closer than they actually are*. Occasionally novice divers will find themselves reaching for an object that is actually slightly beyond their reach. This modification of depth perception can be compensated for with training and experience.

When the cornea of the human eye interfaces with water rather than air, it loses much of its refractive power because the index of refraction of the cornea is nearly the same as that of water. Consequently, vision is extremely poor; images appear blurred.

PROPAGATION OF SOUND

The average speed of sound underwater is about 4900 ft/sec, compared to a speed of less than 1100 ft/sec in air. Sounds such as those produced by striking a steel scuba cylinder with a metal object (i.e., diver's knife) travel relatively long distances and are heard clearly by other divers. However, determining the direction of the sound source is not always easy. *The faster speed of sound underwater almost eliminates the important time delay between your near ear and your ear detecting the sound, a factor so necessary to determining direction.*

Although sound moves faster in water, it travels very poorly from air into water. All but about 1/10,000 of the sound is lost during the transition through the air-water interface. Diver-to-diver communication by voice is ineffective underwater. Since the human voice originates in the throat, an air environment, most of the sound is lost as it enters the water. As a result, very little intelligible sound ever reached another divers ear.

HEAT TRANSFER

Each winter thousands of scientific and recreational divers subject themselves to climatic and water conditions equivalent to those found in the polar latitudes. Furthermore, scientific divers frequently work in polar regions. Probably most cold weather diving is conducted in fresh water lakes where the water temperature generally ranges from 33° F to 40° F (.5° C to 4.4° C). To further complicate the situation, cold water is present in the deeper northern lakes throughout the entire year. In addition, researchers now recognize that extended diving in tropical water temperatures can also result in significant, even life-threatening, heat loss.

The body loses heat in several ways when exposed to excessively cold temperatures. An unprotected diver loses heat to the water surrounding him mainly by convection and direct conduction through his skin.

Conduction is the direct molecule to molecule transfer of heat through a substance or through materials which are in contact with each other. The body warms, by conduction or radiation, a thin layer of water or air next to the skin. If the water surrounding the diver is moved by currents, either natural or diver produced, heat is transferred away from that area surrounding the body by convection. Even if the body is left completely still and there is no water movement, convective currents are formed in the heat transfer process. The water next to the body expands slightly as it is warmed by conduction from the body. Being then slightly lighter than the surrounding water, it rises and colder water replaces it. Thus convection currents are formed.

The body also loses heat from exposed surfaces through radiation. Any warm body or object emits waves not unlike radio waves. Diver heat loss by radiation is negligible compared to that by convection and conduction. However, the diver is cautioned to protect the uncovered surfaces such as the head, neck, and hands prior to the dive. These areas, where blood supplies are very close to the surface, radiate considerable amounts of heat and may be responsible for serious cooling of the diver prior to entering the water.

Evaporation of perspiration from the skin and water vapor from the lungs contributes significantly to the amount of heat lost by the body. Although perspiring is not generally a problem faced by the cold water diver, the evaporation of water from the lungs is. Although I have no figures for heat lost through respiratory evaporation, the magnitude of the problem can be appreciated when one considers that 1/12 oz. (2.5 ml) of perspiration evaporated cools the body approximately 2° F (.94° C). Consider the fact that scuba cylinders must be filled with moisture-free air. Consequently, with each breath considerable amounts of water vapor and heat are transferred to the air which you breathe out. Even under normal conditions, the body loses a significant amount of heat with each exhalation.

Also a considerable amount of energy is required to heat the cold air that is breathed from the scuba. One might believe that the breathing of this air is not as bad as breathing air above water in cold weather since the water temperature is certainly not below freezing. However, recall what happens when you open a cylinder valve and allow air to escape from cylinder pressure to atmospheric pressure. The valve cools significantly and within a short time frost forms even at room temperature. Now, consider what happens in the regulator when the air from the cylinder expands to a lower pressure, especially under periods of high respiratory requirements. Although I have not been able to find data relating to the temperature characteristics of air delivered by a regulator, one might suggest that it is somewhat cooler than the surrounding water. Heat lost through respiration can be a significant factor. For deep mixed-gas diving several organizations are prewarming the breathing gas just before it is inhaled by the diver.

As one can clearly see, cold water diving presents problems which put considerable stress on the body's resources before we even concern ourselves with breathing resistance, emotional stress, and swimming exertion. Although widely studied, all the implications of cold stress on the diver are not clear. One thing is clear, however, to cope with the unusually high stresses involved with working in cold water the potential diver must be healthy and extremely physically fit.

SUMMARY

The basic principles of physics provide a foundation in understanding the reasons for employing various diving techniques and procedures. They assume particular significance in studying the effects of pressure and the underwater environment upon the human body.

ACKNOWLEDGMENTS

This section is a modified version of Chapter 2: Diving Physics by Somers published in Bove, A. and Davis, J. *Diving Medicine* (Philadelphia: W.B. Sanders Company, 1990).

Manuscript revised: 22 October 1989
Manuscript revised: 8 January 1990
Manuscript revised: 14 June 1990

CHAPTER 2-2

COMPRESSION PHYSIOLOGY

INTRODUCTION

The human body is designed to function in a gaseous atmosphere of approximately 20% oxygen and 80% nitrogen at a pressure of about 15 lb/in^2. Significantly decreasing or increasing the pressure exerted on the body or changing the partial pressures of the gases of the breathing medium can induce radical physiological changes. Prolonged breath holding while subjecting the body to significant pressure changes, as during skin diving, can result in unconsciousness without significant signs to indicate the onset of complications. Subsequently, the diver may drown.

The human's normal atmosphere, oxygen and nitrogen, produces both toxic and narcotic effects when breathed at high pressure. In addition, the inert gas is absorbed during pressurization and must be eliminated from the body at a prescribed rate to avoid complications. Low-level gas contaminants such as carbon dioxide and carbon monoxide have serious implications at the higher pressures encountered while diving and may cause unconsciousness, with subsequent drowning.

One must also consider the direct physical effects of pressure. The human body has been exposed to pressure exceeding 2000 fsw without apparent residual damage. Exactly how much pressure the human body can endure is still unknown. The body contains several rigid or semirigid gas-containing spaces (middle ear, paranasal sinuses, lungs and airways, and gastrointestinal tract) which because of restricted openings are subject to mechanical damage when pressure differentials exist between the internal space and the external environment.

The effects of high pressure on the human body and breathing media must be fully understood by the diver. If physiological reactions to high pressure are not recognized by the diver and properly controlled, injury or death may occur. For discussion purposes, the physiological and medical aspects of diving can be classified into the following categories:

respiration under pressure,
barotrauma,
breath-hold diving,
breathing media contamination,
nitrogen narcosis,
decompression sickness,
oxygen toxicity, and
exposure to cold.

The material is presented herein to broaden the scope of knowledge of the recreational scuba diver, scientific diver, and search and rescue diver. For a more detailed discussion of the general subject of diving physiology and medicine the reader is encouraged to consult *Diving Medicine* [1] and other references given in this manual. Physicians will find *Diving Medicine* [1] and *Hyperbaric Oxygen Therapy* [2] most useful for a clinical overview of hyperbaric and diving medicine.

COMPRESSION PHYSIOLOGY

Among the first adaptations that an individual must experience when exposed to changes in ambient pressures is equalization of pressure between the air-containing structures of the body and the ambient atmosphere. With the exception of these air-containing spaces the entire body consists of fluids and solids, which for all practical purposes within the limits of routine diving are incompressible. Consequently, most of the body is generally not subject to *pressure injury*. Human subjects have been exposed to pressure well in excess of 2000 feet of sea water without pressure injury.

However, the middle ear and paranasal sinus cavities are lined with membranes containing blood vessels. As the external pressure being exerted on the body is changed, this pressure change is transmitted to the membrane linings of these air spaces. Furthermore, air spaces may also be attached to or surrounding the body (i.e., masks and dry suits). Gases contained within the gastrointestinal system or in decaying teeth are also influenced by pressure changes.

The lungs are the largest gas containing spaces in the body, however, the chest cavity is flexible and special physiological changes occur as the lungs are compressed during breath-hold dives. During scuba dives, the pressure within the lungs remains in equilibrium with ambient pressure unless an obstruction in the air passage occurs during ascent. This subject will be discussed in the section titled *Decompression Physiology*. Unless the pressure in these spaces is maintained equal to the ambient pressure, significant injury can occur. This pressure injury is called *barotrauma*.

EAR AND SINUS BAROTRAUMA

Barotrauma and related phenomena can involve external, middle, and inner ear structures. Air is normally contained within the external auditory canal, middle ear, and Eustachian tube. The fluid-filled inner ear is also subject to pressure-related injury.

The external ear canal is open to the ambient atmosphere. Exclusive of anatomical-physiological abnormality or artificial obstructions (i.e., ear plugs or wax deposits), pressure is transmitted freely within the external canal. In diving, water may fill the external canal. The external ear is separated from the middle ear by the tympanic membrane or ear drum.

The middle ear is an irregular shaped structure that connects with air cell systems of the temporal bone. With the tympanic membrane intact, the only communication for pressure equalization between the middle ear and the ambient atmosphere is through the Eustachian tube.

This tube, approximately 36 mm in length in an adult, connects the middle ear to the nasopharynx. The nasopharyngeal ostium (opening to the Eustachian tube) is normally closed except when opened by a positive middle ear pressure or when opened by muscular action upon the surrounding tubal cartilage during swallowing or yawning.

The Eustachian tube is lined with membrane which is similar to that lining the nose, sinuses, and nasopharynx. Abnormal nasal function can result from acute or chronic inflammatory diseases, allergy, chronic irritation from excessive smoking, prolonged use of nose drops, or from chronic obstruction. This contributes to inadequate Eustachian tubal function. In diving these conditions can predispose the diver to middle ear, inner ear, and paranasal sinuses barotrauma.

The inner ear consists of a system of fluid-filled bony channels containing membranous structures within the temporal bone. The inner ear is divided into the vestibular system which contains the semicircular canals and the cochlear system containing the spiral cochlear or auditory system. Changes in cerebrospinal fluid pressure can be directly transmitted to the inner ear compartments. Consequently, any maneuver that increases the cerebrospinal fluid pressure, such as a Valsalva maneuver, can cause an increased pressure in the inner ear fluid compartments with distension of the round window membrane into the middle ear.

The diver must be familiar with middle ear ventilation maneuvers, use of systemic and topical drugs to improve nasal function, symptoms and nature of ear and sinus barotrauma, vestibular dysfunction induced vertigo, noise related otologic injuries, and external ear infections. Farmer presents a detailed discussion of transient and permanent auditory and vestibular dysfunction with clinical implications [6].

Middle Ear Barotrauma

Middle ear barotrauma (areotitis media, aural barotrauma, barotitus media, ear squeeze) is the most common transient otologic problem seen in diving. The middle ear is connected with the throat by the Eustachian tube, which functions to drain and ventilate the middle ear. When Eustachian tube blockage (mucus or congestion, tissue overgrowth, local inflammation and swelling) prevents pressure equalization in the middle ear, painful barotitus media, or ***middle ear squeeze***, may occur, with possible tympanic perforation (rupture of eardrum). The diver will generally experience discomfort and pain in the first few feet of descent. Further descent will result in increasing pain, with stretching of the eardrum and dilation and eventual rupture of the blood vessels in both the tympanic membrane and the lining of the middle ear. Actual rupture of the eardrum may occur with a pressure differential of as little as 259 mm Hg (5 psi) or at a depth of about 10 feet.

Generally a slight blockage of the Eustachian tube by mucus or swelling can be overcome by maneuvers for clearing the ears such as swallowing, yawning, or exhaling against closed mouth and nostrils (Valsalva maneuver). Failure to initiate equalization within the first few feet of descent may result in natural closure of the Eustachian tube opening. Variations in ability to ventilate the Eustachian tube may in some instances be an anatomical factor of the individual's tube size.

When a diver surfaces after experiencing ear squeeze, they may spit blood which drains to the throat through the Eustachian tube. If drainage and/or discomfort persist, a physician should examine the injury and prescribe treatment. First aid treatment of ear squeeze is ordinarily contraindicated. The diver simply should not resume diving until discomfort/drainage has subsided and healing is complete. If discomfort and/or drainage persist, a physician must evaluate the injury. Antibiotics may be indicated to combat infection.

When the *eardrum ruptures*, a sudden relief in pain may be experienced. If the diver's ears are exposed directly to the water, the entry of cold water into the middle ear may cause a violent upset of the sense of balance. The diver may experience extreme vertigo (dizziness) because of thermal effect on the inner ear and semicircular canal and may also become nauseated and vomit. This reaction usually subsides in a minute or so as soon as the water in the ear warms body temperature. Blood is generally present in the external auditory canal. Except in the presence of infection, healing generally takes place in a few days to a few weeks, depending on the severity of the injury. During this time diving is prohibited and water should not be allowed to enter the external auditory canal. Antibiotics may be necessary, especially if the diver has been in polluted water.

Statistical information on scuba diving ear barotrauma and subsequent complications is limited. However, it is likely that the most frequent and most serious complication of diver aerotitis media is temporary or permanent impairment of auditory acuity.

Pressure Equalization in the Middle Ear and Paranasal Sinuses

Pressure equalization in the middle ear during compression or descent is accomplished by opening the nasopharyngeal ostium (opening to the Eustachian tube in the back of the throat) and admitting air through the Eustachian tube. The muscular action upon the surrounding tubal cartilage created during a swallowing or yawning type maneuver facilitates opening the tube. Most commonly divers use the Valsalva maneuver to force air into the Eustachian tube. This maneuver is accomplished by pinching or closing off the nostrils and blowing. The blowing action increases the pressure within the nasopharynx.

Although most individuals are capable of equalizing pressure in the middle ear, many divers develop complications by letting the increasing pressure *get ahead* of them one or more times during descent. Too often they equalize only after some damage had been done. *A diver should not wait for pain as a signal to equalize pressure in their ears. The equalization maneuvers should start immediately when the diver begins his descent or at least at the first "sensation of pressure change" on the ear.* Pain is an indication that barotrauma already is present.

The diver is cautioned to use the Valsalva maneuver with discretion. Increased intrathoracic pressure produced during a vigorous maneuver can result in hypotension in normal individuals. This is primarily due to impairment of venous return to the heart and the potential of the pulmonary stretch reflexes inducing certain cardiac arrhythmias. The combination of these two influences is probably responsible for incidents of syncope (fainting) that have occurred upon performing the Valsalva maneuver [3]. In fact, the cardiovascular response to this maneuver has been implicated in aircraft accidents [10]. Obviously, the implications to scuba diving are that a prolonged and intensive Valsalva maneuver could possibly result in unconsciousness and subsequent drowning. However, to my knowledge, no diving accidents have been directly attributed to this specific phenomenon.

Vigorous Valsalva maneuvers have resulted in *outward* ear drum rupture. In one case the diver successfully equalized pressure in one ear, but not the other. In an effort to equalize pressure in the unresponsive ear he continued vigorous blowing against closed nostrils, over pressured the ventilated ear, and ruptured the ear drum.

Body position during descent may also influence pressure equalization. When the diver descends in a head first position, blood vessels in the lining of the Eustachian tubes often dilate due to the increase in blood supply to the head. Consequently, the tube walls swell and restrict the flow of air into the middle ear. On the other hand, descending in a feet first position avoids this problem. The phenomenon can be demonstrated by allowing the arm to hang down and observing the dilation of vessels on the back of the hand and in the forearm. Raising the arm overhead reduces the vessel dilation.

Inner Ear Barotrauma

Round window fistulao (membrane rupture) in divers has been recognized by physicians [4]. The probable mechanisms of round window rupture have been suggested by Goodhell [7, 8]. During rapid descent or ascent inadequate middle ear pressure equalization results in a pressure differential between the middle ear and the labyrinth. This pressure differential can lead to rupture of the round window. Too vigorous a Valsalva maneuver can induce rupture. During this maneuver intracochlear pressure can rise significantly because of the accompanying increase in cerebrospinal fluid pressure which is transmitted through a patent cochlear aqueduct.

Symptoms associated with round window rupture have consisted primarily of severe neurosensory hearing loss and tinnitus (ringing in the ears) with or without associated vertigo and nausea. The frequency of round window ruptures associated with rapid compression and decompression in shallow water diving is not known. Current evidence suggests that inadequate Eustachian tubal function during diving appears to be the primary causative factor. Forceful Valsalva maneuvers should be avoided.

Alternobaric Vertigo

Transient vertigo related to unequal middle ear pressure equilibration has been experienced by divers both during descent and ascent [14]. This phenomenon has been attributed to unequal vestibular end organ stimulation as a result of unequal inflation or ventilation of the middle ear cavities during descent or ascent. One study indicates that 16.7% of 2,053 Swedish divers surveyed were likely to have experienced diving related alternobaric vertigo [11]. The vertigo episodes reportedly last from a few seconds to 10 minutes. A higher frequency of middle ear equalization problems was also noted in the vertigo experience population. Middle ear equalization problems were usually more dominant in one ear.

Alternobaric vertigo can be prevented by proper equalization of pressure in the middle ear. Individuals should not dive if difficulty with pressure equalization exists (at the surface) or if a Valsalva maneuver produces vertigo. If ear *fullness* or vertigo are noted during descent, the diver should stop and ascend until equalization can be accomplished even if they must return to the surface. If symptoms are noted during ascent, the ascent should be stopped and the diver should descend until the symptoms disappear providing air supply and conditions permit. In this case middle ear ventilation may be facilitated by yawning, swallowing, or similar maneuvers.

Transient vertigo can also result from the unequal entry of cold water into the external auditory canal, secondary to obstruction of one canal by cerumen, otitis externa, ear plugs, hood seal, or bony exostoses.

Paranasal Sinus Barotrauma

Blockage of the sinus ostia (opening) results in aerosinusitis, or *sinus squeeze*, with painful edema (swelling) and hemorrhage in the sinus cavities. These cavities are located within the skull bones and are lined with mucus membrane continuous with that of the nasal cavity. The mechanism to equalize this sinus cavity is much the same as that described for aerotitis media (middle ear squeeze). With normal gas pressure within the sinus cavity and an excess pressure applied to the membrane lining during descent, a vacuum effect is created within the cavity. Unless the pressure is equalized, severe pain and damage to the membrane will occur.

A diver who has experienced sinus squeeze will often surface with blood in their mask or will notice a small amount of blood and mucus discharge from their nose following the dive. Sinus squeeze can be avoided by refraining from diving when there is nasal congestion as a result of an allergy, cold, or infection. If discomfort develops in the sinus areas during descent, it may be relieved by the Valsalva maneuver; if not relieved, terminate the dive. Following aerosinusitis, infection may develop as indicated by persistent pain and discharge; medical attention and systemic antibiotics are generally necessary.

Use of Decongestants to facilitate Equalization of Pressure in the Middle Ear and Paranasal Sinuses

In some instances the use of a long-acting nasal vasoconstrictor (decongestant) prior to diving may be beneficial. A survey of a large group of divers, instructors, and physicians indicated that, as the occasion demanded, 56 percent of the divers had used an oral-nasal decongestant, 75.1 percent had used nasal drops or a spray, and 19.5 percent had used an inhaler [9].

The vasoconstrictive action of an oral decongestant used as a pre-dive prophylactic agent tends to keep the nasal passages, sinuses, and Eustachian tubes clear by shrinkage of the nasopharyngeal mucus membrane. Divers are encouraged to seek medical advice prior to using decongestants of any type. Often the physician will prescribe a specific decongestant and instruct the diver in its use. Avoid indiscriminate use of drugs and never use a decongestant to facilitate pressure equalization when you are suffering from upper or lower respiratory infections, i.e., colds. Those suffering from allergies should consult with their physician.

Numerous nasal spray and oral decongestants are available without prescription. However, discretion must be exercised in the use of decongestants due to possible individual associative reactions. It is important that the nasal spray or systemic decongestant be used on a *trial basis* at least 24 hours prior to the dive to rule out idiosyncratic reaction. Although rare, drowsiness resulting from the antihistamine or the development of marked nasal mucosal edema precludes safe diving. Furthermore, the decongestant must be *long-lasting*. Rebound vasodilation during a dive following the use of a short term vasoconstrictor could result in adverse consequence (i.e., inability to ventilate middle ear or sinuses during ascent).

Reuter recommended a preventive approach to ear barotrauma which includes the use of nasal spray, systemic decongestant, or middle ear ventilation by self-inflation [12]. The use of the nasal spray oxymetazoline HCl (i.e., Afrin) 20 minutes prior to the dive was recommended. A systemic oral decongestant with or without an antihistamine may also be used 20 minutes prior to the dive. Pseudoephedrine HCl (i.e., Sudafed) has been used for individuals who are made drowsy by antihistamine combinations.

It is important to use nasal sprays properly. Dr. S. Harold Reuter recommends the following procedure [13]:

1. With the head erect, insert nozzle in nostril, point the spray bottle in the direction of the eye, and squeeze briskly so the spray will come out in a fine mist.

2. Then, with the head facing the floor, insert nozzle in nostril, point the spray bottle toward the top of the ear, and squeeze briskly.

3. Wait 5 minutes — this will allow time for the front nasal passages to open. Then repeat 1 and 2 to open the back nasal passages.

4. When blowing the nose, always do so *gently*, and with the mouth open.

Rebound Phenomena

On ascent, the ears and sinuses generally vent the expanding gas without much difficulty. However, occasional blockage may result from mucus or swelling of tissue injured during descent and cause a *reverse ear or sinus squeeze*.

In the event of symptomatic developments during ascent, the diver must terminate ascent, descend slowly until the discomfort subsides, and execute a swallowing or yawning maneuver to facilitate pressure equalization. A release of pressure in the middle ear or sinus will generally be obvious to the diver. The diver may then resume a cautious, slow ascent. Corrective procedures may be required several times during ascent.

The after effects of short duration vasoconstrictors used prior to descent may produce tissue swelling in individual cases, and consequent Eustachian tube or sinus ostia restriction. Divers are cautioned with regard to the rebound_phenomena, when the effect of the drug subsides, especially after topical nose drops. This can lead to even greater nasal congestion with increased problems of pressure equalization in the ears and sinuses. Prolonged use of topical nasal medication can result in chronic nasal irritation and mucus inflammation.

External Ear Canal Barotrauma

A closed, watertight diving suit hood or solid ear plugs can produce external ear squeeze unless, during descent, gas is admitted into the ear canal by some means. External ear squeeze can result, wherein the mechanism and consequences are essentially like those of middle ear squeeze. Damage to the tympanic membrane may be equally severe, though the force is applied in the opposite direction. Hemorrhagic blebs may form close to the eardrum resulting in blood drainage from the external auditory canal. The common foamed-neoprene wet-type suit generally eliminates these hazards; however, there is potential hazard with thin, tight-fitting hoods or thin latex dry suit hoods. An inner fabric or open cell foam hood must be used with latex hoods. Ear plugs are contraindicated in diving not only because of the potentiality of external ear squeeze but also because the unequal pressure may force the ear plugs deep into the external auditory canal.

Otitis Externa

Excessive exposure of the lining of the ear canal to water or humid atmospheres can produce softening of the tissue and cause pH shifts. Also, divers are occasionally exposed to water with high bacteria content. Local ear canal trauma can be induced by individuals placing fingers or objects in the ears. The conditions can all contribute to the development of infection and inflammation of the external auditory canal wall tissue or otitis externa (external ear infection).

Bacteria flora found in diver otitis externa is frequently mixed with *Pseudomonas* and *Proteus* predominating with *Staphyloccus aureus* [5]. Symptoms include irritation with itching or burning, discharge, acute inflammation, tissue swelling, and pain. Untreated, progressive serious involvement of tissue and possibly bone and cartilage can occur. If symptoms of infection are evident, medical treatment is required. This includes pain relief, cleansing of the auditory canal, and antibiotics. Pain may be quite severe.

Some physicians recommend routine use of prophylactic topical ear solutions to cleanse and accelerate drying the ear canal following dives as a preventive measure. This is particularly beneficial for those individuals with a common susceptibility to ear infection and those living in warm, humid environments. Farmer considers a topical ear solution containing a buffered weak acid such as 2 per cent acetic acid and aluminum acetate (commercially available as otic Domeboro solution) to be useful [6]. Auro-dri (a preparation of 2.75% boric acid in isopropyl alcohol) is also available in many drug stores.

Some authorities suggest that solutions of high alcohol content will dissolve and remove the longer chain fatty acids in cerumen which are felt to be protective [6]. Thus, they conclude that the use of alcohol in this manner should probably be avoided. Individuals who wish to use an ear rinse solution as a preventive are encouraged to consult with their personal physician.

Otologic Injuries Related to High Noise Levels

High noise levels are not normally associated with scuba diving. However, all divers should be aware of potential risk associated with hyperbaric chamber pressurization and air discharge involved with scuba cylinder filling procedures. Using existing damage-risk criteria, noise levels encountered in some diving helmets (surface-supplied divers) or hyperbaric chamber activities could possibly induce permanent hearing loss.

Furthermore, noise resulting from the discharge of high pressure air from cylinders can be detrimental. Persons subject to conditions involving frequent burst of high pressure are encouraged to use protective attenuation such as earplugs or earmuffs. Persons working in hyperbaric chambers should wear ventilated protection devices.

EQUIPMENT INDUCED BAROTRAUMA

Gas-containing structures attached to the surface of the body are potential sources of local *squeeze*. Failure to equalize pressure during descent under the diver's face mask can result in damage to the skin and particularly to the eyes. The mechanism of damage is similar to that of middle ear or sinus squeeze. The most easily damaged tissues are those covering the eyeball and lining of the eyelids and the spaces around the eyeball. Excessive pressure differential may cause conjunctive and even retrobulbar hemorrhage with tension on the optic nerve and possible loss of vision. Subcutaneous hemorrhage and swelling of the facial tissue under the mask may be evident. The condition is avoided by the diver simply admitting air into his mask through his nose.

The classical form of *divers squeeze* may be encountered in helmet-closed suit (i.e., conventional deep-sea rig) diving when the pressure within the helmet suddenly drops below that of ambient. The condition results either from the loss of pressure within the supply line, with subsequent venting to a lower pressure or by sudden increase in the depth of the diver, as in a fall or diver hose rupture near or at the surface, without compensation by increasing gas supply pressure. The helmet itself constitutes the unequalized rigid space, and the external pressure of the water acts to force the a portion of the diver's body into it. For the same reasons, a similar condition can occur when the diver is using a surface-supplied, full face mask. Serious pulmonary barotrauma can also result from the pressure loss. Because of these possibilities, a non-return valve in the supply line at the helmet or mask is essential in all surface-supplied diving equipment. Proper diving procedures and tending are necessary to prevent falls.

A closed, watertight diving dress (suit) used without appropriate undergarments can also produce body squeeze or barotrauma during descent. The squeeze is usually noted as a pinching sensation in the area of suit folds and ridges, causing welts on the skin. Skin pinching and injury can be minimized by wearing layers of cloth undergarments. The squeeze condition generally produces only temporary discomfort and the skin welts and bruises disappear within a few days.

DENTAL BAROTRAUMA

Tooth discomfort (tooth squeeze) associated with pressure change has been noted by divers and hyperbaric chamber personnel. Gas containing spaces may exist at the roots of infected teeth or beside fillings that have undergone secondary erosion. During descent the diver may experience pain as this space fills with blood or other body fluids in response to the pressure differential between the gas space and surrounding tissue. Expansion of the gas in this space may also be restricted during ascent by the blood in the space, resulting in pain.

Dental barotrauma may occur in a tooth with a cavity and very thin cemetum. If a sufficient pressure differential develops between the cavity space and the ambient atmosphere, the tooth may implode during descent. On the other hand, the pressure may equalize within the cavity if the descent is slow and the cemetum sufficiently thick. However, in this case, rapid ascent could lead to explosion of the tooth because gas escape through the small cavity opening is restricted.

Divers are cautioned regarding exposure to pressure following oral surgery, dental extractions, or manipulations. Gas may pass into the tissues through interruptions of the mucosa and be present as a surgical emphysema.

Dental barotrauma is a relatively rare occurrence. However, divers are encouraged to maintain a good oral hygiene routine with periodic dental evaluations (including x-ray). Avoid diving after dental extractions or surgery until complete tissue resolution has occurred.

Referred pain from paranasal is sometimes difficult to differentiate from symptoms of dental barotrauma. This is particularly noted in the upper bicuspids or the first and second molars. In cases where pain is sporadic or constant but not isolated to a single tooth, paranasal sinus barotrauma is suspect.

SUMMARY

All divers must understand the affects of pressure on the human body. The most common injuries encountered by entry-level divers are related to compression or descent. Middle ear and sinus barotrauma can easily be prevented by developing proper equalization techniques and avoiding pressure exposures when suffering from respiratory infections. Vasoconstriction decongestants may be used as a prophylactic measure. Pressure in the external ear canal must also be equalized during descent. Vigorous and forceful Valsalva maneuvers can cause middle and round window damage and should be avoided. Alternobaric vertigo (dizziness) can occur during both ascent and descent. Reverse blockage (inability to vent gas from ear and sinus spaces) resulting in severe pain and tissue damage can occur during ascent. External ear infections can result from extensive exposure to humid environments and prophylactic measures are recommended in some situations.

Attached air containing spaces such face mask must also be equalized during descent. Failure to equalize pressure in a face mask can result in serious eye damage. Decaying and infected teeth may also contain gas spaces that are subject to barotrauma.

Compression barotrauma is easily avoided through use of proper diving techniques and common sense diving procedures. First aid measures generally involve a hands-off and do no further damage approach. Diving should be discontinued until the condition clears. Injuries must be monitored for continued discomfort and fluid discharge and any indication of infection. In such cases a physician must be consulted immediately.

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Manuscript Completed: 16 December 1989
Manuscript Revised: 26 December 1989
Manuscript Revised: 8 January 1990

NOTES:

CHAPTER 2-3

PHYSIOLOGY OF BREATH-HOLD DIVING

INTRODUCTION

From the beginning of recorded history man has attempted to extend the confines of his terrestrial environment. This is evident in Greek mythology. Records of human diving experiences are noted in Homer's Illiad and Herodotus' writings. Aquatic mammals such as the porpoise have been revered since Aristotle's time. However, Paul Bert in 1870 appears to be among the first to study diving vertebrates [1]. Irving's classical review in 1939 discussed many of the physiological adjustments that account for the extraordinary diving ability of some aquatic mammals [2]. Subsequently, it was recognized that humans, to a limited extent, could adapt to the aquatic environment.

The diving abilities of mammals reflect physiological adaptations and acclimatization. The most profound and generalized changes are observed in the cardiovascular and respiratory systems. Strauss presents an excellent review of these adaptive changes and their underlying physiological mechanisms [3]. Special emphasis is placed on the presence or absence of these adaptations in the human breath-hold diver. Much of the information presented here is summarized from Strauss.

Aquatic mammals exhibit multiple changes or adjustments in their respiratory system during dives. Several of these changes can also be observed in the conditioned human diver. The most notable respiratory changes in all aquatic mammals are: (1) adaptations to resist the effects of thoracic squeeze, (2) changes which reduce or eliminate the possibility of developing decompression sickness, (3) adaptations which make the organism less responsive to the effects of hypoxia and hypercapnia (carbon dioxide buildup), and (4) those changes which improve the efficiency of ventilation during the surface interval and recovery phase following a breath-hold dive.

The cardiovascular changes observed in aquatic mammals are exceptionally remarkable. In contrast to the respiratory adaptations which tend to be instrumental in protecting the mammals from problems associated with pressure, the cardiovascular changes are responsible for improving dive duration. The immersion bradycardia reflex (marked slowing of the heart) is the most well documented of these responses in all aquatic animals including humans. Bradycardia alone cannot account for the long dive durations observed in aquatic mammals.

Bradycardia, in itself, would be detrimental to the organism. There are four major compensating factors which complement the bradycardia response. They are: (1) profound peripheral vasoconstriction and a preferential shunting of blood from the extremities to the great vessels, heart, lungs, and brain; (2)morphological changes in the vascular system; (3) increased ability for the noncritical tissues to function anaerobically and remain isolated until the dive is completed; and (4) increased ability to carry, store, and utilize oxygen.

PULMONARY CHANGES DURING BREATH-HOLD DIVES

Adaptations to Resist Thoracic Barotruama

As a diver descends while holding his breath, the flexible portion of the thorax is compressed and the diaphragm elevated. Consequently, the air within the lungs and airways is compressed and the system assumes a more *expiratory* position. Classical diving physiology literature has stated that no difficulty is experienced until the position of maximal expiration is reached; then the volume of air equals the residual volume of the lungs plus the volume of the airways. Beyond this point, further descent while breath-holding may result in pulmonary congestion, edema, and hemorrhage in the lungs. The diver may experience a sensation of chest compression, breathing difficulties, and possible chest pain.

Further descent may result in collapse of the chest wall [4]. This condition is generally called pulmonary barotrauma of descent or *thoracic squeeze*. Although classical diving textbooks and literature make reference to breath-holding thoracic squeeze, actual clinical documentation appears to be limited.

Rahn, however, suggested that during breath-hold dives to greater depths, blood is forced into the thorax, replacing air and resulting in a significant decrease in residual volume [5]. Impedance plethysmograph measurements of thoracic blood volume displacements during breath-hold dives to depths of 130 fsw confirmed that a significant shift in blood volume into the thorax does take place [6]. Furthermore, Robert Croft, a U.S. Navy diver, and Jacques Mayol successfully dived to depths of 240 fsw and 231 fsw, respectively.

These are considerably greater depths than could be predicted on the basis of total lung volume/residual volume ratios. Mayol's total lung volume and residual volume is 7.22 and 1.88 liters, respectively. Based on total lung volume/residual volume ratios, Mayol's depth threshold would have been 90 fsw. Theoretically, a blood shift of 980 ml into the thorax was necessary, with a corresponding replacement of air and reduction of his residual volume to approximately one-half that measured. Underwater photographs taken during the 240 fsw dive show pronounced caving in of the thorax, compression of the abdomen, and skinfolds flapping around the chest. More recently, Mayol successfully completed a breath-hold dive to 316 fsw [7].

Post-dive breathing patterns may be significant in compensating for intrathoracic blood volume changes. After surfacing, the Ama divers of Japan breathe slowly and whistle during the exhalation phase. The valsalva-like effect of the whistling may partially displace the intrathoracic blood volume and, thereby, counteract the effect immersion has in reducing the total lung volume [5].

Increased lung capacity is also another important factor which increases the theoretical depth to which a breath-hold diver can descend. Schaefer observed increases in total lung volume and a relative decrease in residual volume of the lungs in subjects exposed to repeated breath-hold dives [8].

Adaptations to Prevent Decompression Sickness

Aquatic mammals have made a number of adaptations to eliminate the occurrence of decompression sickness. Most mammals dive after full exhalation and, thus, reduce the available nitrogen for tissue saturation by 80 to 90 percent. This may also facilitate diving bradycardia and peripheral vasoconstriction responses as well as aid in achieving negative buoyancy for descent [3]. The Ama of Japan also dive after inhaling to only about 85% of their total volume [9].

Adaptations to Carbon Dioxide Buildup

Aquatic mammals are less sensitive to low alveolar oxygen concentrations and high carbon dioxide levels than nonaquatic mammals. Analogous adaptations have been observed in trained human breath-hold divers [10]. Schaefer observed that trained and conditioned breath-hold divers had significantly decreased ventilatory response to 10.5% carbon dioxide, better oxygen utilization, acceptance of larger oxygen debt, and increased tolerance to elevated tissue carbon dioxide levels as compared to non-diving humans. These responses disappeared three months after diving was discontinued. This suggests that physical conditioning and repeated breath-hold diving exposures are necessary to develop and maintain these adaptations.

Adaptations Which Improve Recovery Time

Aquatic mammals have respiratory adjustments which improve the efficiency of air exchange and reduce the recovery time following a stressful dive. Human respiratory exchange function is relatively inefficient when compared to other mammals. The seal and porpoise have markedly slower respiration rates, much greater oxygen utilization percentages and larger tidal volumes than humans. As the tidal volume approaches the total lung capacity, ventilation becomes increasingly efficient and compensates for the lower respiratory rate. The respiratory rate in the porpoise and seal is 2 to 4 and 3 to 4 ventilations per minute as compared to the human rate of 15 per minute.

The effects of these characteristics are fourfold [3]. First, the lower respiration rate and large air exchange volume with each cycle reduces the energy expenditure required for ventilation. Second, the elevated oxygen utilization increases the efficiency of each breath and eliminates the need to increase respiration rate. Schaefer reported significant increases in inspiratory reserve volumes, tidal volumes, vital capacities, and total lung capacities in well-trained and experienced human breath-hold divers [8]. These changes signify improved efficiency in respiratory exchange. High and low ventilatory response groups can be defined in humans [11]. The low ventilatory response group is characterized by large tidal volumes, lower respiratory rates and improved tolerance to elevated alveolar carbon dioxide tensions. Third, the fully inflated lung assists in buoyancy during surface swimming and resting, thus reducing energy expenditure. Fourth, improved efficiency in respiration relates to conservation of body heat.

CARDIOVASCULAR CHANGES DURING BREATH-HOLD DIVES

Remarkable cardiovascular changes are observed in aquatic mammals during immersion. The well documented *dive reflex* plays a major role in oxygen conservation and extending dive duration. The dive reflex consists of a reflex bradycardia, peripheral vasoconstriction with preferential shunting of blood from extremities, morphological changes in the vascular system, increased ability for the "noncritical" tissues to function anaerobically, and increased ability to carry, store, and utilize oxygen.

Bradycardia

The immersion bradycardia reflex involves significant reduction in heart rate. In humans the onset is usually gradual and after 30 seconds the rate may slow to 50% of normal [12]. Temperature is important; a 20% greater bradycardia was observed in Ama divers during the winter than in summer [13]. This temperature effect has also been reproduced in the laboratory with facial wetting [14]. Reduction in human heart rate to 8 to 10 beats per minute has been documented [15]. The mechanisms of immersion bradycardia are summarized by Strauss [3]. Among several hypotheses proposed to explain the immersion or diving bradycardia reflex, Andersen suggests that the reflex is initiated by stimulation of the trigeminal nerve [16]. This mechanism is consistent with the rapid initiation of the response, its independence from anoxia and pressure, and the importance of facial immersion.

Peripheral Vasoconstriction and Preferential Shunting of Blood

Bradycardia alone cannot account for the long dive durations observed in aquatic mammals. Strauss summarizes four major compensations which complement the bradycardia response [3]. First, there is a profound peripheral vasoconstriction and preferential shunting of blood from the extremities to the great vessels, heart, lungs, and brain. This permits the oxygen stored in the blood to be used almost exclusively to profuse the heart and brain. The heart's oxygen requirements are reduced. Incisions through muscle and skin of aquatic mammals do not bleed during submergence, however, profuse bleeding does occur immediately after surfacing [17] and limb blood flow in humans falls "nearly to zero" during breath-hold dives [18, 19]

Morphological Changes

Secondly, morphological changes in the aquatic mammals vascular system involves stretching of the highly elastic blood vessel walls and a bulbous enlargement of the aorta [20, 21]. These changes help maintain blood pressure and provide for adequate perfusion of the brain.

Anaerobic Function in Noncritical Tissues

Third, there is an increased ability for noncritical tissues in aquatic mammals to function anaerobically and remain isolated during the immersion. Muscle tissue has the ability to function anaerobically in the absence of oxygen. As the anaerobic metabolic process continues, an oxygen debt is incurred. This debt must be corrected during the recovery period. Metabolism decreases exponentially as the breath-hold dive progresses [22]. Schaefer reports that the lactic acid (substance produced during anaerobic metabolism) content of breath-hold divers' blood increased from an average pre-dive level of 9 mg % to 55 mg % one minute after a dive to 90 fsw was completed [23].

Increased Oxygen Storage Capacity

Fourth, diving mammals have a 50% greater oxygen storage capacity than terrestrial animals of corresponding size [24]. Higher blood volumes, enriched stores of hemoglobin or myoglobin, diminution in the size of the erythrocyle and elevated hematrents, and decreased pH of the arterial blood secondary to lowered buffering capacity all contribute to a greater affinity for oxygen transport, storage and utilization.

Summary of Physiological Changes

In summary, it should be noted that there are three categories of changes [3]. Changes that are universal to the animal kingdom, and occur spontaneously with anoxia, include peripheral vasoconstriction, bradycardra and decreased blood pH. The rapidity of onset, degree of change, and reversibility distinguish aquatic from non-diving mammals. Next, there are a group of adjustments that are highly developed in aquatic mammals, but can be developed in non-diving mammals, especially man, with practice or exposure. These include ability of the blood to transfer and carry more oxygen, increased ventilation efficiency and improved ability to tolerate oxygen debt. Finally, those changes peculiar to the aquatic mammals include capability to collapse the lungs during submergence, increased flexibility and compressibility of the thoracic wall, highly elastic vasculture, decreased size of the erythrocyles, dilation of the aorta, and diving after full exhalation.

It should be emphasized that snorkel breathing while the face is immersed was found to abolish bradycardia [12]. Consequently, this also suggests that the scuba diver should not experience bradycardia.

A diver with atherosclerotic heart disease or abnormalities of the heart's conduction system is at some risk while diving [15]. Even healthy young adults have experienced syncope and died on sudden immersion in cold water. With the strong vasoconstriction and ischemia of extremities and kidneys, divers with peripheral vascular or renal disease may be at increased risk of damage to these organs.

Dircks suggests that all divers should have an electrocardiogram in order to detect possible congenital or acquired heart disease [15]. He also recommends that the diver observe the following precautions to protect himself/herself from *exceptional* and possible adverse effects of the dive reflex [15]:

Avoid rapid cold water entry followed by immediate full breath-hold diving;

Enter the water slowly and splash cold water in the face prior to the dive;

Exercise briefly on the surface before diving;

Wear protective mask or hood over the face in cold water;

Avoid deep breath-holding while scuba diving;

Don't perform a maximum inspiration maneuver before diving into the water;

Avoid diving when experiencing anxiety or fear;

Avoid vertical, head first immersion;

Do not perform the valsalva maneuver while entering the water; and

Avoid excessive hyperventilation and excessive duration breath-holding.

IMPAIRED CONSCIOUSNESS DURING BREATH-HOLD DIVING

Hypoxia and Carbon Dioxide Retention

Prolonged voluntary breath-holding while swimming underwater can result in a loss of consciousness and subsequent drowning. Craig studied cases of near drownings and deaths resulting from loss of consciousness while swimming underwater and found that during such circumstances diving accidents were explainable by loss of consciousness due to hypoxia [25, 26]. Hyperventilation is a common practice among underwater swimmers, i.e., skin divers, sponge and pearl divers, etc.

By hyperventilating, the swimmer can significantly deplete the carbon dioxide (CO_2) stores of the body. The partial pressure of CO_2 (pCO_2) in the nerve tissue regulating respiration appears to be the primary stimulus to respiration, with comparatively little stimulus derived from low oxygen partial pressures (pO_2). While swimming underwater, the diver uses O_2 and produces CO_2; however, since the CO_2 is used for replacement of the subnormal body CO_2 stores, there is insufficient CO_2 stimulus for respiration. When the oxygen consumption is increased, as in the first few seconds of exercise, the pO_2 may decrease to a degree incompatible with cerebral function before the rise in pCO_2 commands the diver to surface for air. Loss of consciousness can result from hypoxia (or anoxia, which has about the same meaning) with little specific warning. The victim may actually continue his activity between the time of loss of consciousness and final collapse.

Controlled experiments to study the mechanism of hypoxia and carbon dioxide retention during breath-holding dives revealed that this condition is further complicated by increased ambient pressure and ascent from depth [27, 28]. During these dives the alveolar oxygen tension (pAO_2) decreased linearly, but remained high enough to reoxygenate the blood quite completely during most of the dive. However, staying on the bottom longer than 90 seconds yielded significantly low pAO_2 and arterial O_2 tension (paO_2). The pAO_2 and the Bohr effect (the greater the $paCO_2$, the lower the hemoglobin O_2 saturation) resulted in a significant fall in O_2 saturation; thus, the blood could not carry as much O_2 from the lungs to the tissue as before. Some divers have been reported to have lost consciousness at the bottom; possibly they have contracted the dangerous combination of a low pAO_2 and a very high $pACO_2$.

Shortly after reaching the bottom, a diver may experience a subjective *breaking point* approach sensation due to increased $paCO_2$ stimulus, plus stimuli elicited from smaller lung volume. This sensation is easily overcome by the willpower of trained breath-hold divers. The expert skin diver can actually "condition" himself to voluntarily or involuntarily ignore the breaking point sensation (or urge to breathe) and over a period of time becomes inured to the subsequent pCO_2 buildup that would drive the average person to the surface for air.

During ascent, a relief of the breaking point sensation is experienced because the lung volume increases and the $pACO_2$ falls, even though oxygen may actually diffuse from the alveoli to the blood at a slower rate due to $pACO_2$ decrease. Since the pAO_2 may fall below the venous pO_2, the possibility for O_2 transfer from the blood to the lungs is present. Blood oxygen stores may be depleted rapidly. If during ascent blood deprived of oxygen arrives at the cerebral cortex, the diver may lose consciousness with little or no warning before or just as he reaches the surface. Unconsciousness during ascent when the diver is below the "buoyancy point" is a potentially fatal condition. Ironically, many competitive skin divers wear lead weight belts, making them negatively buoyant for effortless diving.

Bond condemns wearing excessive weights and competitive breath-holding exercises and contests, even under the auspices of a good organization [29]. Unfortunately, competitive breath-holding contests are a common occurrence in nearly every American swimming pool. Bond cites one such experience involving a 16-year old male in excellent physical condition participating in a contest conducted in a swimming pool. Wearing a face mask and weight belt, the young man settled to the bottom of the pool and remained there for nine minutes in full view of almost 200 spectators. Finally, he was hauled to the surface in a state of unconsciousness and not breathing. His breathing was successfully revived; but subsequent examination and electroencephalograms revealed no cortical activity. In other words, this young man was now doomed to live the rest of his life with major neurological deficits.

Decompression Sickness

Neurological phenomena, including unconsciousness as a result of decompression sickness, may occur from repeated breath-hold dives to great depths [30, 31]. The increase in the pAN_2 is high at about 20 m depth. Although the volume of N_2 absorbed during each dive may be small, the increase in tissue pN_2 (ptN_2) could account for the occurrence of N_2-containing bubbles in the tissue following many repetitive and rapid alterations in ambient pressure. Bond relates a personal experience in which he was a victim of decompression sickness as a result of seven hours and 20 minutes of continuous breath-hold skin diving to depths of 80-100 feet [29]. Fortunately, such cases are rare, probably because most human divers cannot breath-hold dive deep enough nor often enough to contract decompression sickness.

Cross discussed the dreaded disease of Tuamotus pearl divers, *taravana* [32, 33]. These pearl divers are true skin divers; they use no breathing apparatus or air supply for their underwater work. Yet, many of those stricken with taravana exhibit symptoms like those of classic decompression sickness — vertigo, paralysis, unconsciousness, and insanity. These divers may make as many as 6 to 14 dives per hour to depths up to 150 feet and stay submerged an average of one minute and 35 seconds. This schedule is continued daily throughout the pearl diving season. On one exceptionally good diving day (good weather and seas), Cross observed that forty-seven divers were stricken with taravana. Thirty-four of the forty-seven suffered vertigo, nausea, and dizziness, and 11 surfaced paralyzed or unconscious and were rescued. Of the 11, six were partially or completely paralyzed, two were *mentally affected*, and two young men died.

Cross suggests that anoxia is the principal cause of taravana, with its effects on the central nervous system and the brain accounting for the many and varied symptoms. He points out that Mangareva divers space their dives 15 minutes apart, instead of the 4 to 8 minutes used by the Tuamotus divers, and do not suffer from taravana [33].

Certainly anoxia or hypoxia explains many of the symptoms, and it should also be stated that continuous daily and seasonal exposure of brain tissue cells to hypoxia conditions could possibly result in cumulative and irreversible brain damage. However, decompression sickness is also an equally significant explanation, especially when considering the cumulative underwater time and depth [30, 31].

Frequently, loss of consciousness while underwater is referred to as shallow-water or underwater blackout. The U.S. Navy defines shallow-water blackout as an "accident in which a diver loses consciousness, presumably from carbon dioxide excess without an adequate respiratory warning" [34]. Bond considers lowering of oxygen levels of vital organs as a primary cause [29].

For comprehensive physiological studies and reviews of breath-holding, readers are encouraged to consult Strauss [3], Rahn and Yokoyama [35], and Mithoefer [36].

CONCLUSION

Numerous studies support the fact that significant physiological changes occur in the human body during periods of breath-holding and submergence [35-43]. In order to reduce the possibility of adverse effects resulting from these changes, breath-hold skin divers are encouraged to limit pre-dive hyperventilation and submergence time. Studies and experience also show that impaired consciousness without diver awareness is possible during prolonged breath-holding submergence. Team diving procedures are encouraged to enhance the overall safety and enjoyment of breath-hold diving.

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ACKNOWLEDGMENTS

This paper was published by the Michigan Sea Grant College Program as part of the Diver Education Series — Publication No. MICHU-SG-86-503. It is the result of work sponsored by the Michigan Sea Grant College Program with grants from the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and funds from the State of Michigan.

Manuscript published: 1986
Manuscript revised: 21 November 1989
Manuscript reprinted: 15 June 1990

CHAPTER 2-4

RESPIRATION & BREATHING GASES IN DIVING

Most healthy individuals seldom really think about the act of breathing or the gases that they are inhaling. The earth's atmosphere is composed primarily of nitrogen and oxygen. Oxygen is essential to life — without it the human would not survive. People smell smoke and automobile exhaust, but seldom relate to the specific problems of breathing gas contamination.

In everyday recreational and work activities many people experience increased respiratory demand and, on occasion, they become out-of-breath or exhausted — this is overexertion. For most this problem is simply resolved by sitting down to rest and breathing deeply.

However, breathing is not that simple to the diver. Unlike fishes, humans can not extract oxygen from water. Nor can humans make long duration breath-hold dives like most marine mammals. The breath-hold diver is limited to at most a few minutes at the most underwater. Failure to promptly return to the surface for air can result in unconsciousness and subsequent drowning.

To remain underwater, humans must don a breathing apparatus and carry a supply of the atmosphere to depth with them. The air is fed to the diver through a series of valves and tubes which offer some resistance to air flow. As the diver descends deeper into the ocean the air, which must be breathed at ambient pressure, becomes denser. The diver must now work harder to breathe. Increased quantities of carbon dioxide are produced and retained by the body.

As the diver descends deeper and deeper, the gases — nitrogen and oxygen — begin to affect the central nervous system. Soon the nitrogen becomes intoxicating and at greater depths the oxygen — so essential to sustaining life — becomes toxic.

The diver's scuba cylinder must be filled with compressed air. In this filling process pure air is drawn from the surrounding atmosphere and compressed into the scuba cylinder via a high-pressure compressor. If the surrounding atmosphere is contaminated, the contaminants are drawn into the scuba cylinder. If the compressor is faulty or operated incorrectly, oil mist or carbon monoxide may be introduced into the air supply during compression. Carbon monoxide can cause unconsciousness without warning to the diver.

As one can see, divers do not simply breathe in a normal sense. Although breathing air from scuba underwater has become commonplace in sporting America, it is much more complicated than gasping for air on a tennis court. Many tennis players have become intoxicated, but not from breathing nitrogen; I am certain that one has never convulsed from breathing too much oxygen.

In the following discussion, I will review the fundamental concepts of breathing, introduce underwater breathing, and review the various gases that influence the divers well-being. Keep in mind that this is only a superficial coverage of the subject and readers are referred to the *The Underwater Handbook*, *U.S. Navy Diving Manual* and *Underwater Medicine* for additional information [6, 12, 14].

FUNDAMENTAL OF RESPIRATION

Respiration is generally thought of only in terms of *breathing*. However, the process of respiration also includes the utilization of oxygen and various exchanges of gases which take place throughout the body as a part of the metabolic process. Gas exchange associated with breathing is sometimes considered as *external* respiration whereas other aspects are identified as *internal* respiration.

Ventilation of the lungs is achieved by changing pressure within the pleural space. Inspiration is achieved by muscular movements which elevate the ribs and depress the diaphragm. This lowers the pressure in the pleural space and air at a higher ambient pressure flows into the lungs in response to the pressure gradient until equilibrium is reached. The air flows from the mouth and nose to the lungs through the trachea which divides into a network of tubular passages called bronchi. The bronchi divide into smaller broncheoles which carry air to the numerous tiny air sacs, or alveoli, where gas exchange between the lungs and the pulmonary capillaries takes place. Expiration is achieved by simply stopping inspiration. As the muscles relax, the elastic recoil of the lungs forces the air out.

Part of the pressure generated by the respiratory muscles is used to overcome flow resistance in the airways. Flow resistance is related to flow rate and the pressure gradient between one end of the tube and the other. During periods of relatively normal breathing, the pressure generated by the respiratory muscles is used primarily to overcome the elastic recoil of the lung. However, during active ventilation, as in exercise, flow resistance becomes a much more significant factor and necessitates that expiration be achieved by contraction of expiratory muscles. Maximum ventilation is limited by flow resistances, specifically during expiration.

When breathing at one atmosphere, normal humans, even at maximal exercise, utilize only 50 to 60 percent of the maximum voluntary ventilation. Maximum ventilation is a function of flow resistance which, in turn, is dependent on gas density. In humans, flow in large airways is generally considered as turbulent and is inversely proportional to the square root of gas density.

When the gas density is increased fourfold (as at 100 fsw or 4 ata), turbulence and resistance within the airways reduces the flow to approximately one-half normal. However, at a depth of 100 fsw exercising subjects regularly approach 100 percent of their maximum voluntary ventilation as compared to 50 to 60 percent at sea level. Consequently, at 100 fsw there should be virtually no ventilation-imposed exercise limitation in the air breathing diver [1].

All underwater breathing apparatus has discernible resistance to gas flow and breathing. Some scuba constitute a formidable workload on the respiratory system. Although modern diving apparatus does have considerably better flow properties than many earlier models, some modern open-circuit scuba regulators have unsatisfactory flow properties at depths in excess of 100 fsw during periods of maximum ventilatory requirements.

The ventilatory control system responds to arterial oxygen and carbon dioxide tension. The principal sensing site or respiratory center, in the area of the medulla oblongata of the brain, is sensitive to the level of carbon dioxide and acids in the blood. This center controls rate and volume of ventilation. Peripheral chemoreceptors, located chiefly in the carotid bodies, monitor the level of oxygen and carbon dioxide in the blood leaving the lungs. These sensors respond primarily to hypoxia (depressed oxygen tension). Hypercapnia (elevated carbon dioxide tension) is a powerful stimulus to respiration. Hypoxia is a relatively minor stimulus, and the arterial oxygen tension may become critically low before the chemoreceptors send impulses to the respiratory center. Increased airway resistance, internal and external, depresses the ventilatory response to hypercapnia and, to a lesser degree, hypoxia.

Respiratory sensitivity is reduced by a number of conditions encountered by divers at elevated ambient pressure. Of particular significance is low breathing rates, higher oxygen partial pressure, and increased gas density. Experienced divers appear to have reduced ventilatory responses to both carbon dioxide and exercise. Although carbon dioxide retention does tend to conserve air and limit ventilatory effort, the dangerous implications of carbon dioxide poisoning are significant.

ALTERED RESPIRATORY PATTERNS

Normally, experienced divers tend to ventilate less during exercise than nondivers. Scuba divers normally take long, slow inhalations followed by a long, slow exhalation, particularly during periods of low exercise. Underwater a diver may breathe at a rate of 6 to 10 cycles per minute compared to 10 to 20 cycles per minute on the surface. Breathing pattern modifications resulting from voluntary prolonged inspiratory breath-holds, anxiety, physical stress and equipment insufficiency can have adverse effects on the diver.

Controlled Breathing

Alteration of breathing pattern and reduction in breathing rate is some what normal for experienced divers at low exertion levels. It has become quite fashionable to breath lightly and conserve air. Many instructors and guides encourage air conservation techniques. In addition, deep divers use air conservation breathing techniques to increase dive time at depth on a limited air supply.

Some divers use a technique called *skip-breathing*. The diver draws a full breath and simply holds that breath for 20 to 30 seconds or more, exhales, draws another breath, and repeats the process. This pattern of breathing can lead to significant carbon dioxide retention. *If the process is carried to extremes, the diver can lose consciousness without prior respiratory warning from carbon dioxide poisoning.* The term shallow water blackout has also been used to identify this condition. Needless to say, skip-breathing is discouraged.

Unfortunately, there is a fine line between acceptable air conservation techniques and skip-breathing. I certainly endorse techniques for efficient use of air supply, however, I discourage competitiveness and peer pressure techniques used to promote air supply conservation. Beginning divers will generally consume more air than experienced divers. Women will generally consume less air than men. Some individuals are more physiologically efficient and others will tolerate a slightly higher level of carbon dioxide without adversity.

Beginning divers are simply encouraged to relax underwater. As the diver becomes more relaxed and gains confidence and proficiency, breathing patterns will adjust. The diver should simply concentrate on relaxation with a long, slow inhalation-exhalation pattern. Do not breathe too deeply.

Hyperventilation Syndrome

Hyperventilation initiated by anxiety and/or physical stress may result in unconsciousness or muscle spasms as possible consequences of excessive depletion of carbon dioxide with subsequent acid-base imbalance in the blood and body. The diver may not be aware of his pending problem. In water this can result in drowning. Some individuals are more susceptible to low CO_2 tension (hypocapnia) than others; however, loss of consciousness and muscle spasms could probably be induced in almost anyone with sufficiently prolonged hyperventilation.

Both scuba and surface-supplied divers should be aware of the problems associated with hyperventilation. If the diver notices that he is involuntarily hyperventilating, he should take immediate steps to slow his breathing rate. A scuba diver should notify his buddy, and if the situation cannot be corrected, promptly ascend. When he reaches the surface, he should inflate his buoyancy system. Don't attempt to swim to the boat or shore unaided since unconsciousness may be imminent. A tender should continuously monitor the diver's breathing for signs of hyperventilation. If the diver starts to hyperventilate, he should be asked to stop work and rest. Holding his breath for short periods will aid in replenishing low CO_2 levels and possibly avert further complications. Drowning and the hyperventilation syndrome are discussed in detail by Prasser [11].

Hyperpnea-Exhaustion Syndrome

Various problems in diving such as equipment malfunction, reaction to venomous animal wounds, cold stress, exhausting swims, etc, may cause a diver to panic. A frequent manifestation of panic is *rapid, shallow breathing* (hyperpnea), resulting in insufficient ventilation of the lungs. Subsequently, there is an accumulation of carbon dioxide in the lungs, blood, and body tissues (hypercapnia).

The diver's situation is further complicated by possible decrease in buoyancy due to inadequate inflation of the lungs. The onset of the hyperpnea-exhaustion syndrome is indicated by rapid, shallow breathing; dilation of the pupils; inefficient swimming movements; and signs of exhaustion. The diver will experience anxiety and exhaustion. Collapse from exhaustion, unconsciousness, and subsequent drowning may follow. Divers exhibiting the signs or symptoms of this manifestation should immediately terminate the dive, surface, and inflate buoyancy system. Tenders and diving partners should watch for signs of distress. This condition may be responsible for some near-drownings and drownings in scuba divers who were swimming on the surface when they apparently lost consciousness.

Overexertion and Exhaustion

Nearly everyone has experienced the "out-of-breath" feeling, from working too hard or running too fast. It is possible for a person to exceed his normal working capacity by a considerable margin before the respiratory response to overexertion is apparent. The end result is generally shortness of breath and fatigue. On land, this presents little problem.

Underwater (under increased ambient pressure), the problems of exertion are modified by several factors and are considerably more serious. Even the finest breathing apparatus offers some resistance to the flow of air. As the depth increases, so does the density of air, and consequently, it moves through the body's airways with greater resistance to flow. When shortness of breath and fatigue are brought on by overexertion, the diver may not be able to get enough air. The feeling of impending suffocation is far from pleasant, and it may lead the inexperienced diver to panic and a serious accident may occur.

Man's ability to do hard work underwater has definite limitations, even under the best of conditions. Many situations can lead to exceeding these limits. They include:

working against strong currents;
prolonged heavy exertion;
wasted effort;
breathing resistance, especially with poorly designed and maintained breathing apparatus;
carbon dioxide buildup;
insufficient breathing medium, contamination; and
excessive cold or inadequate protection.

The diver will realize that he has overextended himself by recognizing such indicators as labored breathing, anxiety, and the tendency toward panic that accompanies the overexertion feeling.

If the diver feels the typical "air hunger" and labored breathing starting to appear, he should do the following:

* Stop, rest, and ventilate to get a maximum flow of air.
* Breathe deeply. Ventilate helmet or mask with free flow.
* Inform the buddy or tender.
* Do not surface rapidly — terminate the dive with a slow, controlled ascent.
* Upon reaching the surface, the diver should inflate the buoyancy compensator and return to the boat or shore, or if too exhausted, ask for buddy assistance or signal for an immediate "pickup."

The "buddy" and surface crew should

* render all possible assistance;
* watch for signs of panic that might lead to a serious
* underwater accident;
* help diver aboard; and
* provide rest, warmth, and nourishment.

Overexertion can be prevented if the individual knows and observes his limitations, takes into consideration the working conditions, and plans the diving operation accordingly. For example, plan the dive so that you can move with the current and not against it. Divers should keep themselves in excellent physical condition. The equipment must always be maintained and in excellent working condition. Be alert for signs of fatigue!

INERT GAS NARCOSIS

Among the major factors likely to cause performance impairment in divers at increased ambient pressures is inert gas narcosis. Although the most common inert gas (nitrogen) associated with diving is physiologically inert under normal conditions, it has distinct anesthetic properties when the partial pressure is sufficiently high. The problem of compressed air *intoxication* has long been recognized by divers and researchers. Early researchers inference was based on the hypothesis that narcotic potency is related to the affinity of an anesthetic for lipid or fat or the Meyer-Overton hypothesis.

In fact, the narcotic potency of inert gases may be related to many physical constants including molecular weight, absorption coefficients, thermodynamic activity, Van der Waal's constant and the formation of clathrates. Lipid solubility appears to give the best correlation, although polarization and molar volume are also important to the mechanism of narcosis, which involves interaction of the molecule with neuronal membrane. Consequently, the molecule size and the degree of electrical charge upon it are important considerations [4].

Many theories of compressed air intoxication were advanced by various early investigators. Damant attributed part of the intoxicating effects to the increased oxygen pressure [7]. Bean, a University of Michigan physiologist, expressed doubt that nitrogen was the responsible agent, and contented that the sole causative factor is a rise in body CO_2 tension brought about by raised gas density [2]. Manifestations of anxiety and claustrophobia, a combination of all of the aforementioned factors, or the pressure itself have also been suggested as causes [13]. However, encephalographic studies by Bennett and Glass leave little doubt that high nitrogen pressure constitutes an important causative factor of compressed air narcosis [5]. Associated causes may include the density and oxygen partial pressure of the respired mixture, which, in turn, may cause an increased carbon dioxide tension that synergistically potentiates the narcosis [3].

Nitrogen-carbon dioxide synergism is seldom addressed in the discussion of nitrogen narcosis, however, in recreational diving it may be an important factor. Synergism involves the combined action of two separate agents having a greater total effect than the sum of their individual effects if used separately. Recreational scuba divers encounter several factors that may influence carbon dioxide retention. First, some divers are less than physically fit. Poorly conditioned individuals produce and retain more carbon dioxide than highly condition individuals. Recreational scuba divers carry a limited amount of air and thus practice controlled breathing techniques. Improper breathing can result in carbon dioxide retention. The density of air increases significantly with depth. Normal breathing resistance afforded by the scuba as well as potentially less than adequate pulmonary ventilation caused by higher density air can lead to increased carbon dioxide retention. Finally, increased oxygen partial pressure also apparently enhances carbon dioxide retention.

Nitrogen narcosis, or compressed air intoxication, characterized by symptoms similar to alcohol intoxication, first becomes evident at a depth of about 100 ft. Beyond this depth, most compressed air divers show some impairment of thought, judgment, and the ability to perform tasks that require mental or motor skill. Such impairment, even if mild, obviously constitutes a potential hazard to the diver's safety. Bennett states that at depths greater than 180 fsw, no trust should be placed in human performance or efficiency when breathing compressed air [4]. Most divers lose their effectiveness at about 200 fsw, and about 250 fsw, the average diver is, for all practical purposes, useless or at least a menace to himself.

Test subjects made errors in recording arithmetic data. Studies have shown that subjects tested under pressure (the influence of nitrogen narcosis) make more errors in recording arithmetic data and that there may be a change in their sense of time [13]. Apparently, intellectual capacities are affected more severely than psychomotor or manual abilities. The ability to carry out fine movements is also impaired. The implications for divers is obvious.

Like alcohol, the effects of nitrogen vary with the individual person, and by conscious effort, the hazards can be minimized within certain limits. Miles tabulates the sequence of events for the average man under the influence of high-pressure nitrogen in a breathing medium of air as follows [10]:

100-150 fsw: Light head, increasing self-confidence, loss of fine discrimination, and some euphoria.

150-200 fsw: Joviality and garrulousness, perhaps some dizziness.

200-300 fsw: Laughter may be uncontrolled and approach hysteria (in a hyperbaric chamber setting). Power of communication lessened, and mistakes made in simple motor and mental tasks. May be peripheral numbness and tingling. Less attention paid to personal safety. Delayed response to signals and stimuli.

300 fsw: Depression and loss of clear thinking. Impaired neuromuscular coordination.

350 fsw: May approach unconsciousness with the additional danger of oxygen poisoning.

Several predisposing factors may advance the onset of symptoms and ameliorating factors may help to increase the tolerance to nitrogen narcosis. Alcohol, marijuana, and social drugs taken prior to diving greatly enhances the nitrogen effect. Alcohol and nitrogen become almost additive. Rapid compression will also facilitate the onset of narcosis. Hard work and fatigue will increase susceptibility, as will any circumstance causing retention of carbon dioxide.

High partial pressure of oxygen also appears to elevate susceptibility. At depths greater than 200 fsw, the neurotoxic effect of oxygen may well be the predominate factor. In the inexperienced diver, anxiety and apprehension are likely to advance the onset of symptoms. However, experience, strong will, and frequent deep diving all help to increase the tolerance to high-nitrogen tensions.

Acclimatization may also play a role in nitrogen tolerance [13]. Studies have shown that the mean additional time to solve mathematical problems at elevated pressures is reduced by 5 to 10 percent in acclimatized divers compared to non-acclimatized divers. Acclimaization is accomplished by frequent and progressive exposures to higher pressures. Unfortunately, the acclimatization effect probably diminishes in about a week.

The principles of prevention of adverse consequences of nitrogen narcosis lie in common sense and proper diving procedures. Compressed air divers must observe definite depth limitations. The U.S. Navy considers 60 fsw as a normal working limit for open circuit scuba and 190 fsw as an absolute limit. The US Navy also discourages exceeding no-decompression limits when using compressed air scuba. Surface-supplied air diving is limited to maximum depths of 190 fsw with a demand mask and 285 fsw using deep-sea diving equipment. A medical officer and on-site hyperbaric chamber is required for depths beyond 190 feet. In reality, helium-oxygen breathing mixtures are generally used beyond a depth of 180 fsw in commercial and military diving.

Scientific divers working under guidelines of the American Society of Underwater Sciences normally limit compressed air scuba dives to 130 fsw and recognize 190 fsw as an absolute limit for specially trained divers. All deep dives are subject to approval of a Diving Control Board. In reality, most scientific scuba dives are in a depth range of 30 to 60 fsw. Of 30,638 accurately documented scientific dives in 1987 and 1988, only 1.6 percent were in the depth range of 100 to 130 fsw and 0.115 percent exceeded a depth of 130 fsw.

Recreational diving instructional agencies recognize 130 fsw as the maximum depth of scuba diving and some recommend a limit of 100 fsw. *In recreational and scientific compressed air scuba diving any dive beyond a depth of 60 fsw should, in my opinion, be addressed as a deep dive.*

In reality, recreational scuba divers, especially shipwreck and cave divers, often exceed these limits. 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.

Unfortunately, deep air diving has again become fashionable in recreational diving. Published and unpublished accounts of recreational dives, using compressed air scuba, to depths of 200-300 fsw are not uncommon. Many recreational divers, including prominent certification agency instructor trainers, openly exceed the limits specified for recreational scuba diving. Unfortunately, they also get hurt.

In 1967 Hal Watts (personal communication) made a record compressed air scuba dive to 390 fsw and in 1968 one of his associates reached 437 feet. More recently, a diver has allegedly completed a series of air dives to 450 feet. In Lake Superior 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 of the others while diving on other deep shipwrecks. The trained diver need not be reminded that even 200 fsw is beyond the depth limit deemed reasonable and proper by the Navy for compressed air scuba. Not only is the diver subjected to extremely high pN_2 and subsequent nitrogen narcosis but also oxygen toxicity and decompression sickness. At least one case of compressed air oxygen toxicity has been documented at a depth of about 220 feet (D. Rutkowski, personal communication). The popular appeal and machismo associated with such stunts tends to lure unsuspecting novice divers to depths beyond the capacity of their equipment, knowledge, skill, and physiology.

The treatment of gas narcosis is no problem. Simply reduce pressure (ascend), and recovery is complete, except in severe cases where temporary amnesia is possible. In all cases tiredness due to pressure exist [10].

DEPTH BLACKOUT

Cave diving researchers have documents cases of depth blackout [9]. The victim simply appears to fall asleep with their eyes open and does not move except for breathing. For unknown reasons the sleeping victim apparently retains the scuba mouthpiece and continues to breath, lying inert on the bottom, until their air supply is exhausted. Cases of 15 survivors (rescued by other divers) were analyzed. In all cases the incident of blackout occurred on the individuals deepest dive to that time and the shallowest occurrence involved heavy exertion prior to blackout. Victims do not recall any symptoms prior to blackout. Authorities suspect that this condition results from a cumulative and combined effect of nitrogen, oxygen, and carbon dioxide.

OXYGEN TOXICITY

The toxic effects of excess oxygen breathing are of considerable importance in diving and hyperbaric treatment of diving accidents. The administration of 100% oxygen to humans continuously for long periods (generally exceeding 24 hours) at normal atmospheric pressure causes pulmonary manifestations. Under pressures slightly above 1.0 atmosphere for a sufficiently long time or at sufficiently high pressures (2.5 ata), humans develop central nervous system oxygen toxicity which can eventually lead to grand mal seizures.

Oxygen toxicity is a function of pressure and duration. The safe period of oxygen inhalation is further reduced by immersion, exercise, and carbon dioxide inhalation. High pressure oxygen poisoning affecting the brain and causing convulsions can definitely occur at pO_2 of 2.0 ata and sometimes even lower. Central nervous system oxygen toxicity has been identified as the causative factor in an incident in which a diver convulsed at a depth of about 225 feet (breathing compressed air). This has lead some individuals to suggest that the limit for compressed air dives of any type should be less than 218 feet (1.6 ata pO_2). Some physiologists consider oxygen toxicity to be a greater threat to compressed air divers at depths exceeding 200 feet than nitrogen narcosis.

Oxygen tolerance varies with individual divers and may also vary from day to day. Exercise while breathing oxygen increases susceptibility to oxygen toxicity. The Navy administers an oxygen tolerance test which requires breathing pure oxygen for 30 min. at 60 ft in a dry chamber. The US Navy recommends a 25-ft (1.6 ata) depth limit for a duration not exceeding 75 minutes. Current trends are toward even lower exposure limits with a pO_2 of 1.4 ata. Scientific divers breathing mixtures of nitrogen and oxygen currently use a 1.6 ata/30 minute limit.

Warning symptoms of oxygen toxicity, in order, are: muscular twitching, nausea, abnormalities of vision and hearing, difficulty in breathing, anxiety and confusion, unusual fatigue, lack of coordination, and convulsions. Oxygen poisoning is reversible and the convulsions are not dangerous in themselves but may result in physical injury, air embolism (uncontrolled ascent), and drowning (particularly with scuba). The convulsions are usually self-terminating with no apparent lasting effects.

In routine compressed air scuba diving the diver need never be concerned with oxygen *toxicity*. However, divers using gas mixtures other than air, using compressed air at depths of 200 feet or more, or using pure oxygen closed circuit scuba are at risk of oxygen toxicity.

BREATHING GAS CONTAMINATION

Atmospheric air compressed into scuba cylinders or pumped directly to the diver may or may not be of satisfactory purity. The initial atmospheric air may be contaminated or contamination may occur during the compression process. The quality of air that the diver breathes should not exceed the following [14]:

Oxygen: 20 to 22% by volume
Carbon Dioxide: 1000 ppm
Carbon Monoxide: 20 ppm
Total Hydrocarbons: 25 ppm
Oil vapor or mist: 5 mg/m^3
Solid and liquid particles: None

Although state and federal agencies have established air purity standards for commercial divers, there are no specific standards or regulations that control air quality for recreational scuba diver suppliers. To my knowledge only one state has laws pertaining to the testing and sale of compressed air for scuba divers.

Fortunately, most suppliers of compressed air for scuba divers are very conscientious. Furthermore, advancement in compressed air technology and purification equipment insure that most commercial air supplies will be of high quality. However, most scuba diving suppliers do not routinely submit air sample for laboratory analysis. Those who do generally proudly display the record of analysis.

Generally, the greatest risk of air supply contamination is associated with portable air compressors used in remote area diving operations. Care and maintenance of these compressors is often substandard and operator may be careless.

Carbon Dioxide Excess

Carbon dioxide (CO_2) is a natural by-product of oxidation and metabolism. The CO_2 tension in the human body increases with the rate of production due to physical exertion and inadequate ventilation of the lungs. Under normal conditions CO_2 is the primary respiratory stimulant to the respiratory center in the medulla. Normal concentrations of CO_2 in atmospheric air are 0.04% and a pCO_2 of 40 mm Hg is the normal alveolar tension. Breathing a medium containing 2% CO_2 slightly increases the respiratory rate. The effects of CO_2 are dependent upon the pCO_2. In accordance with Dalton's law of partial pressures, a 2% CO_2 mixture at the surface (1 atm) will at 132 ft (5 atm) have essentially the same effects as a 10% mixture would at the surface.

The effects of increased pCO_2 on body functions are extensive and variable. Adequate respiratory ventilation is of considerable importance when considering the design of all diving apparatus, hyperbaric chambers, underwater habitats, submersibles, etc. The following discussion will only include those aspects of carbon dioxide excess relative to operational diving. Historically, there has been a wide tendency to use carbon dioxide as an underlying cause of many of the accidents and illnesses encountered in diving. It has been blamed for nitrogen narcosis, oxygen poisoning, shallow-water blackout, and as contributory to decompression sickness. Accidents with no obvious cause were frequently attributed to carbon dioxide excess.

As a diver without breathing apparatus descends, the alveolar pressure of carbon dioxide does not rise appreciably because of absorption of carbon dioxide by the circulating blood to maintain a pCO_2 of about 40 mm Hg. During a breath-hold dive the rise in alveolar CO_2 is due to the accumulation of gas from metabolic processes. For all intents and purposes, carbon dioxide excess can be considered secondary to anoxia in loss of consciousness while breath-hold diving. Voluntary lowering of the normal pCO_2 by hyperventilation prior to the dive retards the respiratory response and enhances the development of hypoxia.

In diving with breathing apparatus, excessive accumulation may result when the carbon dioxide absorbent unit is inefficient or exhausted in closed and semi-closed circuit scuba and mixed-gas helmet rigs or when there is an inadequate gas supply to sufficiently ventilate the helmet, mask, or chamber. The resulting accumulation and subsequent inhalation of carbon dioxide (5% concentration) produces respiratory stimulation (i.e., panting, breathlessness, distress, etc.), cerebral dilation, and headache. As the concentrations increase, the diver may become confused, irrational, and drowsy, and if the concentration rises above 10%, the diver will generally lose consciousness.

Scientific divers may have opportunities to use the advanced equipment mentioned above and must be properly and completely trained. *However, this equipment is seldom encountered by the recreational scuba diver and, thus, presents no concern at this time.*

The 1000 ppm carbon dioxide level also appears to be a conservative figure for compressed air standards. Researchers have note no adverse effects at a 30,000 ppm (sea level equivalent) carbon dioxide level and state that chronic carbon dioxide toxicity is not a serious problem in conventional air diving [16]. The 1000 ppm maximum value for carbon dioxide appears to be readily attainable and acceptable within the diving community.

Conditions which enhance the retention of CO_2 in the body include unusual exertion, inadequate ventilation, high oxygen tensions, increased density of breathing medium, and inadequate gas supply to ventilate the breathing system and remove carbon dioxide; this is extremely important under conditions of heavy exertion. Increased alveolar oxygen pressure affects the carbon dioxide response. Increased breathing resistance, whether due to apparatus design or gas density, favors CO_2 retention and therefore decreases sensitivity to CO_2. Increased breathing resistance causes pCO_2 and exertion levels to rise in parallel, whereas ventilation response remains constant, or even decreases.

If divers do not ventilate their lungs sufficiently to eliminate as much CO_2 as is produced, self-poisoning can occur. A number of accidents in which the diver has lost consciousness for no apparent reason have been explained on this basis. Deliberate reduction in breathing rate to conserve air in the use of open-circuit scuba is an extremely dangerous practice. Most authorities consider it better to breathe normally and consume more air than to practice periods of breath-holding between inspirations and risk the lethal consequences of CO_2 buildup.

Carbon Monoxide

Carbon monoxide (CO) is probably the most serious breathing media contaminant. Carbon monoxide readily combines with the blood hemoglobin, forming COHb, and renders the hemoglobin incapable of transporting sufficient oxygen. Hemoglobin, in fact, combines with CO about 200 times as readily as with oxygen. The diffusion capacity for CO also increases progressively with increasing exercise. When this occurs, tissue anoxia develops even though the supply of oxygen to the lungs is ample. At sea level the toxic effects of CO is proportional to the amount of COHb formed. However, at depth, a diver may tolerate a considerably higher ratio of COHb because some of the oxygen transport requirements are met by the oxygen in solution (due to increased pO_2 at depth). Since the reconversion of COHb to oxyhemoglobin is relatively slow compared to the time required for COHb to form, the diver may develop symptoms of CO poisoning immediately on ascent.

Consequently, contamination of scuba air with even small amounts of carbon monoxide can be very dangerous. At present, U.S. Navy specifications and purity standards for high-pressure, compressed, diver's breathing air allow for a maximum of 20 ppm carbon monoxide [14]. Earlier standard specified only 10 ppm.

Maximum allowable carbon monoxide has been debated for some years. In 1976, Erickson suggested that a standard requiring 10 ppm carbon monoxide as the upper limit is not medically justified for air diving; the 20 ppm limit is more than medically adequate [8]. He emphasizes that the affinity of carbon monoxide for hemoglobin (Hb) remains constant with depth within the entire range of air diving. The percent carboxyhemoglobin (COHb) does not increase with depth. The toxicity of 20 ppm carbon monoxide in air at 70 msw is no greater than at the surface. A carbon monoxide level of 30 ppm in air results in a measured equilibrium value of about 5% COHb. This value is, according to Erickson, medically acceptable. A 3.3% (approximate) COHb equilibrium value corresponds to a 20 ppm carbon monoxide level in air; 10 ppm carbon monoxide has a corresponding value of about 1.7% COHb. As a matter of perspective, 17 U.S. cities have recorded carbon monoxide levels greater than 10 ppm over 50% of the time during a one-year period. Also, the average light cigarette smoker will have a COHb level of about 3.8% and the extremely heavy smoker may have 19% COHb [15].

The wide spectrum of symptoms associated with carbon monoxide poisoning include headache, dizziness, nausea, weakness, confusion, and other mental changes. The tender or diving partner may note failure to respond, clumsiness, and bad judgment. Frequently no symptoms are evident; the diver may lose consciousness without warning and breathing may cease. In general, the symptoms parallel those of other forms of anoxia, with one exception – the victim's coloration is red instead of blue. In spite of the displacement of oxygen, hemoglobin combined with CO has a bright red color. Consequently, a victim who becomes anoxic because of carbon monoxide poisoning often exhibits an unnatural redness of lips, nail beds, and sometimes the skin.

When carbon monoxide poisoning is indicated, get the victim into fresh air (or non-contaminated area) as soon as possible. If breathing has stopped, start artificial respiration at once. Even if a non-breathing victim is revived, monitor closely since respiratory arrest may soon reoccur. The victim should be given oxygen as soon as possible; administration of oxygen increases the amount of oxygen reaching the tissue in spite of the inactivity of the hemoglobin and it also accelerates the elimination of CO from the blood. A carbon monoxide victim must be treated under medical supervision. Low level carbon monoxide poisoning has been successfully treated by oxygen breathing at atmospheric pressure. However, the best treatment of carbon monoxide poisoning victims is administering oxygen at 2 to 3 ata pressure in a hyperbaric chamber. Records of rapid and complete recovery are establishing hyperbaric oxygen as a standard method of treatment.

Contamination with carbon monoxide can arise from two primary sources:

1. The gas may be present in the intake air from having the compressor intake located too close to or downwind from the exhaust of a gasoline-driven engine or other source of exhaust gas. In large cities and industrial areas, CO is a common atmospheric pollutant and may rise, at times, beyond the safe concentration for divers' air. Consequently, the air supplier must be constantly aware of atmospheric pollution levels and/or take measure to remove excessive CO during the air compression process.

2. Oil-lubricated compressors, particularly when not operated or maintained properly, can develop high cylinder temperatures that cause partial combustion (oil flashing - or dieseling) of the lubrication oil. All breathing air compressors must be maintained in accordance with manufacturers' specifications.

Both of the above conditions can cause air contamination when cylinders are filled using an electrically-powered compressor.

Oil-Vapor Contamination

At one time oil vapor, from oil-lubricated compressors, was probably the most common contaminant of scuba air supply. Fortunately, this is no longer the case — oil contamination appears to be quite rare. Fortunately oil contamination is fairly easy to detect. Oil fumes give an unpleasant taste and odor to the breathing mixture, and under pressure the concentration may be sufficient to cause pulmonary irritation, cough, and in extreme cases, pneumonia. Do not use contaminated air. Avoidance of excessive oil vapor in compressed air requires careful and regular compressor maintenance , water and oil vapor condensers, and an effective filtering system.

If you detect an oily odor or taste, discontinue the use of the air supply immediately. Not only must you be concerned about lung damage, there is also a possibility of other contaminant such as carbon monoxide.

For additional information on air supply contamination and subsequent medical conditions the reader is referred to the *U.S. Navy Diving Manual* and *Diving Medicine* [6, 14].

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ACKNOWLEDGMENTS

Portion of this paper were previously published in a booklet titled *Respiration and the Diver* by Somers as part of the Michigan Sea Grant College Program's Diver Education Series. The author is indebted to Cyril Grum, MD, for his review of *Respiration and the Diver* and his many helpful comments.

Manuscript completed: 1 October 1989
Manuscript revised: 27 December 1989
Manuscript revised: 9 January 1990
Manuscript revised: 15 June 1990

NOTES:

CHAPTER 2-5

DECOMPRESSION PHYSIOLOGY

INTRODUCTION

During descent a diver is subject to barotrauma in gas filled spaces if the pressure within the spaces is not maintained equal to the increasing ambient pressure. Failure to equalize pressure in ears, sinuses, and attached gas spaces leads to compression injuries.

The same is true during ascent. Pressure within gas filled spaces must remain in equilibrium with ambient pressure. If a pressure gradient develops, serious injury can result. Gas contained in the middle ears, sinuses, gastrointestinal system, and lungs must be vented. The most serious ascent related injury is pulmonary barotrauma. Pulmonary overinflation can result in gas entering the circulatory system and bubbles lodging in the brain — an air embolism. These are the direct effects of pressure change.

As soon as you submerge or breathe gas at higher pressure your body begins to absorb or take up more of the inert component of the gas mixture. Since, for all practical purposes, inert gas is neither used or produced by the body, this gas will continue to be absorbed until equilibrium is achieved (saturation) or the ambient pressure is reduce. Upon reducing ambient pressure the process is reversed and the gas is eliminated (desaturation). Normally, the gas diffuses from the tissues to the blood, from the blood to the lungs, and then from the body in expired breath. However, if pressure is reduced too rapidly, the gas contained in solution in body fluid and tissues may come out of solution (form bubbles) within the tissues and blood. This leads to the development of decompression sickness.

The discussion of decompression physiology presented in this manual is minimal and simplified. Readers are referred to the *US Navy Diving Manual* and *Diving Medicine* for a more comprehensive discussion of the subject [4, 14].

PULMONARY BAROTRAUMA

In a diminishing pressure situation, e.g., a diver ascending from depth, the air in the lungs is expanded because of the decreasing external pressures. If the normal exhalation route of the expanding gas is interrupted either voluntarily, as in breath-holding, or involuntarily, from local respiratory tract obstruction, the intrapulmonary pressure progressively distends alveoli and ruptures of alveoli ensue. A pressure differential of about 100 mm Hg (2 psi or 4 fsw equivalent) may be sufficient to rupture alveoli tissue. *This means that a scuba diver can experience a life-threatening pulmonary barotrauma in a swimming pool!* Localized partial or complete bronchial obstructions include ball-valving bronchial lesions, mucus, bronchospasms, etc. Bronchial mucus and irritants, particularly tobacco, are prime offenders.

From the point of rupture the gas may dissect along bronchi and enter the mediastinum to create *mediastinal emphysema*. A diver with mediastinal emphysema may experience such manifestations as substernal pain, breathing difficulties, and even collapse due to direct pressure on the heart and great vessels. Cyanosis may be evident.

From the mediastinum the gas frequently migrates into the subcutaneous tissues (*subcutaneous emphysema*), most often in the neck and supraclavicular region. This will add manifestations evident by enlargement of the neck, voice changes, breathing difficulties, and crepitation (cracking sensation) upon palpation of the neck and supraclavicular region. If there is a weakened area on the surface of the lung, such as alveolar emphysematous blebs, rupture may take place into the pleural space with the development of a *pneumothorax*. Pneumothorax is an infrequent but serious complication of diving. This may result in partial or total collapse of the lung on the side involved. As the diver continues ascent, the air entrapped in the pleural space expands at the expense of the collapsing lung and may eventually cause displacement of the heart. This is an extremely serious complication because both breathing and circulation are impaired. Manifestations include chest pressure and pain, breathing difficulties, and cyanosis.

The most serious consequence of alveolar rupture is the release of gas bubbles into the pulmonary circulation, and via the pulmonary vein, left heart, aorta and carotids, into the cerebral circulation. The cerebral area is most frequently affected since the diver is usually in an erect or head-up position and the bubbles tend to rise. Any bubble too large to pass through an artery will lodge and obstruct circulation to adjacent areas or organs. This obstruction is the embolus. Since air is probably the most common breathing medium for divers, the term *air embolism* is most frequently used; however, with the advent of extensive mixed-gas diving, gas embolism is also correct terminology. Air embolism is probably second only to drowning as a cause of scuba diving fatalities.

The wide clinical spectrum of symptoms and signs associated with cerebral air embolism include headache, vertigo, cranial nerve involvement, visual, auditory, and speech disturbances, loss of consciousness, coma, paralysis (hemiplegia), convulsions, loss of vital signs, and death. Death results from coronary and/or cerebral occlusions with cardiac arrhythmias, respiratory failure, circulatory collapse, and irreversible shock. *The onset of symptoms is dramatic and sudden, usually occurring within seconds of surfacing, or even prior to surfacing.* Many cases occur without development of any symptoms prior to unconsciousness; the diver may or may not experience discomfort or pain in the chest prior to or during alveoli rupture. The tearing of lung tissue often results in bloody froth at the mouth; however, the absence of bloody froth does not preclude the possibility of air embolism.

Ascent related pulmonary barotrauma can best be prevented by observing the following procedures or rules:

Careful selection of personnel: Each candidate for diving duty or training must undergo a complete medical examination including an evaluation of his medical history. History of tuberculosis, asthma, or chronic pulmonary disease may be disqualifying; the lungs should be normal as determined by physical and X-ray examination (chest roentgenograms taken at full inspiration and full expiration). The daily condition of the diver must also be considered; a severe cold (especially with respiratory complications) is temporarily disqualifying.

Proper, intensive training of every diver in the physics and physiology involved in diving: Many cases of air embolism have occurred simply because the diver did not understand Boyle's law and its application to diving. A thorough understanding of diving physiology and an awareness of the consequences of air embolism promotes a positive attitude toward the observance of basic diving procedures and safety standards.

Proper, intensive training of every diver in the use of diving equipment and diving and safety procedures: This is especially important in the use of scuba. When an improperly trained diver loses his gas supply underwater, his first overwhelming instinct is to hold his breath and surface immediately. Training and proper indoctrination gives the individual confidence which is so important during times of danger so that intelligent and proper action will be taken, thus avoiding panic.

Divers must always be properly weighted and in control of their buoyancy: Lost of buoyancy control during ascent is a common problem. In most cases the diver is simply unable to maintain control during the last 10 to 20 feet of ascent and drifts rapidly to the surface. The diver must be weighted in a fashion to allow him/her to maintain a safety stop at 10 to 30 feet with approximately 500 psig of air remaining in their cylinder.

Never hold your breath during ascent from a dive in which a breathing apparatus was used: Breathe regularly during normal ascents. If the breathing apparatus fails or gas supply is exhausted, an emergency swimming ascent may be unavoidable;

exhale continuously during ascent to prevent overexpansion of the lungs.

Divers should avoid smoking: There is sufficient evidence to indicate that smoking causes serious irregularities in the lung tissue and excessive bronchial mucus. Subsequent blockage of airways and weakened tissue can result in rupture of lung tissue.

The only recognized standard and effective treatment of cerebral air embolism is hyperbaric therapy. First aid procedures for suspected pulmonary overinflation injuries and subsequent medical conditions are discussed in Section 7 of this manual. Complete and authoritative discussions of this topic are available in US Navy [14], Davis and Hunt[6], and Bove and Davis [4].

DECOMPRESSION SICKNESS

The term *decompression sickness* refers to the signs, symptoms and basic underlying pathological processes caused by rapid reduction in ambient pressure from higher to lower pressure (i.e., ascending from a dive). The basic underlying pathological process in decompression sickness is the local formation of bubbles in body tissue, both intravascular and extravascular. The resulting symptoms vary widely in nature and intensity depending on the location and magnitude of bubble formation. When the diver is breathing air, the primary constituent of these bubbles is nitrogen with a small fraction of carbon dioxide.

To understand the basic causes of the bubble formation phenomenon it is necessary to examine what happens to air when breathed under increased ambient pressure. In accordance with the laws of partial pressures the amount of a given gas that will dissolve in a given liquid is determined by the percentage of that gas in the total mixture and by the ambient pressure. When the pressure of the gas mixture is increased, a pressure gradient exists between the tensions of the dissolved and undissolved phases of the gas. This gradient drives each gas into solution in proportion to its partial pressure until an equilibrium is established between the dissolved and undissolved phases of the gas. If the ambient pressure is then decreased, the tension of the gas in the dissolved phase, exceeds that of the gas phase, and the pressure gradient is reversed. The factor of time for equilibrium to be established in either direction is a principal factor in the discussion of decompression sickness.

Nitrogen is the only principal component of air that is inert; it therefore is unaltered in the respiratory process and, for all practical purposes, quantitatively obeys purely physical laws. Consequently, at gaseous equilibrium, the partial pressure values of nitrogen in the alveolar air, venous and arterial blood, and body tissues are identical. Oxygen and carbon dioxide are actively functional in the metabolic processes and under ordinary diving circumstances, the metabolic cushion renders the tissue tensions of these two gases of little significance in the mechanism of bubble formation.

Nitrogen will not dissolve in all body tissue at the same rate or in the same amount. This is because nitrogen is transported from the alveoli to the tissue in solution by the blood. Consequently, tissues rich in blood supply will equilibrate at a faster rate than those having more limited circulation. Nitrogen is approximately five times more soluble in fat than in water; tissues high in lipid content (e.g., spinal cord, bone marrow, and fat deposits) must take up a proportionately greater amount of nitrogen before saturation (equilibrium) is reached. When the pressure gradient is reversed, the slowest tissues to release all extra nitrogen will again be those with limited circulation or high lipid content.

From the diver's point of view, the degree of tissue saturation and, consequently, the amount of time required for tissue desaturation (subsequent decompression time) is dependent upon the depth, or pressure, of the dive and the amount of time at depth. Unfortunately, individual physiological variables also influence tissue saturation and desaturation.

Bubbles tend to form in any tissues that are saturated with nitrogen whenever the ambient pressure is reduced to a point where a *steep* pressure gradient is driving the gas out of solution. Haldane first postulated that when the tissue partial pressure of nitrogen is more than twice that of the ambient partial pressure of nitrogen, symptom-producing bubble formation will occur [8]. Once this 2:1 threshold pressure gradient is exceeded, the number and size of symptom-producing bubbles formed will be directly proportional to the magnitude of the disparity between these two partial pressures. Under these conditions the rate of diffusion of gas from the tissues into the expired air, via the blood and alveolar membrane, is too slow to cope with the volume of nitrogen evolved. Hence, the nitrogen comes out of a solution locally in the tissue in the form of bubbles.

Spencer demonstrated that bubbles can be detected in the venous circulation using the Doppler bubble detector without giving rise to symptomatic manifestations of decompression sickness [13]. Bateman had previously suggested that some degree of bubble formation probably occurs whenever the tissue partial pressure of nitrogen even moderately exceeds that of the surrounding atmosphere [1].

The above discussion would lead one to believe that internal gas bubbles are the principle factor in decompression sickness. These tiny bubbles are just one factor, possibly the initiating one, in the development of decompression sickness. Numerous changes in blood including clumping of red cells, rouleau formation, shunting of blood in small vessels and decreased platelet count have been noted following decompression. Hemoconcentrations or fluid shifts and blood chemistry changes also occur. Numerous biologically active substances associated with *stress* have been observed in the blood of decompression sickness victims.

Obesity, physiological aging, excessive physical exertion during the dive, pre-dive physical condition, alcohol consumption, dehydration, and poor general physical condition are factors that may predispose an individual diver to decompression sickness . As previously pointed out, fatty tissues constitute a large nitrogen reservoir due to the 5:1 oil-water solubility ratio. During a deep or lengthy dive a considerably amount of nitrogen is dissolved in the body tissues. Obviously, if the diver is obese, during ascent the blood — essentially a watery tissue — will not be capable of transporting in solution the increased volume of gas evolved from the excess fatty tissues. Consequently, the blood will supersaturate and lead to intravascular bubble formation on the capillary level. This will result in subsequent supersaturation and extravascular bubble formation in *blocked* tissue. Aging introduces an increasing proportion of tissue with sluggish circulation and, therefore, the increased possibility of local bubble formation.

Excessive physical exertion increases the respiration rate and the rate of circulation of the total blood volume. Consequently, during excess exertion under pressure, larger amounts of nitrogen are transported to the tissue per unit of time than normally.

Consider the circumstances where a diver is working hard underwater, e.g., moving heavy objects, swimming against a strong current, etc. This diver's tissues may absorb excessive nitrogen equivalent to 10-20 min. of extra diving time under normal conditions, and even if the diver is on a no-decompression dive schedule , he/she may suffer decompression sickness when surfacing without decompression stops. Poor physical condition is a direct extension of the above situation.

It has also been demonstrated that forceful movement of muscles and joints under increased ambient pressure results in an increase in bubble formation at those sites during decompression. Excessive carbon dioxide buildup in tissue has also been empirically and experimentally observed to lower the threshold for bubble formation during ascent. Scuba divers commonly use various methods (e.g., skip-breathing or controlled breathing) to lower air utilization and increase dive time. These practices can result in excessive carbon dioxide retention in tissue and could possibly be a factor predisposing a diver to decompression sickness.

Negative pressure breathing (as when using scuba) triggers diuresis. This loss of fluid from the body via diuresis, combined with fluid loss associated with breathing dry air, causes a degree of dehydration which may well reduce the efficiency of the circulatory system. Reduced circulatory efficiency may in turn modify the normal nitrogen absorption/elimination functions and contribute to the formation of extravascular bubbles (i.e., decompression sickness). Consequently, it is possible that drinking large quantities of liquid (such as fruit juice and water) prior to and between dives could be significant in avoiding decompression sickness.

Most divers do not realize how important it is to avoid drinking alcoholic beverages before and between dives. The immediate apparent effects such as mental disorientation, impaired physical coordination, vertigo, poor judgment, and general physical weakness are serious enough in themselves to disqualify the diver. However, it is also an established medical fact that alcohol produces a diuretic effect thereby causing a dehydration of the body. This results in blood thickening and reduced circulatory efficiency, which could contribute to the onset of decompression sickness. It is recommended that the diver refrain from alcohol before diving.

Although specific time periods between alcohol consumption and diving are not clearly defined in the literature, it is felt that the diver should refrain for 12 to 24 hours prior to the dive. Consumption of small quantities such as wine or beer with dinner the evening prior to diving is a matter of individual discretion. However, those consuming large quantities of alcohol and exhibiting signs of intoxication are at a much greater risk of decompression sickness and should refrain from diving for *at least 24 hours*. Persons exhibiting signs of after effects of intoxication (hangovers) should not be permitted to dive.

Needless to say, these *modifying factors* cannot be overlooked in operational diving. If all of these factors were accounted for in standard dive tables, the tables would be impractical for normal diving and divers. Consequently, the discretion of the diving supervisor and the individual diver must be relied upon to take these factors into account when planning the dive schedule.

Today, recreational and scientific scuba divers are encouraged to dive conservatively and remain with no-decompression limits. The original US Navy no-decompression limits have been reduced for recreational and scientific diving applications. In addition, authorities emphasize not exceeding 60 feet per minute during ascent and making a stop at 10 to 30 feet for 5 minutes when ascending from any dive deeper than 60 feet.

Slightly reduced dive times and a few minutes of decompression are a small price to pay when one considers the possibility of serious injury, lifelong physical impairment, and the many hours in a hyperbaric chamber required to treat decompression sickness. Divers are cautioned with regard to use of the US Navy standard air decompression tables for exceptional exposures. Current data suggests that these decompression schedules are not adequate.

The symptoms of decompression sickness are variable in their nature and intensity depending on the location and size of the bubbles and circulatory factors. Decompression sickness is sometimes classified as Type I or Type II. Type I includes cases of less serious symptoms such as pain and skin itching or mottling. Type II includes serious manifestations such as those resulting in neurological damage. Localized pain is the most predominant symptom, occurring in the majority of all cases, and is the only symptom in more than half of the cases. The onset of pain, sometimes likened to that of a severe toothache, is often gradual with fairly rapid increase in severity; if untreated, it almost invariably progresses to an *unbearable* stage. The location of the pain is usually rather localized at first and extends centrifugally to involve a progressively larger area. Generally, the pain is neither aggravated nor alleviated by motion or local palpation.

Joints and tendinous structures are the most common location of pain symptoms. Various theories regarding the mechanism of pain production have been postulated. A gaseous bubble developing in the tissue must displace and deform adjacent structures, which possess varying degrees of elasticity and deformation resistance. Furthermore, given the same amount of gas, the deformation pressure in a *tight tissue*, such as a tendon, ligament, and joint capsule, must be greater than that in *loose tissue*, such as fat. When this deformation pressure exceeds a certain threshold value, nerve fibers are stimulated by the mechanical deformation. On this basis, tight tissues are the most probable sites for symptom occurrence.

Localized skin rash and itching is experienced fairly often by divers during or immediately following decompression. A peculiarly irregular, modified *rash* is the most common type of skin lesion related to decompression sickness. The distribution tends to be related to subcutaneous fat deposits and is characteristically found, in order of frequency, in the pectoral region, back of shoulders, upper abdomen, forearms, and thighs. Decompression causes complete disappearance of the visible lesion; however, tenderness may persist for several days. The underlying pathological changes and mechanism of skin lesion production in decompression sickness are clear. Individual susceptibility varies.

Transient blurring of vision and other visual disturbances occasionally accompany more serious manifestation of decompression sickness. Visual disturbances are probably secondary to vasomotor decompensation and shock and are rarely of CNS origin.

Central nervous system manifestations are probably the most serious consequence of inadequate decompression. The great variety of bubble formation sites yield a comparable variety of disturbances, sometimes bizarre, often multiple, and certainly unpredictable. Theoretically, bubble formation can produce almost any symptom. Damage may be extensive or confined to minute structures. Most CNS lesions occur in the spinal cord, particularly in the lower segment; cerebral damage is relatively rare.

Quadriplegia, paraplegia, and paralysis of a single or several extremities in every combination have been observed. Early vasomotor collapse and shock are associated with more serious manifestations. Various body organs and functions may be affected. Permanent residual damage may result in loss of bowel and bladder control, sexual dysfunction, and/or some degree of residual paresis in one or both of the lower extremities.

Other manifestations include respiratory distress (chokes), headaches, nausea, and fatigue. The *chokes* is a rare but interesting symptom of delayed development of substernal distress, often described as burning. The condition is aggravated by deep inspiration and subsequent burning pain in all phases of respiration and an uncontrollable urge to cough. As the pain intensifies and spreads, respiration becomes difficult and coughing more severe. The victim becomes cyanotic, very apprehensive and progresses into clinical shock with subsequent loss of consciousness on occasion. The condition can be fatal if untreated.

Headache, nausea, and fatigue generally are considered to be nonspecific reflex phenomena secondary to the conditions previously discussed. Marked fatigue, often out of proportion to the physical exertion expended, is frequently experienced following deep dives, particularly if the decompression has been marginal. The onset of fatigue is generally 2-5 hours after surfacing and is characterized by an overpowering urge to sleep. The underlying mechanisms responsible are not known; however, fatigue is frequently considered a minor manifestation.

Certain symptom patterns are evident. Study of case histories indicates that certain symptoms and anatomic sites are more frequently involved than others. Symptoms may appear immediately after surfacing or more than six hours later; the first symptoms of decompression sickness have occurred more than 36 hours after diving.

Divers and support personnel must be capable of recognizing symptoms of decompression sickness and *analyzing* the situation. If a diver experiences joint pain, extreme fatigue, severe dizziness, numbness and/or extreme weakness in arms or legs, visual defects, and other "unusual symptoms" following a dive, he may be suffering from decompression sickness. The diver and/or support personnel should immediately evaluate the diving schedule for the day and determine the following:

* Were the dives timed accurately?
* Were depth measurements accurate?
* Did the diver remain within *no-decompression limits* or undergo proper decompression?
* Were repetitive dive computations correct?
* Were appropriate adjustments made in the dive schedule(s) for *modifying* factors such as cold and exertion level?

* Was the diver injured during the dive?

* Was the dive conducted in accordance with a specific *plan*?

* Were the tables read accurately?

If the diver is exhibiting apparent symptoms of decompression sickness and the answer is "NO!" or "UNSURE!" to one or more of the above questions, it is possible that the diver has developed decompression sickness. Symptoms generally appear within 2 to 3 hours following the dive. However, delay of symptoms up to 24 hours are possible.

If decompression sickness is suspected, immediate first aid and treatment procedures are necessary [12]. The victim should refrain from further physical activity. In many incidents the symptoms of decompression sickness and air embolism will be indistinguishable from each other. Fortunately, however, the same first aid measures may be applied to each as well as hyperbaric therapy.

The stricken diver should be placed in a supine position (lying on back). Victims with impaired consciousness should be turned slightly to the left- or right-side to minimize aspiration of vomitus. The airway must be free of obstruction and the victim *continuously* monitored for breathing difficulties, vomiting, and further onset of symptoms. Respiratory or cardiac arrest is possible. The attendant must be capable of recognizing these symptoms and administering cardiopulmonary resuscitation. Keep the victim warm in order to help combat possible onset of shock. Place the victim on 100 percent oxygen breathing as soon as possible. Do not administer drugs or pain killers to the victim! However, some authorities do recommend the use of aspirin for its benefits as a decoagulant Arrange for transport and medical attention. It is generally considered most advisable to obtain immediate medical attention even though the local medical facility may not be equipped to provide hyperbaric treatment.

Other life-threatening manifestations caused by or associated with decompression sickness may require immediate attention. The examining physician must be provided with a complete history of the dive(s) and subsequent onset of symptoms. Many local physicians may be unfamiliar with diving and the clinical aspects of decompression sickness. Fortunately, the Divers Alert Network (DAN) at Duke University Medical School provides a 24-hour per day consultation service to assist divers and physicians. *All divers and support persons must be capable of supplying the local physician with the DAN number — (919) 684-8111.* Ideally, divers should also be familiar with the location and telephone numbers of the nearest hyperbaric treatment facilities and physicians.

If it is determined that the diver is definitely suffering from decompression sickness (or air embolism), transport by the most rapid and feasible means of transportation. Generally, the physician at the treatment facility will advise as to the choice of vehicles. If the distance is relatively short, ground transport in an ambulance is generally advisable. If the victim is some distance from the treatment facility, air transport may be necessary (U.S. Coast Guard helicopter or commercial air ambulance). Flight at a low altitude will not appreciably aggravate the victim's condition and is of minor consequence when the alternative is delay. The use of a pressurized aircraft is most desirable. The Lear jet can maintain sea level cabin pressure up to an altitude of 23,000 feet. Maintain oxygen breathing during transport.

The prevention of decompression sickness is best accomplished by observing the following rules:

Careful selection of personnel. Persons not properly trained in diving and the use of decompression tables and procedures are immediate candidates for a case of the bends and should not be allowed to dive. In addition, persons with old injuries and diseases which could result in abnormally restricted circulation should refrain from diving. In other words, divers must meet certain medical standards.

Observation and evaluation of each diver prior to diving. Alcohol intoxication or hangover, excessive fatigue, or a general run-down condition are sufficient to temporarily restrict an individual from diving activities. All of these conditions may enhance susceptibility to decompression sickness. It is the responsibility of the divers or the diving supervisor to restrict a diver when his physical condition is not satisfactory.

Pay careful attention to the details of the dive. Establishment of a good dive plan with accurate depth and time determinations is mandatory. Never depend on scuba tank volume and air supply duration as a measure of no-decompression limits. A scuba (open-circuit) diver can easily exceed no-decompression limits even when using a standard single cylinder (72 ft^3). All scuba divers should be equipped with a watch (timer) and depth indicator. Keep accurate records of all dives — they may be important in diagnosis and treatment of decompression sickness. Accurate time and depth information must be maintained by tenders in surface-supplied diving.

Strict observance of the decompression tables and computers with due consideration of modifying factors. Adhere to the tables at all times unless there is reason to question the accuracy of depth or time. In this event, decompress the diver for a dive of greater depth and longer duration. Also, take into account working conditions, e.g., physical exertion, water temperature, etc., and lengthen decompression accordingly. When in doubt, always act in the diver's favor by adding to the decompression; never shorten decompression for mere convenience. Avoid excessive exertion following dives; this can initiate the development of bends symptoms.

Report all symptoms or signs immediately. Serious cases of decompression sickness often begin with a slight pain or itch. Failure to treat promptly can result in serious permanent damage or at least prolonged treatment.

Dewey published an excellent paper giving a relatively complete discussion of decompression sickness nearly 30 years ago and Davis presented a excellent discussion for laypersons [5, 7]. For additional practical information, the reader is referred to the US Navy [14], Davis [5], and Bove and Davis [4].

DYSBARIC OSTEONECROSIS

Dysbaric osteonecrosis (aseptic bone necrosis or avascular necrosis) refers to destructive sclerotic and cystic changes in bone which are not infectious in origin. It may occur in association with a variety of conditions such as chronic alcoholism, pancreatitis, sickle cell anemia, and ailments stemming from pressurization and depressurization. Historically, dysbaric osteonecrosis has been known as caisson disease of the bone because it was diagnosed early in this century among compressed air tunnel workers. The condition was first described in a diver in 1941 [2].

Dysbaric osteonecrosis is characterized by lesions in long bones such as the femur or humerus. As long as the lesions are confined to the shaft, they appear to be of limited consequence [10]. However, if the lesions develop in sites adjacent to the joint surfaces of the hip or shoulder (juxta-articular lesions), the consequences can be very serious. Areas of dead bone and marrow (infarct) in these sites can result in buckling of the cartilage around the area infarcted or loss of the subchondral plate over the area of infarct. In the latter case, cancellous spikes of bone grind into the cartilage during movements of the point. Continued fragmentation or crumbling of the bone can grind away large portions of the joint. Eventually, the weight bearing joint fractures and collapses. Disruption of the bearing surface or collapse of the dead bone can lead to secondary conditions of incapacitating arthritis. Other types of bone lesions are also associated with dysbaric osteonecrosis [2].

The exact etiology of dysbaric osteonecrosis (bone necrosis) remains to be unequivocally demonstrated. There is general agreement that dead bone and marrow are the result of gas absorption and release from tissue. However, there is no agreement about how gas absorption or release results in dead bone and marrow. Beckett summarized the major hypothesis [2]. Various investigators have suggested that gas bubbles from anywhere in the body can lead to obstruction of the small blood vessels of bone tissue. Others state that these gas bubbles can damage the lining of small blood vessels and cause chemical alterations that produce clots in the vessels of the bone. An alternate hypothesis is that fat cells which break up upon release of gas anywhere in the body can lead to fat emboli in the small blood vessels in the bone. Some researchers suggest that expanding gas within the cells expands the fat cells to the point where circulation is inhibited.

It has also been suggested that complications may arise from excessive compression rates rather than decompression. The compression phase causes an increase in the osmotic pressure of the blood. In response to a pressure gradient between blood and bone tissue, plasma water is shifted from the blood vessels into the spaces of the bone, thus restricting the bone blood flow. Some investigators feel that there is a correlation between dysbaric osteonecrosis and the number of compression and decompression phases while others have related it to elevated oxygen pressure [9]. None of the above hypotheses appears to be entirely satisfactory.

Dysbaric osteonecrosis has apparently resulted from only a single decompression exposure. In tunnel workers, the lowest pressure associated with the disease is 17 psig or equivalent of 39 fsw [10]. Survey radiographic examination is the primary method of detecting dysbaric osteonecrosis [2].

Published data from approximately 3,800 professional divers throughout the world show that about 800 had radiological evidence of significant skeletal lesions. Navy divers using standard tables appear to exhibit the lowest incidence of lesions (2.3%). Commercial divers have reported incidence in the range of 3 to 33%. Divers in Japan, using traditional techniques, have incidence of osteonecrosis reportedly as high as 40 to 75% [2]. There appears to be no survey data available on the recreational diving population.

Until the etiology of dysbaric osteonecrosis is clearly defined, it is difficult to establish preventive measures. At present, the population of divers at risk appears to include all those diving to a depth in excess of 33 fsw. The apparent predisposing factors include obesity, age, prior decompression sickness, and the number, depth, and duration of dives. In other words, a higher element of risk appears to exist for those participating in large numbers of dives, to greater depths, for longer durations. The incidence is probably greatest among saturation divers. Until this condition is better understood, divers must also assume that there is a relationship between osteonecrosis and inadequate decompression and/or decompression sickness.

Dysbaric osteonecrosis has, to my knowledge, not been described in recreational divers and the topic is seldom mentioned in a recreational diving training program. However, as recreational divers become more aggressive — diving deeper and longer and bending more frequently — they a predisposing themselves to this condition. Furthermore, as the number of aging deep divers increases, the likelihood of bone necrosis appearing in this population increases. Scientific saturation divers are also at higher risk of bone necrosis. I feel that every diver should be aware of the potential risks that they are taking — even the minor risks.

Treatment of dysbaric osteonecrosis is an important consideration in commercial diving. For additional information the reader is encouraged to consult the medical and references list at the end of this discussion [2, 3, 4, 10, 16].

EAR OVERPRESSURE DURING ASCENT

Alternobaric Vertigo

Transient vertigo related to unequal middle ear pressure equilibration has been experienced by divers both during descent and ascent [15]. This phenomenon has been attributed to unequal vestibular end organ stimulation as a result of unequal inflation or ventilation of the middle ear cavities during descent or ascent. One study indicates that 16.7% of 2,053 Swedish divers surveyed were likely to have experienced diving related alternobaric vertigo [11]. The vertigo episodes reportedly last from a few seconds to 10 minutes. A higher frequency of middle ear equalization problems was also noted in the vertigo experience population. Middle ear equalization problems were usually more dominant in one ear.

Alternobaric vertigo can be prevented by proper equalization of pressure in the middle ear. Individuals should not dive if difficulty with pressure equalization exists (at the surface) or if a Valsalva maneuver produces vertigo. If ear *fullness, pain, or vertigo* are noted during ascent, the diver must stop and descend until the symptoms disappear, if air supply and conditions permit. In this case middle ear ventilation may be facilitated by yawning, swallowing, or similar maneuvers.

Rebound Phenomena

On ascent, the ears and sinuses generally vent the expanding gas without much difficulty. However, occasionally blockage may result from mucus or swelling of tissue injured during descent and result in a *reverse ear or sinus squeeze*. In the event of symptomatic developments during ascent, the diver must terminate ascent, descend slowly until the discomfort subsides, and execute a swallowing or yawning maneuver to facilitate pressure equalization. A release of pressure in the middle ear or sinus will generally be obvious to the diver. The diver may then resume a cautious, slow ascent. Corrective procedures may be required several times during ascent.

The after effects of short duration vasoconstrictors used prior to descent may produce tissue swelling in individual cases, and consequent Eustachian tube or sinus ostia restriction. Divers are cautioned with regard to the rebound_phenomena when the effect of the drug subsides, especially after topical nose drops. This can lead to even greater nasal congestion with increased problems of pressure equalization in the ears and sinuses. Prolonged use of topical nasal medication can result in chronic nasal irritation and mucus inflammation.

DENTAL BAROTRAUMA

Tooth discomfort (tooth squeeze) associated with pressure change has been noted by divers and hyperbaric chamber personnel. Gas containing spaces may exist at the roots of infected teeth or beside fillings that have undergone secondary erosion. During descent the diver may experience pain as this space fills with blood or other body fluids in response to the pressure differential between the gas space and surrounding tissue. Expansion of the gas in this space may also be restricted during ascent by the blood in the space, resulting in pain.

Dental barotrauma may occur in a tooth with a cavity and very thin cemetum. If a sufficient pressure differential develops between the cavity space and the ambient atmosphere, the tooth may implode during descent. On the other hand, the pressure may equalize within the cavity if the descent is slow and the cemetum sufficiently thick. However, in this case, rapid ascent could lead to explosion of the tooth because gas escape through the small cavity opening is restricted.

Divers are cautioned regarding exposure to pressure following oral surgery, dental extractions, or manipulations. Gas may pass into the tissues through interruptions of the mucosa and be present as a surgical emphysema.

Dental barotrauma is a relatively rare occurrence. However, divers are encouraged to maintain a good oral hygiene routine with periodic dental evaluations (including x-ray). Avoid diving after dental extractions or surgery until complete tissue resolution has occurred.

Referred pain from paranasal sinuses is sometimes difficult to differentiate from symptoms of dental barotrauma. This is particularly noted in the upper bicuspids or the first and second molars. In cases where pain is sporadic or constant but not isolated to a single tooth, paranasal sinus barotrauma is suspect.

GASTROINTESTINAL BAROTRAUMA

Gas pockets in the gastrointestinal tract do not produce difficulty during descent since the walls are nonrigid and equalization is accomplished by compression of the gas. However, expanding gas in the gastrointestinal tract during ascent may produce difficulties. Expansion of gas swallowed during the dive or formed as a result of eating gas-producing foods prior to the dive can cause severe pain and is capable of producing manifestations including fainting, respiratory embarrassment, and reflex circulatory collapse. Serious symptoms are extremely rare. If a diver experiences discomfort in the gastrointestinal tract, he should slow his rate of ascent or stop ascent and attempt to expel gas. *Air swallowing* is generally more common in novice divers.

SUMMARY

All divers must understand the affects of pressure on the human body. The most serious and life-threatening injuries to divers are generally related to ascent or decompression. Failure to breathe normally can result in lung overinflation with subsequent blockage of circulation in the brain by an air embolism. This can result in a host of neurological deficiencies from minor personality changes to paralysis and even death. Divers should avoid smoking and never dive with a respiratory infection. Medical condition that might result in respiratory distress while underwater (i.e., asthma) can surely predispose an individual to pulmonary barotrauma. Respiratory diseases that have damaged the lungs in such a way that air trapping mechanisms might be present are contraindications for diving.

Depth is not necessarily a major factor in pulmonary overinflation injuries. In fact, a diver can be as seriously injured when ascending from swimming pool depths as from 100 feet in the ocean.

Decompression sickness, or the bends, is an assumed risk of divers. Fortunately, modem dive tables and computers greatly reduce the likelihood of developing decompression sickness. However, several hundred divers do experience this condition each year. More often than not these injured divers have violated dive table schedules or computer diving procedures. Many have simply ignored the predisposing factors such as poor physical condition, fatigue, dehydration, alcohol consumption, cold, and age. Unfortunately, dive tables and computers are based on mathematical models and diver's bodies are not. Even when properly used **no decompression table or computer can guarantee absolute freedom from decompression sickness.**

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Manuscript Completed: 18 October 1989
Manuscript Revised: 26 December 1989
Manuscript Revised: 9 January 1990

SECTION 2
APPENDIX A

SYMBOLS FOR COMMON UNITS OF MEASURE

Symbol	Unit
cf (ft^3)	cubic feet
cfm (ft^3/min)	cubic feet per minute
scf	standard cubic feet
scfm	standard cubic feet per minute
acfm	actual cubic feet per minute
psi (lb/in^2)	pounds per square inch
psig	pounds per square inch, gauge
psia	pounds per square inch, absolute
fsw	feet sea water
fpm	feet per minute
atm	atmospheres
ata	atmospheres absolute
l	liters
cu m (m^3)	cubic meters
cm	centimeter
cu cm (cm^3)	cubic centimeter
gm/cm^2	grams per square centimeter
cm Hg	centimeters mercury
mm Hg	millimeters mercury
kg	kilograms
gm	grams
m	meter
km	kilometer
°C	degrees Celsius
°F	degrees Fahrenheit
°R	degrees Rankin
°K	degrees Kelvin

SECTION 2
APPENDIX B

CONVERSION TABLE FOR UNITS OF PRESSURE

1 pound per square inch (psi)	= 2.31 ft of fresh water
	= 2.25 ft of sea water
	= 0.068 atm
	= 2.036 in Hg
	= 70.3 gm/cm^2
	= 0.0703 kg/cm^2
	= 5.17 cm Hg
1 atmosphere (atm)	= 14.696 psi
	= 29.92 in Hg
	= 33.9 ft of fresh water
	= 33 ft of sea water
	= 1.033 kg/cm^2
	= 1.013 bars
	= 760 mm Hg
1 foot of sea water (fsw)	= 0.445 psi
1 gram per square centimeter (gm/cm2)	= 0.394 inch of fresh water
	= 0.001 kg/cm^2
	= 1 cm of fresh water
1 kilogram per square centimeter (Kg/cm2)	= 1,000 gm/cm^2
	= 10 meters of fresh water
	= 9.75 meters of sea water
	= 73.56 cm Hg
	= 14.22 psi
	= 32.8 feet of fresh water
	= 28.96 inches of mercury

SECTION 2
APPENDIX C

ABSOLUTE PRESSURE AND PARTIAL PRESSURE OF NITROGEN AND OXYGEN IN AIR AT VARIOUS DEPTHS

Depth, (ft)	Absolute Pressure			Partial Pressure*			
	atm	mm Hg	psi	Nitrogen		Oxygen	
				mm Hg	psi	mm Hg	psi
0 (surface)	1	760	14.7	600	11.6	160	3.1
33	2	1520	29.4	1200	23.2	320	6.2
66	3	2280	44.1	1800	34.8	480	9.3
99	4	3040	58.8	2400	46.4	640	12.4
132	5	3800	73.5	3000	58.0	800	15.5
165	6	4560	88.2	3600	69.6	960	18.6

*Approximate air composition values of 79% nitrogen and 21% oxygen.

NOTES:

SECTION 3

DIVING EQUIPMENT

EQUIPMENT FOR SURFACE SWIMMING AND BREATH-HOLD DIVING

The basic equipment for surface swimmers and breath-hold divers (skin divers) is a face mask and snorkel, a pair of fins, *and* a personal flotation unit. Most divers will also wear some type of environmental protection garment and may require a weight belt. A knife is also recommended. Many ocean divers also use a surface float.

The selection of equipment is a matter of personal preference and diving requirements. Today, most skin divers that I have observed are equipped with reasonably good masks, fins, and snorkels. However, the use of buoyancy devices is sadly lacking. In the following paragraphs I have attempted to identify the necessary equipment for skin divers and, in some cases, provide some insight into the modern evolution of the equipment designs.

I caution the diver against equipment selection based solely on color coordination, fashion appeal, and interesting gimmicks. A prudent shopper will look for quality, utility, fit, comfort, and safety.

FACE MASK

The face mask protects the diver's eyes from adverse environmental factors (i.e., the burning experienced by most people when they open their eyes in salt water or a pool) and provides increased clarity and visibility underwater by placing an air space between the eyes and the water. Otherwise, divers would be subjected to the typical blurred vision one encounters when opening the eyes underwater while swimming.

Some scuba divers' face masks also provide tunnel vision, magnification, refraction and, in some cases, distortion. The normal field of vision for two eyes is about 60-70° upward, 100° to each side and 80° downward. The binocular field of vision is approximately the same up and down, but extends about 60° to the side [9].

Using representative masks available at the time of the study (late 1960s), these investigators found that while upper vision was relatively free of restriction, the side vision was significantly restricted and the lower field was seriously restricted. Fortunately, the diver tends to adapt to these limitations. Several mask configurations were developed in an attempt to reduce the tunnel vision effect; however, in the *wrap-around* model distortion resulted from curvature of the glass and a *side-panel* type mask actually interferred with the field of vision where the panels created blind spots.

Ironically, more than twenty years after the Weltman and associates report [9] a few divers' masks are still available with serious field of vision restrictions. Fortunately, some improvements and advancements have been made in mask design. Manufacturers of better masks are critically evaluating the angle at which the mask fits relative to the diver's face. The downward view angle has been significantly improved in several models. Several masks are designed to fit extremely close to the face and thus provide for a more natural or normal field of view. This close fit construction also has an extremely low displacement volume. Various manufacturers are currently producing both curved and three-panel (side-panel) masks. The problems of distortion and *blind spots* have not been completely resolved, however these modern masks appear to be a significant improvement over most earlier models.

Face Mask Selection

There are two general classes of face masks: the separate face mask and full-face mask. The separate face mask, covering only the eyes and nose, is normally used for diving with SCUBA and for skin (breath-hold) diving. Full-face masks may be used by specially trained SCUBA divers equipped with communications units and those working under extreme environmental conditions (polluted water or extremely cold water). SCUBA diving using a full face mask alters the procedures for dealing with air sharing emergencies and requires special training.

The face mask consists of a faceplate, a frame (face blank or body), and a head strap. Face plates of shatterproof, clear tempered glass are recommended. Plastic face plates are subject to discoloration, abrasive damage, and considerable fogging during dives. The frame is a flexible rubber carrier designed to hold the face plate and provide a watertight seal. The major portion of the frame should be of sufficient rigidity to hold the face plate or lens away from the eyes. The edge should be soft and pliable enough to ensure perfect fit to the contour of the face and comfort; however, it must be sufficiently rigid to retain its shape. Today, most face mask are made of pure translucent silicone which is considered superior material for shape retention (memory), durability, and resistance to environmental factors such as sun and salt. Black silicone is also used by some manufacturers.

Masks are usually fitted with a nylon or plastic lens retainer. The retainers are now available in assorted colors. An adjustable silicone strap holds the mask to the diver's head. This strap is usually about 1-inch wide on the sides and wider at the rear of the head for better security and comfort. The head strap should be secured to the lens retainer with buckles or anchors which facilitate adjustments and prevent slippage of the strap.

Today, most SCUBA diver masks are designed with nose a pocket to facilitate pinching the nostrils and equalization of pressure during descent. Other types of nose-blocking devices include: (1) a foamed-neoprene rubber pad positioned below the nostrils for sealing off the nostrils by pushing upward on the mask and (2) finger pockets in the mask frame on each side of the nose to facilitate pinching the nostrils shut with the fingers.

A few masks are also equipped with a purge valve, a device to facilitate clearing water from the mask. This purge device consists of a thin, circular, silicone rubber check valve, generally protected by a vented plastic cover and housing. Underwater, this one-way check valve is held closed by increased water pressure. Exhalation through the nose forces water through the valve from inside the mask. Caution must be taken when selecting masks equipped with purge valves since many are subject to failure and leakage. Only high-quality masks with large check valves are recommended.

Face-mask selection is a matter of individual preference, fit, comfort, and diver requirements. Masks are available in a variety of sizes and shapes, ranging from larger, wraparound models with side lenses for greater peripheral vision to small, lightweight, compact models with minimal internal volume. Breath-hold divers find the compact models to be most satisfactory. Avoid extremely large-size masks, built-in snorkels, narrow head straps, and goggles. Purge valves and nose-blocking devices are optional. The diver should keep the following points in mind:

lightweight;
comfortable fit;
wide angle vision;
easy closure of nostrils for equalization;
low volume;
easy strap adjustment;
secure strap fasteners; and
tempered safety glass.

Fit, without question, is the most important consideration in selecting a mask! No two faces are alike and extreme care most be taken in fitting a mask. The mask should fit comfortably and form an airtight seal on the face. To test for proper fit, the mask is placed in position without securing the head strap. Tilt you head back and look upward toward the ceiling. Place the mask gently on your face. The mask skirt should *touch* the face at four points simultaneous — above the upper lip, forehead, and temples. Now, while still looking up, place your finger in the center of the mask lens and press in gently. Only a slight pressure should be placed on the mask lens. Inhale through your nose to form a vacuum inside the mask. The mask is properly sealed if it will remain in place without being held. Dive shop salespersons will generally be of great assistance in selecting a properly fitted mask.

Optical Correction for Divers

Those individuals who need to wear eyeglasses generally require some form of optical correction underwater. Large-size prescription lenses can be permanently bonded to most face plates with optically clear epoxy by an optician specializing in underwater vision problems. This type of correction is generally required by individuals with severe visual problems.

Optical lenses may be mounted in a special frame secured to the inside of the face plate. These are easily removed for transport or changing to another mask. In an emergency, an old pair glasses may be adapted for use in masks by removing or cutting the temples, building up the sides of the mask with neoprene pieces, and wedging the glasses into place. Some trainees also use this method to reduce initial cost.

However, today most divers requiring optical correction select a mask that is designed to accept standard optical lenses. Several manufactures offer ground lenses in 1/2 diopter increments from –1.0 to –6.0 to retrofit several of the masks in their line of products. The diver simply takes his prescription to a diving equipment supplier, selects a compatible mask, and the salesperson installs the lenses. Naturally, persons with severe visual problems will find it more difficult to obtain perfect visual correction in this manner. However, most divers do not wear a mask for extensive periods of time and a close approximate correction appears to be satisfactory. If you have any concerns about your personal requirements, consult your optometrist.

Many divers wear *contact lens* while under water. Naturally, there is always the risk of losing a lens in the event that the mask is dislodged and/or flooded. In addition, if hard lenses are used eye injury is possible. During decompression from a 150 foot/30 minute dive, small bubbles in the precorneal tear film under *hard contact lens* have been observed by researchers. The bubbles generally disappear after 30 minutes at surface pressure; however, patches of damaged corneal tissue could be seen in the areas where bubbles had been [3].

At the time of bubble formation, the divers exprerienced a feeling of soreness in the involved eyes, saw halos and radiating spokes when viewing lights, and had decreased sharpness of vision. Symptoms lasted for about two hours after returning to sea level.

Bubbles were not observed if a *soft lens* was worn instead of a hard lens, or if a single 0.4-mm hole was made in the center of the hard lens.

The permeability and flexibility of the larger soft lens which contains a large amount of water allows exchange of gas and nutrients. With each eye blink nutrient tears are pumped across the cornea-lens interface. These features are responsible for rapid turnover of the nutrient tear film and dissolved gases. Consequently, bubble formation does not occur during decompression.

Eye symptoms experienced by the divers wearing hard contact lenses were the result of corneal epithelial edema (excessive fluid in the thin skin covering of the cornea). This edema was caused by formation and trapping of nitrogen bubbles in the precorneal tear film.

The placement of a small hole in the hard lens allowed the passage of tiny amounts of tear exchange and the flow of gas and nutrients in solution.

Researchers have concluded that: (1) the use of hard contact lenses by individuals working in the hyperbaric environment can cause injury to the cornea, (2) the injury causes discomfort and temporary visual impairment, and (3) the injury causes the eye to be prone to infection. They suggest that injury can be avoided by using fenestrated hard contact lenses, membrane contact lenses, or ***preferably a prescription face mask instead of contact lens.***

It should be noted that many sport divers have used contact lenses for shallow water diving without complaint or discomfort. However, I am not aware of any sport divers who have actually been examined for possible damage to corneal tissue following dives. ***Consult you eye care professional for advise before using contacts for diving.***

Prevention of Mask Fogging

Ventilation across the face plate is generally poor in any mask and the glass tends to fog easily. To minimize fogging, thoroughly smear the inside of the face plate with saliva and rinse lightly prior to donning. Anti-fog solutions such as mild liquid soap or a special commercial preparation may be applied to the inside of the face plate. The face plate should be frequently washed in detergent to remove oils and film that enhance fogging. If the mask fogs during use, admit a small amount of water into the mask and roll it across the fogged areas.

A number of anti-fog solution a available at dive shops. A thin coating of this solution on a clean lens can prevent fogging throughout a dive. Such solutions have been highly promoted in recent years. In fact, on overzealous sales person informed on of you students that a special solution was absolutely necessary because spitting in a mask could cause eye disease. I later asked a physician about this saliva-transmitted eye disease and was informed that I should not be concerned. In fact, the physician suggested that you could probably urinate in you mask without risk. However, do not ask someone else to spit in your mask. The possibility of transmitting disease from one individual to another is real. Interestingly, on my last tropical diving holiday I observed a diver requesting her buddy to do just that — spit in her mask.

Divers are cautioned with regard to use of commercial anti-fog solutions. Several years ago divers reported eye irritation resulting from the use of certain solutions. Apparently the problem was serious enough to require a recall of at least one product. However, one of the primary findings at that time was the fact that divers tended to use excessive amounts of the solution, far in excess of the amount indicated in the directions. *Be certain that you follow the manufacturer's directions for use of anti-fog solutions.*

Some companies now market mask lenses that are laminated with an anti-fog material. Making the lens extremely hydrophilic, it causes the water droplets to spread over the surface rather than bead up. These lenses increase the cost of a mask by 30 to 50 percent.

At least one firm has marketed a mask with color correction lenses for Caribbean diving. At shallow depths (up to 50 feet or so) the lens apparently restore red, yellow, and skin tone colors. The current status of the mask is unknown to the author. It has apparently not achieved high visibility and popularity in the diving community at this time.

Preventive Maintenance

Masks should be washed in fresh water after each dive and allowed to dry before storage. Also, the mask should be protected as much as possible from direct sunlight. Store silicone mask separate from black rubber products to prevent discoloration of the translucent silicone. Ideally, store the mask in a protective bag or box. Do not simply throw it into a dive bag where it may be damaged or broken by other equipment. An optically corrected mask can cost well in excess of $100 to replace and your dive trip could be seriously compromised without it. I often slip my compact model mask into the foot pocket of my fin for transport to the dive site.

Periodically inspect the mask straps and strap retention system for deterioration and damage. This is especially important before traveling to remote locations. Many divers include a spare mask strap in their repair kit.

SWIM FINS

Swim fins increase the propulsive force transmitted from the legs to the water. Used properly, the swim fins conserve the diver's energy and facilitate all underwater movements. Swim fins are available in a variety of sizes and designs. Variations in characteristics include materials; size and shape of foot pocket; and size, shape, angle, and degree of stiffness of blade. Selection of fins is a matter of individual preference, mission requirements, fit, and physical condition. Performance is dependent upon fin design, the style of the diver's kick, and the force which this style applies to the water.

Egstrom [2] and Christianson [1] found that different divers perform better with different fins. Study subjects who were less experienced and in poor general physical condition showed a tendency to favor more flexible fins. Divers with longer legs tend to expend less energy than divers with shorter legs.

McMurry [4] evaluated the effectiveness of several fin designs by having subjects exercise at predetermined submaximal workloads using a swimming ergometer. Oxygen uptake, heart rate, and swimming speed were measured. Based on these studies McMurry recommended that divers give specific consideration to fin surface area and flexibility. As surface area increases, diver oxygen consumption decreases. The flexibility of the fin relates directly to the speed attained by the diver. The more flexible the fin, the greater the speed. Overall, this researcher found that the most efficient fins at submaximal workloads were fairly stiff fins with a surface area of 770 to 855 cm^2.

This study also showed only limited performance differences between different fin designs that redirected water through tubes or vents in the fin. The term *vented* refers to a fin with an opening through the fin just forward of the foot pocket. The design is based on the concept that this area of the fin is the least efficient portion of the fins. The force generated from this area tends to lift the diver rather than deliver forward propulsion. The vent apparently also decreases the effort involved in the up-kick movement. This design is incorporated into one of the most popular fins in use today — a fin that was introduced to the American diving community in 1965.

Other design factors have been used to direct water movement. For example, a fin designed with relatively large ridges on the sides is considered to allow for maximal force application to the water and tends to direct the flow of water in such a manner as to maximize forward propulsion.

A diver must take great care in selecting proper fins. One must consider the type of diving activity and individual leg strength. Keep in mind that large, stiff fins require more energy in order to use them properly and efficiently. Placing extremely large, stiff fins on a weak, poorly conditioned diver could induce unnecessary fatigue and give little or no increase in swimming efficiency.

Diving equipment manufacturers have devoted considerable attention to the design of fins over the past few years. Application of basic principles of physics and fluid dynamics have resulted in interesting, if not unique, fin designs. Unfortunately, only limited fin testing has been conducted by impartial agencies and it is quite difficult for divers to sort out the difference between marketing strategies, gimmicks, and effective designs. As one dive shop owner told me, "Select a fin that fits the foot comfortably without excessive foot movement in the foot pocket, and hope for the best!"

In general terms there are two styles of fins — swimming and power. Swimming-style fins are smaller, lighter weight, and slightly more flexible than the power style which allow them to be used with a wider, more rapid kick of less thrust. The blade may have a greater angle and some utilize an open vent or overlapping blade principle which gives the swimmer maximum thrust with minimum energy requirements. This style uses approximately as much force on the up-kick as on the downward kick. The swimming-style fin is less fatiguing for extensive surface swimming, less demanding on leg muscles, and more comfortable. This type of fin is recommended for trainees and the average diver.

Power-style fins are longer, heavier, and more rigid than swimming fins. They are used with a slower, shorter kicking stroke with emphasis on the down kick. This style fin is designed for maximum power thrust of short duration with a sacrifice in comparative comfort, and is desirable for working divers who are required to swim while encumbered with multiple-cylinder SCUBA, heavy suits and extra equipment. Many divers own both swimming-style and power-style fins. Buoyant and nonbuoyant models are available in both styles; this factor doesn't generally affect the quality or performance of the fin.

Swim fins are available in open- or enclosed-heel models. Open-heel models are recommended for use with rubber boots. They are much easier to don and fit more comfortably. The open-heel models have an adjustable strap or a one-piece nonadjustable strap. Adjustable strap models are designed to accommodate a wide range of foot sizes; however, they are less comfortable when worn without foot protection.

Fin materials have changed significantly over the last few years. Years ago most fins were make of gum rubber. Fins of various rubber compounds are still available today, however most fins today are made of various synthetic materials such as polyethylene, polyurethane, graphite compounds, fiberglass compounds, and assorted plastics. Foot pockets are still generally constructed of rubber. Naturally, every manufacturer claims to use the best of available materials and, to be quite honest, I really can't identify the most ideal material or combination of materials. The only thing that I am certain of is that fins can now be purchased in a variety of colors.

The strap buckle must be sturdy and designed to hold the strap securely in place. Since open-heel fins have a closed toe section, the fin must be properly sized to prevent cramping of the toes. Open-heel fins are generally larger and stiffer than closed-heel models. Closed-heel fins are often used for diving in warmer climates where exposure suits and boots are not required. Even in warmer waters most divers prefer some sort of foot protection to prevent chafing and blisters, especially if they wear fins for long periods of time.

Basically, the fin must fit comfortably and It must be properly sized to prevent cramping or chafing. Since most divers wear neoprene boots, the fin must be fitted with boots. Fortunately, even adjustable fins are now available in three or four size ranges. Furthermore, the fin must match the individual's physical condition.

Preventive Maintenance

Fins should be rinsed in fresh water after each dive and protected from excessive exposure to direct sunlight. Prior to each diving trip fin straps and buckles must be carefully inspected for damage and deterioration. Many divers include an extra fin strap in their repair kits. Be certain to include a special tool for threading a replacement strap if required (consult manufacturers instructions). Several years ago at least one buckle design did require a special tool.

In general, avoid excessive walking on land or decks with fins. In addition to potential damage to the fin and posing a maneuverability problem this can also be risky for the diver and other persons on a crowded deck.

SNORKEL

The snorkel is a curved rubber, silicone, and/or plastic tube which enables the diver to breathe while swimming on the surface with his face submerged without moving his head. For efficient and easy breathing, the tube diameter should be 5/8- to 7/8-inches and not exceed 15 inches in length. The mouthpiece should be pliable and nonrestrictive with a cross-section that is approximately equal to that of the tube. Above all, the mouthpiece must be comfortable when the snorkel is angled in the swimming position. If the angle is correct, little or no bite pressure will be required to achieve a comfortable watertight seal. Contoured, large-tube snorkels are popular for skin divers. These offer minimal resistance to breathing and swimming. The snorkel is secured to the mask strap with a snorkel holder.

Early snorkels were simple L- or J-shaped tubes fitted with a mouthpiece. It wasn't until the late 1960s that a human performance researcher reviewed the snorkel from a standpoint of diver ventilation requirements and breathing resistance [2]. Dr. Egstrom noted that during high work load breathing and when hyperventilating, divers experienced excessive breathing resistance and inadequate air flow while using some snorkels. In fact, at that point in diving history, 80% of the snorkels tested failed to meet the ventilation requirements for even moderately heavy work loads [Respiratory Minute Volume (RMV) = 75 liters per minute (lpm); peak flow = 250 lpm]. In fact, there are stories about a diver who, under extreme panicky distress and respiratory demand, actually partially inhaled one of these small diameter snorkels. Allegedly, the diver died and legal actions were subsequently initiated against the snorkel manufacturer.

Other factors must also be considered. Breathing resistance brings about a decrease in pulmonary ventilation resulting in carbon dioxide retention and a reduction in available oxygen. Furthermore, the snorkel adds dead air space to the respiratory system, thus decreasing alveolar ventilation. Ultimately, this can lead to decreased capacity for physical exertion.

Today's snorkel designs and configurations are not a product of happenstance. Dr.

Egstrom's research established guidelines for all future snorkel design. Turbulent flow was reduced significantly by avoiding excessive bends, restrictions, and corrugations in snorkel tubes. For efficient and low resistance breathing, the tube diameter must be at least 5/8-inch and generally not exceed 7/8-inch and the tube length should not exceed 15 inches.

Today, most snorkels are fitted with some sort of purge valve near the mouthpiece area to facilitate purging water from the snorkel. During submergence the snorkel fills with water. As soon as the diver reaches the surface and the tube of the snorkel is elevated above water, the weight of the water in the tube will force water out through the valve. The remaining water is forced out by diver exhalation. The effort required to purge water is minimal.

In contrast, when using a snorkel not equipped with a valve, the diver must exert enough exhalation force to lift the column of water in the snorkel and expel it from the top of the tube. Early skin divers devised a *displacement technique* for effortless purging of snorkels not equipped with valves. When surfacing from a skin dive, the diver tilts his/her head back and looks upward with the open end of the snorkel is pointing downward. As the diver nears the surface he/she exhales a small amount of air into the snorkel. *This air displaces the water.* At the surface the diver simply rolls the head forward until the snorkel is in its normal upward position, exhales, and takes a cautious breath of air. If the diver has executed the displacement technique properly, the snorkel will be completely clear of water even before the initial exhalation. This technique does require a bit of practice to master.

The displacement technique of snorkel purging is, in my opinion, nearly as effortless as the use of a snorkel equipped with a purge valve. In fact, not too many years ago instructors often discouraged divers from purchasing purge valve snorkels. Early valve designs and materials were prone to leakage. However, today the majority of snorkels are designed with purge valves. Keep in mind that the displacement method does not work with many modern purge valve snorkels and that it is seldom taught in today's scuba diving courses.

The cost of a purge valve snorkel is about 75 to 100% greater than a conventional snorkel. At least one manufacturer makes an innovative snorkel with an elaborate valve arrangement at both the top and bottom of the snorkel and claims that it is the driest breathing, easiest purging snorkel ever made. I do not doubt this claim. This is essentially the Mercedes of snorkels and sells at a 100 to 400% higher price than a simple no-valve snorkel. However, as manufacturers strive to one-up each other to market new and unique products, we must hope that the basic principles of human respiration and snorkel design are not put aside.

Most self-contained divers carry a snorkel to facilitate surface swimming when the SCUBA air is depleted or to conserve air while surface swimming to a dive site. Actually, the snorkel is not only an item of convenience, but also of safety. A surface swimming diver can fatigue quickly if he must lift his head for each breath. In addition, the diver's chance of ingesting sea water is much greater without the snorkel. Many divers carry the snorkel attached to the mask strap while SCUBA diving, however the diver should be careful to prevent accidental dislodging of the mask. This is especially true when working around lines. I have observed masks being dislodged by snorkel entanglement in tow lines for surface floats on many occasions. This has lead some divers to carrying snorkels in other locations on the body. A snorkel with a *flexible or adjustable* lower tube may be more desirable for leaving attached to the diver's mask while using scuba.

When scuba diving the snorkel is positioned on the left side of the mask to prevent interference with the scuba regulator hose. One of the scuba diving training exercises involves switching from snorkel to scuba to snorkel with the face submerged.

Preventive Maintenance

Snorkels require limited maintenance. They should be rinsed in fresh water after diving and protected from excessive exposure to direct sunlight. Periodic replacement of purge valves may be required for some models. Following periods of storage, especially in basements and garages, check the interior of the snorkel for occupancy by undesirable organsims.

BUOYANCY UNITS

Today, the vast majority of scuba divers use a jacket-type buoyancy control device (BCD). With few exceptions, these BCDs are fitted with a more-or-less permanent cylinder band and are bulky and excessively cumbersome for a skin diver. Consequently, I see an increasing number of skin divers venturing into the tropical ocean with no flotation capability at all. The BCD remains on shore or boat because it is designed for scuba diving. In addition, most modern BCDs are, in my opinion, inadequate for skin diving since they lack an emergency CO_2 inflation system.

A carbon dioxide inflatable yoke-type buoyancy unit (previously referred to as a lifejacket) is, in my opinion, ***mandatory*** for skin divers. It is one of the diver's best safeguards against drowning, especially in rough seas or when highly fatigued. **However, it is not and must not be used as a substitute for swimming ability and physical fitness.** The term lifejacket is no longer used in the diving industry. Apparently, there is fear that the term will imply "absolute lifesaving capability" and if a diver does drown, for any reason, the great American legal system will spring into successful action. In military circles, UDT/SEAL personnel still use the term lifejacket.

By the way, if you are ridiculed for wearing a buoyancy unit while skin diving, keep in mind that NAVY UDT/SEAL surface swimmers and skin divers wear buoyancy units. If it is right for physically fit Navy divers, it is right for you. So don't let the narrow-minded, macho stupidity of an inferior, unsafe sport diver deter you from a proper and safe diving procedure.

This paper is devoted primarily to the use of buoyancy units for surface swimming and breath-hold diving. For a complete discussion of buoyancy and scuba diving buoyancy units consult *Buoyancy and the Scuba Diver* [6].

Buoyancy Unit Selection

The skin diver's buoyancy unit must be designed so it can be inflated by manual activation of a gas cylinder or through an oral tube. The only acceptable buoyancy unit is, in my opinion, the *yoke*-type, which holds the diver's head clear of the water when inflated even if the diver is unconscious. Buoyancy units should be lightweight, relatively compact, rugged, comfortable, and provide maximum flotation. Neoprene-impregnated nylon is a desirable fabric.

The UDT-type lifejacket (buoyancy unit), used by researchers at the University of Michigan, is recommended for surface swimming and breath-hold diving. This unit is fitted with a 19-gram CO_2 cylinder and is capable of lifting approximately 19 lbs from 18 ft. The harness arrangement on this buoyancy unit has proven most satisfactory. Some units are fitted with multiple CO_2 cylinders, pressure relief valves, and oral tubes located at the back of the neck. Unfortunately, only a limited number of divers will have access to the UDT-type lifejacket. This is a military issue item and, although it can be acquired for sale to the general public, recreational diving equipment suppliers do not stock this item.

Several yoke-type buoyancy units are manufactured and distributed for the recreational diving industry. Some of these units are higher capacity, more bulky collar-style BCDs that are used by scuba divers. Depending on size and flotation capacity these units use 16- to 38-gram CO_2 cylinders. Although slightly bulky, these units are quite acceptable for skin diving. Others smaller buoyancy units are designed and marketed especially for skin divers. Unfortunately, most of these units represent compromises in design, materials, and harness systems.

Some scuba divers wish to select a yoke-style buoyancy unit for use while skin and scuba diving. Although, I personally favor the use of *selected* yoke-type buoyancy unit for both skin and scuba diving, especially in tropical waters, many modern yoke-type buoyancy units are considered unacceptable for scuba diving. A few good units are still manufactured today. However, most are of the more bulky double-bag construction (outer protective heavy nylon material and inner vinyl bag). If you intend to use a yoke-style buoyancy unit for scuba diving, be certain that it is fitted with a large diameter hose connected to the BCD in the upper neck region, an overpressure valve, an inflation system that is connected to the scuba air supply, and a harness that passes through the crotch to prevent the unit from "riding up" when inflated.

Emergency Inflation System

In the event of an emergency, the CO_2 inflation system becomes an extremely important consideration. However, the CO_2 inflation system has become one of the most scorned and misunderstood items of equipment in modern diving. Some consider it to be a remnant of the era of diving dinosaurs. Dan Orr of Wright State University has reviewed the use of CO_2 inflation systems [5] and a summary of his finding is included in the following paragraphs.

Critics of the CO_2 inflations system suggest that it is ineffective for BC inflation at depth. The CO_2 inflation system used in the skin diver's BCD isn't really intended for inflation at depth. It is primarily a surface inflation device. However, when fitted with a high-capacity CO_2 cylinder, it will provide some buoyancy assistance for emergency ascent, especially in shallow water. I have known breath-hold divers who have activated the CO_2 cylinder if they felt that they might have overextended their underwater time. In the event that they experience hypoxic unconsciousness on the way to the surface, there is a good chance that the buoyancy unit would float them to the surface from shallower depths.

Other critics have stated that accidential detonation of the CO_2 cylinder at depth had resulted in numerous injuries and deaths. A review of literature on diving accidents failed to support the claims of critics. Most critics condemn the CO_2 inflation system as unreliable. In one test, a unit detonated 474 CO_2 cylinders before failure. Like any other component of a diver's equipment, the CO_2 inflation system must be inspected prior to each dive and properly maintained following the dive. A neglected unit is more likely to fail!

In a surface emergency the CO_2 system will inflate a BC in approximately 2 seconds. In contrast, Orr found that full inflation of the BC *using scuba air* required, on the average, 11.54 seconds with 500 psig of air in the scuba to 15.09 seconds with 100 psig cylinder pressure. In cases where test subjects emptied their scuba of air in shallow water, surfaced, and attempted BC inflation from the scuba, 82 had insufficient air to achieve positive buoyancy. For those who were able to inflate their BCs, the average inflation time was 33.57 seconds. Many critics of the CO_2 inflation system, have stated that it is an unnecessary redundancy and expense because the power inflator will still inflate a BC even if the scuba is empty. Keep in mind that in most diving accidents involving fatality, the diver was at the surface and unable to maintain flotation.

Special Training Requirements

A diver, skin or scuba, must learn to use any item of new equipment under controlled conditions prior to ocean diving. Once you have selected a skin diver buoyancy unit, use it the first few times in a pool or shallow, sheltered water. Before donning the unit read the manufacturer's instructions. Inspect the CO_2 cylinder and activating system. Remove and inspect the cylinder to assure that it has not already been emptied (evident by a small hole in the end of the cylinder). While you have the cylinder out, visually inspect the firing pin function by moving the activator up and down. If you wish, you can insert the eraser end of a pencil in place of the cylinder, hold firmly in place, and pull the activator cord. The end of the eraser should be pierced by the upward movement of the pin.

Before reinserting the CO_2 cylinder, apply a light coat of silicone grease to the threads. This will make it easier to remove later and, to some degree, protect the threads from corrosion. Always check the manufacturer's instructions to assure no contraindication to using certain lubricants.

Adjust the unit for comfortable fit while both inflated and deflated. The unit should fit snug and close to the body and should not "flop around" while swimming and diving. On the other hand, it should not be so tightly strapped to the diver that it restricts breathing and movement. If your buoyancy unit is fitted with a crotch strap, be especially careful about fitting it snugly while deflated and then rapidly inflating it in the water. The upward flotation combined with an already tight crotch strap can add a new dimension to pain for bathing suit clad male divers. If you are going to wear a BCD that requires a crotch strap, it is best to also wear a wet suit.

Once the buoyancy unit is properly fitted, practice orally inflating and deflating it, first on shore and then in the water. Oral inflation and deflation procedures must be mastered under controlled conditions prior to use in deep water. On land, press the air out of the buoyancy unit by holding the valve open and pressing against the unit with folded arms. In water, the pressure of the water will force the air out. To evacuate all of the air, such as before making a dive, be certain to hold the end of the hose at a point higher than the buoyancy unit. Never suck the air from a buoyancy unit. First, the interior of a wet buoyancy unit may harbor a number of interesting microorganisms that thrive in dark, moist environments. Lung infections have resulted from the ingestion of certain microorganisms. Second, if the unit has been filled with CO_2, sucking a large volume of this gas into your lungs could cause unconsciousness.

After you have mastered oral inflation, activate the CO_2 cylinder as you might in an emergency. This will cost you a couple of dollars, but it is necessary to assure that your buoyancy unit is fully operational. Some divers will make a breath-hold dive to 10 or 20 feet (*no scuba*) and activate the CO_2 cylinder to determine the response of the unit if it has to be inflated underwater.

Use in Routine Diving

For routine surface swimming and breath-hold diving, the buoyancy unit is simply worn and seldom, if ever, actually used. It is like an insurance policy, necessary, but hopefully never needed. This is one reason for selecting a comfortable, compact, and low-profile unit. Ideally, you should be able to swim and dive with little awareness of the buoyancy units presence.

The buoyancy unit may be used for resting on the surface. ***However, never use the buoyancy unit as a substitute for swimming skill and physical fitness. And, never use a buoyancy unit to compensate for extreme overweighting; remove weights from the belt.***

Divers using the yoke-type buoyancy unit with scuba will use it in much the same fashion as any BCD. However, scuba divers will be dissatisfied with the unit's design if they must swim underwater with a large volume of air in the unit. The air accumulated in the neck region and tends to place excessive lift on the upper body. This makes it difficult to maintain a proper swimming position. The yoke-type BCD is best suited for tropical diving and for use by divers who know how to properly adjust their weight belts and breathe.

When diving from small boats in the ocean I often wear my yoke-type buoyancy unit during the boat trip. I find that many, if not most, small Bahamian and Caribbean dive boats are not equipped with emergency personal flotation equipment. On more than one occasion I have found great psychological comfort in knowing that I had my flotation gear on since there was none on the boat and the sea condition and boat handling was going from bad to worst.

If I am forced to make a long survival swim or surface rescue in the ocean, I feel that the CO_2 inflatable buoyancy unit provides a great deal of security and a resting capability. Most divers find it hard to visualize a situation where such drastic measures might be necessary. True, this isn't an everyday occurence. On the other hand, I can assure you that it has happened.

Preventive Maintenance

Since the buoyancy unit is essentially a piece of lifesaving equipment, it should be maintained accordingly. Rinse and inspect the buoyancy unit after each dive. Remove the CO_2 cylinder and lubricate the threads (of cylinder and metal activator assemblies) before storing. Be certain to reinsert the cylinder prior to the next dive. Periodically complete a detailed inspection and lubricate the activator mechanism. Periodic activation and inflation tests are recommended. I test my unit by CO_2 inflation prior to first use and every 30 dives or every six months, whichever comes first. I will also test the unit prior to major diving trips. The unit must hold inflation for two hours without noticeable leakage. Test dates must be recorded.

The need for preventive maintenance is increased when the unit ages or is used in daily diving. Water must be drained from the buoyancy unit following each dive and the inside rinsed, activation tests must be performed more frequently. Periodically inflate the buoyancy unit and check for leaks by immersing it in water. Small holes may be repaired using an appropriate cement and pieces of similar material. Be certain to follow manufacturer's instructions and use designated materials for repair.

With proper preventive maintenance and care, a good buoyancy unit will last for years. However, abuse and lack of care can shorten the useful life of the unit to a matter of months or even weeks. Buoyancy unit failure is most generally the fault of the user, not the unit itself.

ENVIRONMENTAL PROTECTION

Naturally, thermal protection requirements are dependent on climate and water temperature. Although, skin diving is practiced in all climates and water temperatures, the most active skin diving areas are generally in tropical ocean waters. The early underwater hunters of southern California braved the cool waters of the Pacific Ocean clad only in swim suits. The early latex rubber dry suit enjoyed limited popularity, however, it was soon replaced by the foamed neoprene wet suit in the mid-1950s. The foamed neoprene wet suit remains the choice of most temperate climate skin divers today.

The early tropical skin divers wore only bathing suits and the more hardy ones spent hours in the water. In the 50s it was not unusual for some divers to be in the water for more than 3 hours and, on occasion, long ocean swims were considered to be a pleasant way to spend a day. T-shirts were used to protect the back from sun. However, even in these warm, tropical waters divers would eventually chill, especially during winter months. Various configurations of foamed neoprene wet suits — 1/8- to 3/16-inch, soon appeared on the tropical scene. Shorty wet suits or tunics remain popular today.

In the 1980s several manufactures began marketing stylish *one-piece lycra body suits* in an infinite variety of colors and patterns. These suits became the fashion rage of the tropical diving tourist scene. The were attractive, elastic, and comfortable. They provided excellent full body protection from sun — an important consideration for the northern diver traveling to the tropics. In fact, one of the most serious diving injuries that I have witnessed is a case of severe snorkeler sunburn. Immediately upon arrival in Jamaica a northern diver went for a long midday snorkel. Clad only in a T-shirt the diver spent a couple of hours snorkeling in shallow water. That night the agony of tropical sun burn began. Eventually, the skin peeled in large sheets from his severely blistered legs. After several weeks of misery, infection, and medical care the individual was able to return to diving.

The lycra body suit also provides some protection from stinging marine life and coral abrasions. Some divers wear lycra gloves and full hood as a protection from jelly fish in the upper portion of the water column, especially at night. However, be careful when removing and handling the suit after the dive. Clinging sting cells can still be active and cause considerable discomfort.

Unfortunately, the single layer lycra body suit offers little to no thermal protection qualities. The newer double and triple layer suits that are promoted as a thermal protection garment that is equivalent to a 3 mm foamed neoprene wet suit. Subjectively, I feel that they have so thermal shortcomings and I am awaiting results of scientific studies before I establish a final conclusion. However, the new outer layer does make them more resistant to wind penetration and post-dive surface chilling. All in all, the lycra body suit has a significant place in tropical diving, but not as a serious thermal protection garment.

A *full 1/8-inch foamed neoprene wet-type jumpsuit* is excellent for tropical diving. The suit is thick enough to provide adequate thermal protection for the tropics, yet thin enough to allow for maximum freedom of movement. The new lycra spandex exterior and the soft lycra interior provides maximum flexibility, stretch, and comfort for extended wear both in and out of the water. Buoyancy problems due to neoprene compression are minimal. In addition to thermal protection, this jumpsuit provides excellent protection from injury that might result from contact with marine ceolenterates, bottom materials, and so on. Knee patches are recommended, especially for the underwater photographer. The suit also provides full protection from the sun while snorkeling and during the surface activities associated with dive preparation/completion.

To extend the thermal range of this lightweight jump suit, the diver may add a 1/8-inch hooded vest. This provides additional torso protection and, more importantly, protection for the head and neck area where heat loss is significant, even in tropical diving.

More recently, 1, 1.5, and 2 millimeter suit constructed of neoprene with nylon/tricot bonded to both sides have appeared on the market (in 1989-1990). Although reports from the field are limited at this time, this suit may very well be an important entry into the diving marketplace. It appears to offer the comfort of a lycra suit with a thermal protection quality.

A sturdy, lightweight hard-sole neoprene boot is desirable for protecting the feet when walking on boat decks, docks, beaches, and coral debris, as well as for use with fins. Some divers prefer a low-cut slip-on boot for the tropics; however, be certain that the boot is high enough to prevent chaffing of the foot by the fin strap or top of the foot pocket. Good neoprene boots can provide comfort and versatility for walking, surfing, boardsailing, and boating.

The 1/8-inch jumpsuit is also excellent for other activities in cooler climates. It provides significant thermal protection and body comfort for surfing, boardsailing, rafting, kayaking, water skiing and other water sports. In colder weather it can be used as an undergarment for boating and fishing. The waterproof vapor barrier undergarment principle is quite valid for increasing thermal protection for persons participating in more sedentary activities. In the event that the fisherman or boater falls into cold water, survival time is increased significantly. The soft interior lining makes the jumpsuit relatively comfortable for reasonably long periods of surface wear. For additional information on thermal protection consult *Selecting a Personal Thermal Protection System* [7].

Preventive Maintenance

Environmental protection garments should be thoroughly rinsed in fresh water after diving and hung to dry. Be certain to dry completely before packing or storing. Periodic washing in a mild detergent solution will remove odor and many stains. However, be certain to consult manufacturer's directions before washing. Some zippers require periodic lubrication to assure smooth operation. Store in a cool, dry, dark location. Do not store in a room with ozone producing items such as automobiles and water heaters.

WEIGHT BELT

A weight belt is frequently required to offset natural buoyancy or the buoyancy of a diving suit. Buoyancy factors will be discussed in detail later. The most simple of diver's weight belts is generally constructed of 2-inch nylon webbing with a metal or plastic quick-release buckle. A *positive-release* buckle is recommended since once it is released, it cannot close again. Molded-lead weights are attached to the belt. Weights are available in 1- to 10-pound sizes, although 1-, 3-, and 5-pound sizes are used most frequently. Contoured hip weights are more comfortable; however, they limit weight adjustments.

During recent years an number of neoprene, open mesh nylon, and nylon fabric belts have entered the diving marketplace. Many of these belts are designed with zippered or Velcro pockets. Lead weights are easily placed in the pockets. Neoprene belts are very comfortable for divers wearing only a swim suit or lycra body suit. Recently, several manufactures have marketed small fabric bags that may be filled with lead pellets (or shot). The pellet-filled bags replace conventional solid weights and are very comfortable to wear. In addition, several belts are designed to accept lead pellets in bulk form.

In some cases the pellet-filled weight belt design makes weight adjustment more complicated. However, the added comfort and uniform weight distribution make this type of belt attractive. Furthermore, you can drop a 15 pound pellet belt on a bare foot without injury or discomfort.

Keep in mind that as the skin diver descends, generally head first, a poorly fitted belt will tend to slide up the body. Furthermore, if the diver goes fairly deep, wet suit compression will also allow the position of the belt to change. Some belts are fitted with an elastic or length changing component. At the surface, the belt is actually stretched to fit the diver snugly. If, during descent, the suit compresses, the belt adjusts and remains in place.

Most traveling divers carry either a web belt or pocket-style belt and acquire lead weights at their destination. Nearly all dive resorts now supply lead.

The amount of weight is generally adjusted to achieve approximately neutral to slightly positive buoyancy at the surface. Most divers establish proper weighting through trial and error. Generally, the weight is adjusted so that, at the surface, the diver will float with the water line at approximately eye level with a full breath of air. When the diver completely exhales the top of the head should be just at the water surface. Scuba divers may adjust weight to be just a bit negative at the beginning of the dive since their buoyancy will increase by about five pounds as they deplete their air supply. Naturally, this would not be the case with skin divers. Some skin divers weight themselves to be just slightly positive at the surface. During descent they experience both wet suit compression and slight buoyancy change through thorax compression.

Keep in mind that weight requirements will change when you change equipment, especially suit types and configurations. Also, dive weight requirements vary for ocean and fresh water diving. Although, the amount of weight actually depends on the gross weight and water displacement of the diver and equipment, the amount of weight change required will general be between 3 and 8 pounds or approximately 2.5% of the gross diver/equipment weight. Let's assume that a 180 pound skin diver (with equipment) is properly adjusted to neutral buoyancy in fresh water. When that diver enters the ocean he will have to add approximately 4.5 pounds of weight to compensate for the higher density of sea water. Conversely, if this diver was properly weighted for ocean diving, he would have to remove 4.5 pounds for fresh water diving. Although it is possible to calculate weight change requirements, *always perform a buoyancy check before commencing diving activities.*

In addition to being a buoyancy control device, the weight belt is also an important item of safety equipment. The weight belt is an item of expendable equipment that may be discarded in order to attain positive buoyancy. Always wear the weight belt over all other equipment so it can be readily released without obstruction.

Finally, accident investigations have revealed two important safety factors. First, most distressed divers *do not* discard their weight belts in an emergency. This factor alone could have probably made the difference between life and death for many divers. Weight belt discarding procedures are often neglected in basic diver training. Second, deceased divers are often found on the bottom with an excessive amount of weight on their belts. On one recent occasion, a deceased scuba diver was overweighted by at least 25 pounds.

Breath-hold divers are cautioned against using excessive weight to facilitate easy, rapid descents. Although the descent part of the dive will be easier, ascent will require significant energy and in the event of an emergency, the diver may be greatly compromised. Native divers (e.g., Ama and south seas divers) often use a separate weight to assist in rapid, effortless descent. The weight is secured to a line that is attached to a boat or float. A tender in the boat will retrieve the weight. ***CAUTION:** Using this technique can extend average breath-hold divers beyond both their depth and breath-holding limitations and it's use is discouraged!*

Preventive Maintenance

Weight belts should be rinsed in fresh water following dives. Pellet belts and pellet containers should be periodically inspected for damage that might result in loss of lead pellets. Periodically inspect buckles for damage or signs of excessive wear. and to assure proper operation.

KNIVES

If one were to consider all of the dive knives that are available from diving equipment manufacturers plus those included in survivalist catalogs/stores, the scuba diver has well in excess of 100 models and designs from which to select. Often an individual will select a knife on a basis of aesthetics, status symbolism, or notoriety with little regard for utilitarian purpose.

Many divers do not carry a knife. Is a knife really necessary for diving in clear water? I do not personally recall any entanglement emergency while recreational diving in clear, tropical waters. However, the possibility can not be disregarded; I include one in my dive kit. I feel that a knife is even potentially more important to the skin diver's safety than that of a scuba diver because the scuba diver has more time and, generally, the immediate availability of another diver to resolve an entanglement. However, the skin diver may have only a few seconds to resolve the situation and the buddy may be 20 to 60 feet away on the surface.

The average tropical skin diver needs a *compact, sharp knife* capable of cutting fish line and net in order to resolve an entanglement situation. A notched line cutter is, in my opinion, an important feature. The knife should be constructed of a material that will maintain optimum sharpness and edge retention. Large knives are cumbersome, heavy, increase resistance for underwater swimming, and often must be worn in less desirable locations on the body. Inexpensive models are often difficult to sharpen, do not retain an edge, and may prove to be ineffective as a cutting tool.

Daggers, stilettos, and double-edged knives offer little or no advantages to the diver and may, in fact, have some disadvantages from a standpoint of routine cutting and handling safety. They are advantageous for fighting and killing if you are into that sort of thing.

A good knife also has many other recreational and everyday applications. Consider a model that would be acceptable for other recreational or work use. I selected a model that comes with both a leather belt sheath and a plastic underwater sheath. A universal design nylon belt sheath may be purchased for almost any model knife at many specialty or surplus stores.

For additional information on selection, maintenance, and safety, consult *The Diver's Knife* [8], manufacturers' catalogs, and the instruction booklet included with your knife.

Preventive Maintenance

A dull knife is relatively useless! Periodic sharpening in accord with manufacturer's directions is required. All divers should own a sharpening stone and honing oil. To sharpen a knife, moisten the top of the stone with honing oil. Place the cutting edge of the blade on the stone and raise the opposite side of the blade. Then, as if cutting a thin slice from the stone, draw the cutting edge across and along the stone from heel (handle end of blade) to point. Reverse the blade and repeat the motion. Continue until a sharp edge is obtained. A special tool is available for sharpening the serrated portion of the blade and line cutters. Most good knives and sharpening kits come with complete instructions.

Following a dive the knife should be rinsed in fresh water and wiped dry. Ideally, a very light coat of oil should be applied. Most stainless steel knives are fairly corrosion resistant. However, high quality knives made of steel that will take and hold a good edge will often discolor and rust. These deposites may be removed with steel wool or special material (or compound) supplied by the manufacturer.

Periodically, inspect the sheath and straps for wear and the security of locking or retaining devices and maintain in accord with manufacturer instructions. Many knives have been lost because of retainer failure.

Safety

Keep in mind that a knife is a tool, not a toy! Treat the knife with the same respect as any weapon. With the exception of cleaning the knife it should never be drawn from it's sheath at a dive site except for a specific use or an emergency. At home, keep the knife in a secure location inaccessible to children. Do not pack your knife in carry-on luggage when traveling by air.

SURFACE FLOAT

Many skin divers tow a surf mat, small surf board, inner tube, or life guard's rescue buoy when swimming offshore. The float is used for carrying small items of equipment, spears, and game bags. More importantly, the float may be used for resting and as *a rescue device*. The float is towed with a length of synthetic line or rope coiled on a line retainer. The length of line will depend upon diving depth and personal preference. In navigable waters, the float is fitted with a short pole and a diver's flag. A small hook-style anchor is useful for securing the float to kelp or rock. Floats and lines should be rinsed in fresh water following dives and periodically inspected for damage. Repair and replace as required.

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Manuscript complete: 23 November 1989
Manuscript revised: 8 January 1990
Manuscript revised: 15 June 1990

NOTES:

CHAPTER 3-2

OPEN-CIRCUIT SELF-CONTAINED UNDERWATER BREATHING APPARATUS

OVERVIEW

Self-contained underwater breathing apparatus (scuba) was developed to facilitate complete freedom of movement underwater. Self-contained divers carry breathing medium with them, thus allowing them to operate independent of surface support and free of encumbrance of the umbilical assembly required for surface-supplied diving apparatus. Three major categories of scuba are currently in use:

* Open-circuit demand (compressed air and NITROX)
* Semiclosed circuit (mixed-gases)
* Closed circuit (pure oxygen and mixed-gases)

Open-circuit, demand-type scuba is the simplest type and the one most frequently used by air divers. Consequently, only open-circuit, demand-type scuba will be discussed in detail in this paper. A brief description of other scuba is given below.

Recreational divers generally only use open-circuit scuba. However, scientific divers must know and appreciate the difference between self-contained diving (open circuit: air) and surface-supplied diving so that they can choose the proper equipment for a specific operation. The best way to compare these two types of diving is to consider the advantages and disadvantages of scuba. The advantages of open-circuit scuba include:

* underwater mobility,
* portability,
* adaptability to small-boat operation (requires minimum support equipment), and
* readily available training, equipment, and services.

The disadvantages of open-circuit scuba:

* limited *safe* depth (relative to advanced diving systems),
* limited duration (air supply) ,
* limited acceptability and safety at high levels of exertion,
* inefficient for many diving operations (personnel requirements and field operation cost),
* limited communications capability,
* limitations in thermal protection for self-contained divers as compared to umbilical-supplied divers using hot water suits,
* requires a minimum of two divers for safety purposes (buddy system), and
* relatively unsafe for limited visibility and polluted water diving conditions.

Field experience has shown that open-circuit scuba has definite limitations and that for many projects surface-supplied diving techniques are safer and increase operational efficiency. However, at present, open-circuit scuba is the standard diving apparatus for both recreational and research diving applications. Tethered scuba diving is also gaining acceptance among some dive groups. Using this technique a single diver is deployed for selected diving operations in shallow water. The diver is tethered to the surface by a safety-communications line and maintains constant voice contact with a surface tender. A redundant breathing system is also required.

Open-circuit demand scuba consists of a high-pressure air cylinder(s) , valve or manifold assembly, pressure reduction regulator, and a backpack-harness-buoyancy control assembly. The breathing air flows from the cylinders to a regulator where it is reduced to ambient pressure. The diver inhales and exhales the ambient pressure air through a mouthpiece. The air is discharged directly into the water; no air is recycled as in other forms of scuba. The scuba may be include a simple mouthpiece regulator or a full face mask assembly.

Closed-circuit scuba, on the other hand, involves a recirculation of the breathing gas — pure oxygen or a gas mixture. The diver inhales the gas at ambient pressure and exhales the gas back into the system where the carbon dioxide is removed and oxygen is replenished. *Closed-circuit oxygen scuba* is available to scientific divers. However, divers must observe rigid depth-time limitations (i.e., maximum of 75 minutes at depths of 25 feet or less) because of the toxic effects of oxygen under pressure.

The breathing gas used in *closed-circuit mixed-gas scuba* may be a mixture of nitrogen-oxygen or helium-oxygen depending upon the type of scuba used and operational requirements. Actually, the two gases, oxygen and an inert gas, are contained in separate cylinders and mixed in the apparatus during the dive. The partial pressure of oxygen is preset and continuously measured by a series of oxygen sensors. Inert gas is generally added to the system only at the beginning of the dive and during descent to compensate for increased ambient pressure. Carbon dioxide and moisture is removed by chemical absorption and trapping. All gas is recirculated and there is no intentional discharge of gas from the system except during ascent to shallower depths. Closed-circuit mixed-gas scuba systems capable of supplying a diver with up to 6 hours of breathing gas at depths in excess of 1000 feet are available. However, the units are more frequently used by combat swimmers for clandestine operations (limited bubble discharge) and long duration dives (gas supply availability).

Semi-closed circuit scuba is a system which operates on a mass-flow principle. Breathing gas is metered into the breathing bag on a continuous mass flow basis. The flow is preset in accord with anticipated diver requirements. A small quantity, approximately 20% of the gas from each exhalation is discharged directly into the water. The remainder recirculates through a purification canister, mixes with new gas, and is again breathed by the diver.

Both closed- and semi-closed systems, therefore, permit more efficient utilization of the costly gas mixes. Closed- and semi-closed circuit scuba are extremely expensive and require specialized training. Semi-closed circuit scuba is not commonly used today. However, there is increasing interest regarding the applications of closed-circuit mixed gas scuba in scientific diving. These units cost $25,000 to $35,000 at the present time. In recent years, military special forces swimmers have apparently replace the more expensive and complex mixed gas scuba with pure oxygen units.

DEMAND REGULATOR

The demand regulator is a mechanism which reduces high pressure air in the cylinder to ambient or breathing pressure. The volume of air delivered is regulated by the diver's inspiratory requirements. In open-circuit demand scuba, the diver inhales air from the air cylinder and exhales directly into the surrounding water; in a properly designed apparatus, no gas is rebreathed.

In the design of regulators there are currently several different kinds of valve systems used. Those used in the first stage assembly include unbalanced piston, balanced piston, unbalanced diaphragm, and balanced diaphragm valves. Second stage valves include lever/diaphragm operated downstream poppet valves and tilt-type pilot valves. In the discussion of regulator valve systems, the terms *upstream* and *downstream* are frequently used. Downstream refers to a valve which is forced open by the flow of air. To stop the air flow the valve must be held closed by a mechanical force. The valve opens when air pressure is sufficient to overcome the mechanical force. In an upstream valve, the opposite is true. The valve is forced closed by the flow of air and a mechanical force must always be applied to open the valve.

Details of regulator design, various valve systems used in modern regulators, and in-depth descriptions of different model regulators are beyond the scope of the paper. Each valve type has both advantages and limitations. Most authorities feel that a detailed knowledge of scuba design is of limited consequence to users. The following simplified overview of regulators and other scuba components is included to provide a general understanding and appreciation of diver life-support systems.

Most scuba divers use the single-hose, two-stage regulator. A single-hose regulator is actually two separate pressure reduction regulators or stages connected by a flexible hose. Each stage has an automatic demand valve that opens and closes with inhalation and exhalation. High pressure air from the cylinder enters the first stage where it is reduced to an intermediate pressure of 120 to 180 psig above ambient depending on regulator model. The second stage further reduces the pressure to ambient levels for breathing. When the diver exhales back into the second stage housing, this air is discharged into the surrounding water.

First-Stage Valve Mechanisms

Most modern scuba regulators, both diaphragm and piston type, have balanced first- and second-stage mechanisms. However, in order to better understand the operation of the balanced valve, one must review the design of the unbalanced valve. The unbalanced valve design was standard in earlier model single-hose regulators.

Diaphragm-Type First-Stage Mechanism. In standard *unbalanced* first-stage diaphragm valve assembly of early model regulators the high pressure cylinder air acted to close the valve. Counteracting the closing force of the cylinder air was a large spring pressing against a high pressure diaphragm, which was coupled to the high-pressure valve seat assembly. Movement of the diaphragm moved a stem to open or close the valve seat assembly. The heavy spring was manually adjusted to hold the valve assembly open until the intermediate pressure increases to a predetermined level. The valve stem was contained completely within the high pressure chamber. High-pressure air pushed against the end of the valve stem to force it closed. Consequently, the force exerted on the end of the valve stem had to be overcome when the valve opens. This was a primary factor to consider in assessing the performance of an unbalanced valve assembly. The first stage is depth compensated by water pressure exerted on the high-pressure diaphragm.

In regulators with an unbalanced diaphragm valve assembly, the delivery efficiency of the mechanism varied considerably with the cylinder pressure. The small diaphragms used in these single-hose regulator first-stages were extremely sensitive to fluctuations in pressure and, consequently, slight pressure variations could have marked effects on airflow capacity and breathing resistance. To reduce the amount of variation caused by cylinder pressure differences, it was necessary to reduce the size of the inlet orifice. Unfortunately, a small orifice added resistance to air flow and, therefore, breathing, when high air flow volume was required. Thus the standard first stage diaphragm valve mechanism had definite air delivery limitations under high flow requirements, especially at depth.

Today, only a few scuba regulators use a diaphragm-type first-stage valve mechanism. However, the newer models use a vastly improved *balanced diaphragm valve assembly*. In comparison to the unbalanced first stage common to earlier regulators, cylinder pressure has no significant effect on the seating of the high-pressure valve assembly in this unit. In the balanced diaphragm valve, a valve stem of approximately the same size as the orifice is extended through the opposite (outside) the high-pressure chamber. Consequently, high pressure is not exerted on the end of the valve stem. With the cylinder air pressure neutralized, only the mechanical forces of the spring affect the operation of the valve. These springs can be set at the exact desired intermediate pressure and do not vary with changes in cylinder pressure. Consequently, large orifice diameters can be used, and the breathing resistance produced by moving air through a small orifice is eliminated.

Piston-Type First-Stage Mechanisms. The majority of modern scuba regulators have a *balanced* piston-type first stage. However, as in diaphragm-type regulators, the standard first-stage piston valve used in earlier model regulators was also of the unbalanced design. In order to better understand piston first stage operation and the evolution to modern designs, I will first discuss the operation of the unbalanced system.

The early piston-type first-stage was simple and functional with only one moving part. By using a precision-ground bias spring, the desired intermediate pressure could be maintained with no further adjustment. As the first stage assembly was pressurized, air flows through a small hole (located in the side of the piston stem just behind the soft seat), up through a bore in he piston stem and pressurized the air space between the cap and the large end of the piston. This force acting on the larger area of the piston is greater than the force being applied at the small end of the stem due to the differential in surface areas. This force is also sufficient to overcome the spring tension and ambient pressure. Consequently, the piston moves toward the small end and the soft Teflon disk seats over the high-pressure inlet orifice. This piston valve mechanism is classified as *unbalanced* because high pressure air is acting on the small end of the piston which closes the high-pressure orifice and intermediate pressure air is acting on the large end of the piston.

The piston was depth-compensated through application of hydrostatic pressure to the spring side of the piston by admitting water into the spring chamber. In this manner the intermediate pressure always remained at a predetermined level above ambient pressure. When this predetermined intermediate pressure was achieved, the piston moved downward, and the air flow from the cylinder is stopped by the closing of the valve. As the diver inhaled, the intermediate pressure was subsequently reduced, the piston moved upward, and air flows through the regulator until the diver stopped inhaling and the predetermined intermediate pressure was again reached.

The *balanced* piston valve used in today's regulators also operates under somewhat the same principle. However, in the balanced piston the Teflon disk or valve seat remains stationary, fixed to the inside of the first-stage housing, while the valve orifice, the open end of the piston in this case, moves up and down. Consequently, when the valve is closed, there is no high pressure air forcing against the end of the piston as in the unbalanced valve. The pressure is in balance at both ends of the piston. When the valve opens during inhalation, very little air pushes against the stem since most of the air flows through the stem. The term *flow-through* piston is often used.

Balanced first-stage valve systems dominate the scuba regulator valve market today. The advantages in design and air flow characteristics are obvious.

Second-Stage Valve Mechanisms

Today, most regulators are designed with pneumatically balanced downstream or pilot second-stage valves. Earlier model regulators used a tilt valve principle; however, most modern units are of the lever valve design. The tilt valve is now used in some regulators to operate a pilot valve mechanism. It is also still used in some hyperbaric chamber oxygen masks and demand breathing regulators in some surface-supplied diving apparatus.

Balanced Downstream Level Activated Second Stage. The second-stage valve reduces the intermediate air pressure, generally set at 100 to 180 psig over ambient (depending on regulator model), to ambient pressure. The basic second-stage assembly consists of a water chamber, an air chamber, a flexible diaphragm, a valve assembly, an air inlet from the first stage, and a mouthpiece. In the level valve unit, spring tension is set to counteract or close the valve against the intermediate pressure air transmitted from the first stage. This is an example of the downstream valve principle which refers to a valve which is forced open by the high pressure air.

Spring tension holds the valve closed until the diver draws a breath of air or depresses the manual purge button. As the diver inhales air is evacuated from the air chamber portion of the assembly thus slightly reducing the pressure in that chamber. A slight differential then exists between the water chamber (ambient pressure) and the air chamber. The flexible diaphragm deflects toward the air chamber (lower pressure), activates the lever that rests on the diaphragm, and the lever opens the valve assembly. Air continues to flow into the second-stage chamber until the diver ceases inhalation, the pressure differential is equalized, and the lever valve closes.

Changing the spring tension in this lever valve alters the force required to open the valve. Generally, the adjustment is performed by a regulator service person. Some regulators have been designed with a spring tension adjustment knob penetrating the second stage housing. The diver can turn the knob one way to increase tension and thus breathing resistance. Turning the knob in the other direction reduces spring tension and breathing resistance. Unfortunately, some divers abuse this adjustment capability. Some divers state that they like to feel the regulator breathe. This means that they desire some initial resistance when they start to inhale. Some claim that this reduces air consumption. Unfortunately, these divers do not understand the physiology of breathing and the significance of negative pressure breathing. This resistance can, over the course of a dive, induce respiratory fatigue. The valve should be adjusted so that the breathing resistance is reduced to an absolute minimum without causing the regulator to free-flow between inhalations.

Pilot Valve Second Stage. Some regulators use a pilot valve second stage valve mechanism. The pilot valve is essentially a tilt-valve. As the diver inhales the tilt-valve opens causing the pressure in the pilot chamber to drop. This pressure drop subsequently opens the main poppet assembly. The tilt valve, connected to a small diaphragm, requires very little inhalation effort to open. Once a small air flow is initiated, the air flowing from the first stage opens the main valve assembly. Because the pilot valve is very small, only a slight spring tension is required to counterbalance the pressure; therefore, less force is required to open and close the valve. The pilot valve only opens slightly and operates the air supply valve by flowing a small amount of air into a control chamber. Larger primary air supply valves can be used in regulators second-stages with this system as compared to conventional leverage systems.

Because there is a piston opposite the valve opening which exactly counteracts the opening force of the air pressure, the supply valve is balanced and unaffected by intermediate pressure variations. The system can be described as a pneumatically amplified second stage. This means that a small force (the pilot valve) is pneumatically amplified to move a larger force (the primary supply valve).

The operation of the regulator is initiated by a slight inhalation effort which causes the regulator diaphragm to draw downward. This action moves a linkage that opens the pilot valve and air flows to pressurize the control chamber. This flow opens the main air supply valve. The pilot valve also acts as a safety relief valve in the event of overpressure malfunction in the first stage.

An aspirator port, directed toward the mouthpiece inside the regulator, generates a slight vacuum within the regulator housing when air is flowing. As a result, less effort is required to maintain air flow during inhalation. Consequently, very little diver effort is required to obtain full air flow. These regulators rate quite high on performance tests. Normally, a regulator requires a pressure or suction effort equivalent to a two inch high column of water to activate air flow; the pilot system requires a pressure equal to a one-half inch water column. However, regulators of this design are generally more complex, more expensive, and cost more to maintain than conventional models. Some models also seem to flutter as the diver inhales in shallow water.

Tilt Valve Second Stage. The tilt valve, not normally used in modern scuba regulator design, is an example of an upstream valve. The valve and valve seat are positioned on the higher pressure side of the assembly. Consequently, intermediate pressure air flowing from the first stage forces the valve closed against the seat. A thin rod solidly fastened to the disk portion of the valve passed through the orifice and rests on the diaphragm. As the diver inhales, the pressure is reduced in the air chamber and the higher ambient pressure forces the flexible diaphragm inward. The diaphragm presses against the rod and tilts the valve open. Air flows through the orifice until the pressure differential is equalized, the diaphragm returns to its neutral position, and the valve is forced closed by the flow of higher pressure air.

Tilt valve regulator first stage assemblies must be fitted with a special over-pressure relief valve. In the event of a first stage over-pressure malfunction, the hose leading to the second-stage tilt valve would be over-pressured. The upstream tilt valve would be forced tighter against its seat. Breathing resistance would progressively increase with higher intermediate stage pressure and hose failure is possible.

Fail-Safe. The term fail-safe is often used to describe downstream valves. In the event of a first stage over-pressure malfunction, the downstream valve is forced open by the increased air pressure. Consequently, the air simply escapes and excessive breathing resistance, valve failure, or hose rupture is unlikely. Also, in this type of second-stage valve an over-pressure valve is not required in the first stage.

Exhaust Ports. The exhaust valve port or exhaust "T" in a single-hose regulator is generally located in the lower portion of the second-stage air chamber. A disk shaped non-return valve prevents water from entering through this port. The exhaled air is deflected away from the diver's face through a special rubber or plastic assembly. It should also be noted that some regulators discharge exhaust at the side or end of the housing. Earlier model single-hose regulator exhaust valve ports were small and caused significant exhalation resistance. Most current models are designed with large exhalation valve ports to minimize this resistance.

Purge Button. Single hose regulator second-stage assemblies are equipped with purge buttons. The button allows the diver to manually depress the low-pressure diaphragm, activate the demand level, and, thus, initiate air flow. This is especially helpful if the diver must purge water from the regulator and does not have sufficient air in the lungs to accomplish an exhalation purge. Normal purging is accomplished by a smooth, continuous exhalation with the exhaust valve in a down position.

Breathing Characteristics

In general, the single-hose regulator is characterized as an easy-breathing regulator by most divers. Variations in inhalation and exhalation resistance with body position changes are less noticeable than in early double-hose models. Inhalation is generally much easier since the demand valve is positioned at a higher pressure than the center of respiration of the lung in a normal swimming position. Exhalation must overcome the slightly higher pressure differential. A diver in a vertical position, as when ascending, and looking upward places the demand valve at a significantly lower pressure position (shallower) than the lung's center of respiration. This pressure differential may cause inhalation resistance during periods of high inspiratory demand.

Regulator performance evaluation was traditionally based on breathing resistance or effort. This resistance or effort was expressed in terms of inches or centimeters of water pressure exerted by the diver to inhale and exhale through the regulator. For example, five and seven centimeters of water pressure at the surface was the maximum inhalation and exhalation effort, respectively, considered to be acceptable by US Navy standards. Interestingly, exhalation resistance was a greater barrier to Navy acceptance of early model single-hose regulators than inhalation resistance.

Today, regulator performance is defined in terms of *maximum respiratory work level* or breathing work. The US Navy defines 0.14 kg-m/l (kilogram meters per liter) at a depth of 132 feet and a breathing rate of 62.5 RMV (respiratory minute volume in liters per minute) as the maximum acceptable level. Some authorities in recreational diving suggest that this value far exceeds the requirements of the average diver.

Double-Hose Regulators

The double-hose regulator is only used by select groups of scuba divers working in polar environments today (J. Stewart, personal communication). Historically, the first regulator developed by Cousteau and Gagnan was a double-hose type and most early models built and used in the United States were double-hose types. To my knowledge, only double-hose regulators were officially approved for use by the U.S. Navy divers until about 1970. Today the double hose regulator is practically a collector's item in the recreational diving community.

Air Moisturizers

In the 1970s a scuba air moisturizer appeared on the market. This small device fits between the single hose regulator's first stage and the low pressure hose and automatically cleans and moisturizes the dry air that the diver breathes. It consists of a small cylindrical housing that contains an activated charcoal cartridge, a nylon filter and screen, an ABS plastic cup and Venturi tube, and a fluid retention element. It was intended to prevent the throat and mouth dryness associated with long term scuba air breathing. This is an apparent problem for some divers. However, on one seven day air saturation dive I averaged 8.2 hours per day on scuba with no adverse dry throat effects.

Caution! Theoretically, introduction of moisture into the air supply could have adverse affects on regulator performance in cold water diving. This practice is questionable when diving in water below a temperature of 45° F. The moisturizer did not gain popularity and soon disappeared from the market. A similar device reappeared in 1988 at a trade show, however, the current status of this device is not known to this author.

CYLINDER VALVES AND MANIFOLDS

The cylinder valve assembly is a simple, manually operated, *on-off* valve to control the flow of air from the scuba cylinder and is designed to facilitate attachment of a demand regulator or cylinder filling device. In the United States, most regulators use the standard yoke attachment system. However, many European cylinder valves are designed for screw-in system regulators (regulator screws into valve assembly). This system, the DIN, is now increasing in popularity in the United States, especially among cave divers. It is more acceptable for higher cylinder pressures and is less subject to failure or damage during use.

Most valves now insert into the cylinders with a straight threaded o-ring sealed male connection. The valve is fitted with a high-pressure safety relief assembly, generally a thin metallic disk, designed to rupture at about 3400 psig for 2250 psig cylinders and 4800 psig for 3000 psig cylinders. This relief assembly is intended to prevent damage to the cylinder or possible cylinder explosion in the event of over-pressurization during filling or under conditions of excessive heat. The valve assembly may also incorporate a low pressure warning device.

If the diver's scuba consists of two or more cylinders, a valve-manifold assembly is employed to join the cylinders and provide a common outlet. The manifold consists of sections of high-pressure piping with appropriate fittings specially configured and threaded to accommodate the cylinders. It includes an on-off valve, safety relief devices on each cylinder elbow, and, in some cases, a low-pressure warning device.

The standard on-off scuba cylinder valve is commonly called a *K-valve.* A cylinder valve assembly which incorporates a low-pressure warning mechanism (reserve valve) is known as a *J-valve.*

Low-Pressure Warning Device (Reserve)

Some open-circuit scuba cylinder valves are equipped with a positive warning system to alert the diver when the air pressure within the cylinder is critically low. The most common mechanism is a pressure activated valve with a manual override. This type is generally referred to as a spring-loaded reserve or J-valve reserve. This mechanism permits a free flow of air to the regulator until the cylinder pressure falls to a predetermined level (approximately 300 psig for single-cylinder scuba and regulator; 500 psig for two-cylinder scuba) . At this pressure, a spring forces a flow check valve against the port orifice and restricts the air flow, causing increased breathing resistance. This is followed by total obstruction of air flow. In the past this mechanism was used in some regulator first-stage assemblies as well as cylinder valves.

The remaining air may be released by manually overriding the check valve. The diver activates a lever on the side of the cylinder valve, which mechanically withdraws the plunger valve from the orifice against the action of the spring. The entire reserve air supply is then available to the diver. Unfortunately, this lever may be accidentally activated during the dive or the diver may fail to place it in a proper position prior to the dive. In either case the diver may completely exhaust the air supply at depth without warning.

Spring-loaded low pressure warning valves have apparently failed to operate at the designated pressure. Spring fatigue, material wear, and diver abuse can cause malfunction. The diver should periodically test the valve function on the surface by breathing or slowly flowing the air from a partially filled cylinder (about 600 psig) while observing the pressure gauge. The air supply should drop to zero at the point of flow stoppage. When the reserve lever is activated, the pressure gauge pointer should return to about 300 psig. Caution! This test may not be valid for some spring-loaded, low pressure, warning devices incorporated into regulators. Regulator design may place the gauge outlet upstream from the reserve valve.

The now obsolete audible low-pressure warning system was probably the most foolproof mechanism used in scuba since it eliminated the human error possibility of neglecting to properly position the reserve mechanism and the possibility of accidental activation. In this system an audible signal automatically sounds when the cylinder pressure reaches a given level, less than 350 psig, over ambient pressure. The signal continues during inhalation until the air supply is exhausted or inhalation ceases. The movement of the sound oscillator piston generates a rapid pressure pulsation in the first stage, producing a distinct tactile signal at the diver's mouth. The sound is transmitted through the water so other nearby divers are aware a diver is low on air. This type of warning mechanism was only used in a few regulators and, to my knowledge, is not available at the present time. This mechanism gained only limited popularity among divers, increased the cost of regulators significantly, and compromised regulator performance.

The depth-compensating or restricted-orifice principle is no longer used in scuba as a low-pressure warning mechanism. This device operates on the principle that a stream of air will flow through an orifice of a given size in direct proportion to the pressure differential existing on both sides of that orifice. The orifice size is calibrated so that there will be insufficient air flow through the orifice for normal inhalation when the pressure differential is approximately 200-300 psig. The restriction to air flow is, therefore, dependent also upon depth. Consequently, near the end of the air supply the diver feels a restriction of air flow during inhalation. Direct ascent increases the pressure differential across the orifice and sufficient air should be available for normal ascent.

Once air pressure had dropped low enough, the diver had to immediately ascend unless provisions were made in design for bypassing the restrictive orifice. Descent was impossible. If the diver breathes lightly and consumption (volume per breath) was limited, the diver could "breathe past" the reserve supply at shallow depths. In this case air demand was insufficient for the diver to notice significant restriction and the cylinder(s) could be nearly empty before breathing restriction was evident. If under these conditions the demand would suddenly increase, air flow would be insufficient. Also, the restrictive orifice reduced the flow capacity of a regulator even when the pressure differential was high; this greatly reduced the regulator's operational efficiency. Divers are therefore discouraged from using old scuba equipped with restricted orifice reserve mechanisms.

SUBMERSIBLE PRESSURE GAUGE

A submersible pressure gauge is considered mandatory for all scuba. A special adapter can be used to facilitate use with some double-hose regulators (for the very few polar divers who still use them). The high-pressure gauge is fitted with a length of high-pressure hose, which allows it to be positioned so that the diver may constantly monitor cylinder pressure.

The gauge mechanism or movement commonly used in American pressure gauges is either the C-spring bourdon tube or the spirally wound bourdon tube. The C-spring bourdon tube is a circular, hollow, flattened tube with about one-quarter of the circumference missing. The bottom end of the tube is sealed and anchored in a brass socket. This unit forms the top of the coupling which attaches through the gauge housing to the hose. The other end of the tube is sealed and fastened to a gearing assembly which moves the pointer. As the gauge movement pressurizes, the copper alloy tube attempts to straighten. This linear motion of the tube end is amplified and converted into a rotary motion of the needle through the pinion and sector gear.

The spirally wound bourdon tube is approximately 24 to 26 inches of very small copper alloy tubing wound around a flat plane. The diameter of the wound unit is about 3/4 inches. One end of the tube is anchored to a socket/hose coupling assembly. The other end of the tube is coupled directly to the pointer. As air is introduced into this tube, it attempts to straighten and rotates the pointer.

Gauge movements are generally designed with an accuracy range of ±35 to ±100 psig at a reading of about 500 psig, depending on the manufacturer and unit cost. At full scale (3000 or 4000 psig) the gauge might exhibit an accuracy range of up to ±5%.

The accuracy of the gauge can change with use. Divers are cautioned against using improper gauges for higher pressure scuba. No bourdon tube or C-spring tube should be pressurized to over 75% of full scale. Pressurizing a 3000 psig gauge to 3000 psig will dramatically reduce the gauge's life. A C-spring tube has a life expectancy of about 35,000 pressurization cycles to 80% of rated pressure (under laboratory conditions). However, if pressurized to full pressure, the gauge accuracy will be significantly reduced at about 10,000 cycles.

Pressure gauge housings are generally made of chrome plated brass or polycarbonate (or ABS) plastic. Although the rupture of a bourdon tube is rare, the housings are designed with a blowout or overpressure relief plug. This plug will release at an internal pressure of 4 to 80 psig over ambient, depending on the make and model. This prevents the lens from being blown outward.

The high pressure hose that connects the housing and gauge movement to the regulator first stage generally consists of a neoprene tube inside two fiber braids of synthetic polyester and enclosed by a perforated outer neoprene cover. The outer cover has tiny pinholes along the length of the hose. This allows for air that might have been entrapped during manufacture to escape. Also if there is a minor flaw in the braid, the air can harmlessly escape. Most hoses used on standard scuba are tested to 5000 psig and usually have a minimum burst pressure of 12,000 psig. All pressure gauge hoses have an air restrictive orifice located in the regulator attachment end. This prevents the hose from whipping violently as air discharges in the event of a hose rupture.

As previously stated, a submersible pressure gauge is mandatory for all scuba. The gauge should be secured to the scuba harness or special retainer on the BCD. A gauge that is dangling loose easily catches in rock crevices or on coral underwater and may snag on ship railings or ladders during entry and exit. The gauge housing should be protected by a rubber shock absorbing cover.

If water is detected on the inside of the gauge lens there is probably a leak in the housing, a cracked lens, or a faulty lens 0-ring seal. The interior of a flooded gauge housing should be rinsed with freshwater to remove salt and corrosive materials; shake out excess water. A second rinse with alcohol will remove excess water and accelerate drying. The gauge must be taken immediately to a professional repair facility.

Another potential problem area is the swivel connector used to join the gauge to the hose. Small air leaks do occur at this connector; if leaks are detected, have the problem corrected by a professional scuba service person.

After each use, thoroughly wash the pressure gauge in fresh water. Remove the rubber cover to insure complete washing under the cover. Be certain that the pressure relief plug is in place and that no corrosive deposits have accumulated around the edge. Use a strain reliever on the hose where it joins to the regulator in order to prevent fatigue and damage to the hose fibers. As with a regulator, the submersible pressure gauge should be inspected annually by a professional scuba repair person.

HIGH PRESSURE CYLINDERS

The compressed air supply for open-circuit scuba is contained in steel or aluminum-alloy cylinders. The standard steel cylinder that has been used by scuba divers for more than 35 years has a rated working pressure of 2250 psig and a normal internal volume of approximately 730 cubic inches. When charged to 2250 psig this standard cylinder contains approximately 64.7 cf of free air. The 71.2 cf capacity is at 10 percent overpressure (2475 psig) allowable under Department of Transportation (DOT) regulations, as indicated by a plus (+) symbol adjacent to the initial hydrostatic test date stamped near the cylinder neck. This only applies to the 5 years following the hydrostatic test date with the plus symbol. Today steel cylinders are available in capacities ranging from 13 to 120 cf at service pressures of 2015 to 4500 psig.

In recent years a new high tensile strength steel alloy scuba cylinder with a rated working pressure of 3,500 psig has been approved by the Department of Transportation. This metal allows the construction of a high capacity cylinder that is lighter and shorter than aluminum or other steel cylinders of similar capacities.

Aluminum cylinders are commonly available in capacities ranging from 13 to 100 cf at 3000 to 3300 psig pressure. Aluminum cylinders may be filled to the specified working pressure stamped on the cylinder; the 10 percent overpressure does not apply. The 80 cf/3000 psig is probably the most common size aluminum cylinder used at this time. Single cylinder scuba is most popular among recreational and scientific divers. Divers participating in special diving activities will carry 2 or more cylinders joined with special manifold assemblies. One manufacturer supplies both double and triple 30 cf cylinder units; a special thermoplastic shell is available for the triple unit.

Many factors must be taken into account when designing high pressure cylinders for use by divers. These factors include size, weight, buoyancy characteristics, air capacity, safety, corrosion resistance, maintenance requirements, cylinder life, appearance, and cost. One of the most significant advancement in United States civilian scuba diving equipment was the introduction of the aluminum cylinder in 1971. The aluminum cylinder is more resistant to internal corrosion than steel.

When the aluminum cylinder was introduced into the American diving community, there was some degree of controversy relative to the safety of the cylinders. Aluminum cylinders have been used in Europe since the late 1930s and used by the U.S. Navy since about 1955. Unfortunately, there have been some problems probably resulting from the use of improper aluminum alloys or manufacturing procedures. Since the use of aluminum cylinders began in the United States, there have been three heat-related explosions and one failure from a shoulder cracking problem (William High, personal communication).

However, I am aware of problems with the cylinder/valve interface. Since chrome-plated brass valves are used, the contact between the dissimilar metals may produced an electrolysis reaction causing a corrosive bond between the valve and the cylinder. This can generally be prevented through proper periodic maintenance including 0-ring replacement and valve thread lubrication using a silicone lubricant with dielectric qualities.

In cases of cylinder and valve contact corrosion, the cylinder threads can be significantly damaged when the valve is removed. Since the above are possible problems and scuba service persons have reported cylinder thread damage as a result of improper valve removal, divers are encouraged to have cylinders inspected and serviced only by qualified persons at professional scuba service facilities.

Stress fractures may also be a problem in a few cylinders. Fine hairline fractures may be found in the threads and underside of the cylinder neck. This can result in a slow leakage of air from the cylinder and may also lead to more serious problems. Professional internal inspection is required every year.

The U.S. Navy used a special nonmagnetic aluminum cylinder manufactured under special contract for use by Explosive Ordnance Disposal Teams and Special Warfare Groups. This cylinder did not bear the DOT markings. The U.S. Navy required that these aluminum cylinders be hydrostatically tested every 3 years instead of the 5 year interval required for their standard steel and aluminum cylinders. These special cylinders were slightly larger than civilian issue cylinders and had rounded bottoms. Several incidents of failure (explosion) during filling have been reported over the years in cylinders that were removed from Navy facilities without authorization.

The aluminum alloy cylinder is more resistant to corrosion than the steel cylinder. The corrosion resistance of aluminum depends upon the maintenance of a passive film on the surface of the metal. This protective film, aluminum oxide, is formed when bare aluminum comes into contact with oxidizing substances or the atmosphere. The film forms a tight bond with the base metal which prevents further corrosion. Generally, if a small amount of pure water enters the cylinder, no critical corrosion problems result. However, if salt water enters the cylinder, even aluminum can be seriously corroded.

The corrosiveness of sea water does not arise directly from the high concentration of salt present but is due to the presence of heavy metals dissolved in the water. When sea water comes into contact with aluminum, the heavy metal ions tend to deposit on the aluminum surface creating miniature galvanic corrosion cells. The operation of the galvanic cell requires an electrolyte (conducting fluid) to be present in order to initiate pitting corrosion; sea water performs this function. However, minor pitting in an aluminum cylinder is generally not considered as serious as in steel cylinders. A visual inspection of the interior of aluminum cylinders should be performed annually.

Many divers now reject steel cylinders in favor of the more rust resistant aluminum cylinders. Rust in steel cylinders can be a real problem. Many steel cylinders submitted for periodic hydrostatic testing must be *tumbled* with an abrasive material to remove excessive rust from the interior of the cylinder. However, many divers have used the same steel cylinder for 10 to 20 years without significant internal rusting. The problem lies in the standard of care maintained by the diver and the air supplier. A steel cylinder that receives proper care has an extremely long life expectancy. Many steel storage cylinders bearing dates back to pre-1930 are still in use today.

Exterior and Interior Protection

The exterior of the steel cylinder may be protected against rust and corrosion by galvanized metal (zinc), epoxy paint, or vinyl-plastic coating. The zinc metal, generally applied by a hot-dip process, bonds to the cylinder and protects it from air and water. Galvanized exteriors are recommended for durability against abrasion. Epoxy paint or plastic coating over bare steel cylinders has proven unsatisfactory from a durability standpoint. Even minor abrasion may penetrate the coating and expose the underlying metal allowing oxidation (rusting) to begin immediately. Epoxy paint or plastic over zinc-galvanized surfaces is acceptable and does reduce electrolytic corrosion of the zinc by salt water. However, with proper preventive maintenance electrolytic corrosion is relatively insignificant on the bare zinc coating.

Since internal rusting was a potential problem, many manufacturers applied a protective epoxy lining on the interior of the cylinder in the 50s and 60s. The use of internal coatings was only relatively successful. The development of even a small pinhole in the lining allows the moisture contained in the cylinder to concentrate on the exposed area. Corrosion under the lining causes it to loosen. In some cases, the coatings had a tendency to flake. These small flakes could travel through the valve and into the regulator. Many of these cylinders are still in use today however, the interior coating has generally been removed by tumbling or sandblasting processes as part of periodic maintenance.

Although aluminum cylinders do not necessarily need a coating, a corrosion inhibiting epoxy-polyester finish is applied to the exterior of aluminum cylinders to protect from salt water and for cosmetic purposes. If this relatively resistant coating scrapes off, an oxide layer quickly forms. This layer provides some protection from further corrosion. The cylinder interior has a dense naturally-formed protective oxide layer over the metal base. In addition, an interior coating is chemically applied by the manufacturer.

Divers are cautioned against having cylinders coated using a heat process. A few years ago several individuals were severely injured when filling scuba cylinders that had been color coated using a high temperature process. High temperatures can significantly weaken the aluminum to a point where it will fail or rupture at relatively low pressure. Cylinders heated in excess of 350°F must be condemned.

Cylinder Markings or Symbols and Pressure Designations

High-pressure cylinders are stamped with letters, numbers, and symbols near the neck, giving certain specifications. The following is an example of the markings found just below the neck of a *standard steel scuba cylinder*:

DOT 3AA2250
K7422
USD
1@90+ PST

The DOT designates that the cylinder is acceptable for interstate transport in accordance with Department of Transportation specifications. This federal agency establishes safety standards for the manufacturing, testing, and transportation of most pressure vessels. Cylinders manufactured prior to 1 January 1970 may read ICC (Interstate Commerce Commission) in lieu of DOT; the change to DOT resulted from governmental reorganization and an amendment to the hazardous materials regulations. The type of metal alloy used in manufacturing is designated by 3AA or 3A, indicating chrome molybdenum alloy and carbon steel alloy, respectively. Chrome molybdenum is a better grade of steel and is more common in modern cylinders. The rated working pressure, 2250, follows the material designation. At present the US cylinders are marked using pounds per square inch gauge (psig) as the standard unit of pressure.

A measure of the safety of a cylinder is the ratio of the stress at the working pressure to the ultimate tensile stress. This is known as the safety factor (F_s) and is theoretically calculated using the equation,

$$F_s = \frac{S_t}{S_a}$$

where S_t is the ultimate tensile stress limit and S_a is the actual stress at working pressure. Let us assume that the safety factor for given steel cylinders is 2.282. The theoretical minimum burst pressure is, therefore, 5647 psig. When a 2250 psig cylinder is hydrostatically tested, it is pressurized to 5/3 working pressure or 3750 psig.

In the above example K7422 is the cylinder's serial number, and USD is the distributor's symbol. The hydrostatic test date is indicated by 1@90+. The "" is the registered symbol of the tester and the "+" following the test date designates that the cylinder is approved for overfill to 10 percent above the rated working pressure for a period of 5 years. PST is the cylinder manufacturer's symbol.

The "+" symbol is left over from the World War II days when the government and industry found it necessary to transport as much gas as possible in a given cylinder. Cylinder advertisements in the scuba diving industry are somewhat misleading about the air capacity of steel cylinders. The 71.2 cf cylinders must be overfilled by 10 percent to actually hold 71.2 cf of free air. At the rated working pressure of 2250 psig, the cylinder capacity is only about 65 cf. The basic factor that determines whether a "+" is put on a cylinder is known as the "K" factor. This factor is determined by the elastic expansion, test pressure, internal volume of the cylinder, outside diameter, inside diameter and wall thickness.

Most hydrostatic testing services generally do not place a "+" sign after the second and subsequent hydrostatic test dates. It is my understanding that the "+" sign could be placed on a retested cylinder if the cylinder has not had the wall thickness reduced by rust or corrosion, is within a given elastic expansion hydrostatic test tolerances, and, in the judgment of the examiner, has an "acceptable K factor." These further determinations are difficult and time consuming; most hydrostatic testing services simply avoid applying the "+" on a basis of company policy.

Consequently, the cylinder capacity is 65 cf after the first test. Also, some air filling services may refuse to recognize the 10% factor, even on new cylinders. This is at the discretion of the individual or agency; there is no law that requires them to exceed the working pressure. Divers are cautioned about overfilling cylinders. Rumors about divers filling standard steel cylinders to 3000 psig or more are not uncommon. Repeated overfilling or overheating can cause considerable structural damage in terms of metal fatigue and other factors. The slightest internal or external corrosion could cause the cylinder wall to fail explosively under such conditions.

As a protection against overpressure, purposeful or accidental, a safety disk is installed in the valve assembly. The disk is designed to fail at about 166% of the working pressure. Corrosion of the disk may result in failure at lower pressures. Divers are cautioned against using the higher pressure safety disk (used with the 3000 psig aluminum cylinders) for steel cylinders. The disk burst pressure is generally stamped on the valve or retaining plug. Also, the disks themselves are color coded or stamped with a pressure designation.

Aluminum cylinders have similar markings for designating aluminum alloys, serial number, manufacturer, and distributor. The standard pressure of aluminum cylinders marketed at this time is 3000 to 3300 psig. The "K" factor "+" symbol does not apply to the aluminum cylinder; the cylinders have no designated overfill rating. The safety factor (working pressure to theoretical burst pressure) is about 2.5 for aluminum cylinders.

BACKPACK AND HARNESS

The scuba cylinder is secured to the diver's back with a harness and/or backpack assembly. A few years ago, most single- and double-tank assemblies were fitted with a removable metal or plastic contoured backpack assembly. The waist strap is equipped with a quick-release buckle, and one shoulder strap was generally equipped with release snaps to facilitate donning and permit rapid removal of equipment in an emergency. The backpack must fit the diver comfortably, hold the cylinder securely, and be constructed of corrosive resistant materials.

Today, most backpacks are integrated with a buoyancy unit (BCD). In fact, it is difficult to even find the separate back pack assembly in dive shops and at resorts. If you intend to use a separate collar-style BCD, be certain to include a compact back pack in your travel kit.

The integrated backpack-BCD is available in several configurations and with numerous accessories. The most common BCDs are designed like a sleeveless jacket or vest. The buoyancy bag may be either a single layer of waterproof nylon or two separate bags — an inner bag of waterproof vinyl with an outer protective nylon bag. The single layer bags appear to be gaining popularity because of their low profile and minimum bulk design.

Some BCD buoyancy bags completely encompass the shoulder and have the general appearance of a down vest. More recently, BCDs have been designed with a more open frontal area. An adjustable harness connects the shoulder portion with the lower portion of the bag. Many of these models are fitted with a release buckle. The units are easier to don and doff, less restrictive, easier to adjust to the body, and allow unobstructed access to dry suit inflation valves.

All modern BCDs are fitted with a large diameter air inlet-discharge hose, generally positioned on the right side of the BCD. The hose is attached to the buoyancy bag in the upper shoulder area. The hose is fitted with a valve assembly that is connected via a medium pressure hose to the regulator first stage. A quick connect-disconnect fitting is used. The diver may mechanically flow air into the BCD by depressing a small valve button on the inflation mechanism. The BCD may be orally inflated by depressing another valve and blowing into the BCD. Air may be released from the BCD by holding the valve assembly above the head and depressing the oral inflation valve. In addition BCDs are fitted with a large air discharge-overpressure valve. In some models this valve is part of the inlet-discharge hose assembly and may be mechanically activated by pulling downward on the hose. Other models are separate from the hose assembly and may be mechanically activated by pulling on a cord attached to the center of the valve assembly.

The BCD is secured to the diver by a waist belt consisting of nylon webbing and a buckle; some models also have a smaller chest strap. Many divers now prefer wide Velcro waistbands. A variety of zipper or Velcro closure pockets are incorporated into the BCD as well as special attachments for auxiliary breathing units, pressure gauge hoses, and car keys. BCDs are sized from extra-small to extra large and available in a variety of repulsive colors. Most modern BCDs are not fitted with a CO_2

emergency inflation system. Only a few models currently offer this as an optional accessory.

Although the BCD is considered essential in many diver rescue procedures it is not considered to be a lifesaving or rescue device by the diving industry. Most BCDs have a printed warning against using the unit for rescue-lifesaving purposes and specify use for buoyancy control only.

Nearly all backpack/BCDs are equipped with a nylon strap and cam-action mechanism to facilitate cylinder attachment. This mechanism should be adjustable and equipped with a safety mechanism to prevent accidental release of the cylinder. The assembly should be inspected and adjusted, if necessary, prior to each dive. Some models, especially ones produced in the earlier years of this design, were subject to accidental opening and cylinder release.

For double-cylinder assemblies, the standard harness (without backpack) is still preferred by many divers. Some divers use foamed neoprene sleeves over the shoulder harness to increase comfort and prevent chaffing. Today, with the exception of deep cave and wreck divers, most divers use single cylinders. Consequently, many double-cylinder band and harness systems are of individual design and construction or available only from small specialty companies that service these segments of the diving community.

REDUNDANT OR AUXILIARY BREATHING SYSTEMS

Ironically, throughout the early days of scuba diving divers relied on the controlled emergency swimming ascent or sharing air from another diver's scuba in the event of accidental air supply depletion or unexpected equipment malfunction. Both emergency ascent procedures had inherent risk and were the focus of considerable controversy in the recreational diving community for sometime. Why would a rational person enter a foreign environment, one incapable of naturally supporting human life functions, relying on a single life-support apparatus? This appears to be inconsistent with rational safety practice. Yet today at least 98% of the scuba diving population dive with a life-support system that provides *no independent redundant air supply*. They must depend on another diver or make a controlled emergency ascent if the need arises.

Auxiliary Second Stage. The common system for use in an air loss emergency today is actually not a redundant system. Most scuba divers now use regulators with dual second-stage assemblies to facilitate sharing air with another diver. The original name for the system was the octopus derived from the multiple number of hoses attached to the regulator's first stage. Today terms such as safe-second, alternate air source, and auxiliary air source are also used.

This system offers no apparent advantage to the individual diver who has experienced a malfunction or air supply depletion. Only the buddy or another diver can supply life-support. The advantage lies in the fact that the two divers do not have to share a common mouthpiece assembly as in conventional buddy breathing. The rescue diver simply hands the victim or distressed diver a second mouthpiece assembly. Now the divers can proceed to the surface in a more or less normal ascent mode. This system is, in my opinion, far superior to the emergency swimming ascent or conventional buddy breathing ascent. The octopus system may well be the most feasible auxiliary breathing system for the average scuba diver at the present time. However, there are some significant considerations and problems:

* The fact remains that there is a necessity for an immediately available buddy who has enough remaining air to support two divers in an ascent mode.

* There is the necessity for the establishment of universal techniques and procedures for using the octopus system. Where is the octopus unit carried on the diver? Should the rescue diver give the stricken diver primary mouthpiece and then use the extra mouthpiece? Or does the rescue diver retain the mouthpiece and pass the extra mouthpiece to the victim? These and other questions are discussed in the section on diver problem management.

* Many divers simply let the octopus unit drag freely at their sides over rock, through plant debris, in sand, and so on.

In such cases the mouthpiece may become clogged with debris or the regulator is inoperative when it is needed in an emergency.

* The increased number of hoses, five if a dry suit hose is used, are attached to the regulator first stage. This is both awkward and could present a hazard in some cases.

* Some researchers have suggested that most current scuba regulators exhibit marginal life-support flow characteristics under conditions of extremely high ventilation rates and volumes at depths in excess of 100 fsw for a single diver. For two divers at the deeper depths under stress conditions, some regulators may simply not supply sufficient air for octopus breathing.

Even though the above factors suggest that the octopus is far from ideal, it is the most popular of alternate air sources in use today. This popularity is based on the following:

* Unfortunate and unnecessary scuba diving fatalities have been attributed to controlled emergency swimming ascents and unsuccessful attempts at sharing a single regulator.

* Any circumstance in which a diver must remove the mouthpiece creates a potential hazard.

* Most authorities recognize that the deterioration of motor skill performance, such as in buddy breathing, is quite rapid unless practiced regularly.

* Most divers experience difficulty in maintaining buoyancy and operating a buoyancy control device while sharing a single regulator.

* The fact that perceptual narrowing which occurs under stress compromises the diver's ability to buddy breathe and control buoyancy.

* The octopus system has been actively promoted by manufacturers and instructors.

The following are aspects for octopus breathing methodology that must be considered by any diver:

* The octopus hose should be at least 32 inches long. This facilitates maintaining a desirable distance between the two divers.

* The positioning of the octopus when not in use appears to be the most critical consideration. The following should be considered:

  * Do not let it dangle or drag unattached to the diver.

  * The best location for the octopus when not in use appears to be attached to the chest area of the diver by a firm quick release snap mechanism. The chest area can be reached from virtually any position and keeps the unit readily available for the donor.

  * Placing the octopus in the buoyancy compensator pocket makes quick access difficult and hides the unit.

  * At peak flow requirement associated with simultaneous inhalation by two divers and low cylinder pressure, the regulator may not be capable of delivering sufficient air to meet respiratory demand. Furthermore, the high flow requirements associated with two divers breathing from a single first-stage source might enhance regulator icing or cold induced malfunction.

Compact Auxiliary Scuba. Wreck divers have used a compact auxiliary scuba for nearly three decades. Although this system has taken a secondary place to the octopus and dual-valve manifold (with two regulators), it still has considerable merits for the diver who wants an independent redundant air supply system. The auxiliary scuba consists of a small cylinder (15 to 40 cf) and a regulator. The small, slender cylinder is nested on the back of twin cylinder scuba or attached to the side of a single cylinder. Generally, the secondary second stage mouthpiece unit is carried attached to the diver's chest area (possibly the BCD or shoulder harness). The air valve on the auxiliary scuba is generally turned on prior to the dive. I consider the unit primarily as a self-rescue system and highly recommend that, if this system is used, both divers in the buddy pair have one. The auxiliary compact scuba system is often called a pony tank or buddy bottle.

Dual Scuba. The use of a two full-size independent scuba assemblies mounted in a twin cylinder band/harness system is becoming increasingly popular among divers working in overhead environments (i.e., caves, under ice, and shipwrecks). This system involves carrying two complete scubas in a special back pack. Each scuba is equipped with a regulator and pressure gauge. This system requires an air management protocol that involves switching from one unit to the other several times during the dive and should only be used with special training.

Divers using auxiliary scuba must be certain that the cylinder is fully charged prior to diving. Furthermore, they must assure that the regulator does not accidentally exhaust air during the dive. Some divers have discovered that their auxiliary scuba have been completely drained during the dive. This can be prevented by careful inspection of the regulator after entry and periodic monitoring throughout the dive. Some divers invert the auxiliary scuba to place the cylinder valve in a position so that they can easily reach with their hand. The cylinder is only turned on if and when emergency air is required. A simple on-off valve that may be placed between the hose and the second stage is also available.

Tiny Scuba. Very compact scuba units containing only two to four cubic feet of air are also available today. Although these units are highly praised by some divers and researchers, the amount of available air is limited and may be insufficient in cases of high respiratory demand at deeper depths. Although ideal in concept, the system has limitations and, over the past decade, has gained only limited acceptance in recreational and scientific diving.

Dual Valve Manifold. The introduction of the dual-valve manifold (DVM) was once considered to be one of the most significant advancement in scuba redundant breathing systems. At present, the DVM is available for single- or twin-cylinder scuba. This manifold allows two completely independent regulators to share a common air supply. In the event that either regulator malfunctions, it can be turned off and all the air is available to the second regulator. This system has all of the advantages of the octopus system plus it allows self-rescue in the event that the primary regulator fails. Two factors should be noted. First, primary regulator failure is very rare. Second, most air supply problems involve careless depletion of the air supply. This system is useless for the individual diver in situations of air supply depletion.

The ultimate system for redundant breathing in scuba diving is, at this time, still unavailable. Ultimately, a completely independent, compact scuba similar to the present pony tank may be most desirable. I envision a triple 40- or 50-cf cylinder scuba with one cylinder valved independently as an auxiliary scuba. A special compact auxiliary regulator and refined harness-backpack design is needed.

SELECTING A SCUBA SYSTEM

When selecting an underwater breathing apparatus you are actually assembling various component for a scuba system. Unfortunately, complete scuba systems are generally not pre-assembled. Individuals divers must select from among an overwhelming assemblage of components including a variety of models and price ranges for each. To further complicate the selection process one finds that there are no objective and independent consumer guides to assist in selecting scuba equipment. One is a the mercy of dive store employees, manufacturer advertisements, instructors, and others divers for guidance in the selection process.

Periodically, about every 7 to 10 years, the US Navy Experimental Diving Unit evaluates regulators, BCDs, and pressure gauges and issues a report. This evaluation generally classifies regulator in accord with breathing performance characteristics. The US Navy standard of performance is quite rigid and only a few commercially available regulators qualify in the top category. Those manufacturers with regulators in the top category immediately incorporate this fact into their advertising and promotional materials. Some recreational diving authorities suggest that this Navy standard far, far exceeds the requirements of recreational and scientific scuba divers. Furthermore, many regulator models evaluated by the Navy have already been modified, a few even discontinued, and new ones released before the the Navy reports is even distributed. Keep in mind that it is unlikely for any regulators on the market which has been proven unsafe. The potential legal consequences just won't allow it.

In selecting components of a scuba system I consider manufacturer reputation, equipment reputation for durability and dependability, availability of service, and cost. I generally select items from major manufacturers rather that off-brands. Furthermore, I am a bit cautious about purchasing the new products as soon as they appear on the market. Unfortunately, the American consumer is also the product tester of the diving industry. Consider your person body size when selecting equipment, especially BCDs.

First of all keep in mind that many dive store salespersons are minimum wage workers who may or may not have a working knowledge of diving equipment. Often they are recent graduates of advanced or specialty courses who happen to be in the right place at the right time. Through part time employment in a dive store they often qualify for employee discounts and spend most, if not all, of their meager earning on diving equipment. Depending on the individual they can be quite aggressive and delight in sharing their extensive knowledge of diving with you. Often what they do not know they simply makeup. Please do not conclude that all salespersons are less that competent. Many are quite knowledgeable, especially long term employees, owners, and managers. If you have doubts, seek the advice of the manager or owner. Also, keep in mind that it is their job to sell you the most expensive and highest profit margin equipment possible and as many items of equipment as possible. When you walk into a dive shop you are a potential for a $2,000 to $3,000 sale.

Second, keep in mind that the person who knows even less about diving equipment is the average instructor. Unless an instructor is employed in a dive shop or is extremely active in all facets of diving they seldom have an opportunity to remain abreast of the latest developments in diving equipment. Few attend manufacturer's equipment clinics or try new equipment as it comes onto the market. Many of today's instructors have only a year or two diving experience. Unless they have had exceptional opportunities to attend clinics and so on, their knowledge of equipment will generally be quite limited.

Third, divers are among the worst liars in the world. It is often very difficult to obtain an objective opinion for a dive regarding the performance of a piece of equipment. They will generally always offer an opinion; it is the objectivity of that opinion that concerns me. One of the best ways to develop insights is to talk with a large number of divers. Eventually a pattern of good and bad equipment will emerge. Also, observe divers at dive sites an note items that tend to malfunction more frequently than others.

Ideally, if you have time and opportunity, review the catalogs of several major manufacturers and based on the information gained in class and discussions with fellow students and divers list the items of equipment that you wish to purchase. The scuba system for a beginning diver will generally consist of the following:

* Basic regulator,
* Pressure gauge (many divers purchase an integrated console that also includes a timer and depth gauge or a dive computer),
* Auxiliary second stage (with longer hose and retainer device; some elect an integrated BCD inflator and second stage unit),
* Buoyancy control device, and
* Cylinder.

If you intend to do most of your diving at Caribbean resorts, you may elect not to purchase a cylinder. The other items are basic to all diving and I encourage you to purchase your own equipment rather than rely on rentals.

Next, visit several dive shops, acquire as many opinions as possible, and shop for best prices. Eventually you will identify exactly what you want in a scuba system as well as a good dive shop. Keep in mind that you should be shopping for long term service as well as the best dollar value. You might be able to purchase a regulator for $10 or $20 less through a mail order supplier. However, will that supplier immediately repair or replace the item if something goes wrong?

ACKNOWLEDGMENTS

I wish to express my sincere appreciation to William L. High for reading this manuscript and providing many helpful comments and corrections.

Manuscript completed: 30 January 1990
Manuscript revised: 4 February 1990
Manuscript revised: 21 June 1990

CHAPTER 3-3

MAINTENANCE OF OPEN-CIRCUIT SCUBA

INTRODUCTION

Instruction in preventive maintenance of equipment should begin with the first items of equipment discussed in the classroom and used in the pool. Students should learn the theoretical aspects in the classroom and actually practice proper equipment maintenance procedures during *all* skills training. It may be more expedient for the instructors to wash the regulators after each class; however, those intructors who perform this task are denying the student proper and complete training.

REGULATORS

Open-circuit scuba regulators are durable, but they can be damaged and malfunction unless given reasonable care. Simple preventive maintenance will ensure maximum operating efficiency with minimum repair requirements. Scuba regulators are built extremely rugged externally but are relatively delicate interally. The clearance between parts is close and foreign material or rust and salt corrosion can cause inefficient operation and malfunction. Observe the following preventive maintenance procedures for open-circuit scuba regulators:

* Never stow or transport a scuba cylinder with the regulator attached.

* Do not attempt to lubricate your regulator; only proper lubricants should be applied by qualified regulator service persons. Silicone spray, commonly sold in dive shops, can cause some rubber parts such as exhaust valves and diaphragms to warp. Sprayed into the second stage of a regulator, silicone can be quite dangerous. It can seep under the diaphragm retaining ring and possibly cause the diaphragm to *pop out* during use. Underwater the consequences could be serious. Also, breathing excessive quantities of silicone mist can be hazardous to your health.

* Avoid sharp bends or tight loops that can seriously weaken the internal nylon or cotton braid of both second-stage and pressure gauge hoses. Store with hoses straight or supported. Use stress relieving sleeves on all hoses at the point of connection with the second-stage housing.

* Do not leave the regulator attached to a standing cylinder following a dive. The regulator may be severely damaged if the cylinder is knocked over.

* Do not allow the second-stage to *drag* when snorkel swimming. This may place excessive and potentially damaging strain on the regulator hose where it attaches to the second-stage and can seriously weaken hose fibers especially if the regulator second-stage is caught on kelp or in rock crevices. The second-stage may fill with sand during surf entries/exits. Pressure gauge and auxiliary second-stage hoses are subject to the same type of damage.

* Keep the scuba out of direct sunlight because it causes rubber products to deteriorate rapidly and cylinder pressure to increase significantly.

* Do not allow water or foreign matter to enter the high-pressure inlet of the regulator. *Dry* and insert the protective cap into the yoke to seal the high-pressure inlet immediately after detaching the regulator from the cylinder. When water (salt or fresh) evaporates, it leaves a residue of salts or minerals.

The residue remaining from evaporating water can accumulate on internal parts of the regulator and result in friction, decreased functional efficiency, and excessive wear. For example, it has been shown that only a few drops of sea water remaining in the first stage of a regulator after several uses can result in significant performance degradation to the point of endangering the diver's safety.

Chlorinated swimming pool water is nearly as harmful to regulator parts as salt water. Use only plastic or rubber protective caps with a solid core and fitted with an O-ring to ensure a more positive seal. Avoid metal protective caps since electrolysis corrosion may result from the reaction of contact between two different metals and salt water. Rubber ball type caps are difficult to center and may not seal. Placing excessive pressure on the ball with the yoke screw can cause damage to the filter.

Rinse regulator thoroughly with fresh water after each use as follows:

1. With the dust cap securely in place, rinse in fresh water, preferably warm; a 2-minute warm water rinse is recommended to dilute salt water accumulations and remove all foreign matter. This is extremely important for a regulator with the unprotected piston-type first stage since salt and sand deposits can interfere with the movement of the piston. The entire regulator may be submerged in rinse water.

2. If possible, wash the second-stage assembly by flowing water into the mouthpiece and out the exhaust tee to thoroughly remove sand and salt. *Do not depress the purge button while washing the second-stage assembly.* This action opens the second-stage valve and will allow salt, foreign matter, and water to enter the valve assembly, hose, and possibly the first stage. If there is any possibility of the purge button having been depressed during washing, place the regulator on a scuba cylinder and allow air to flow through it. Rinse the outside of the second-stage housing and run water across the diaphragm.

3. Shake excessive water from the regulator and hang it by the yoke to dry; be sure the hoses are straight or supported; avoid sharp bends.

Occasionally, a regulator may be accidentally submerged in pool, salt or even polluted lake water without the protective cap in place. If this does occur, the interior of the regulator may be contaminated. It is difficult to clean the interior of the first stage without diasssembly. *However, do not attempt to disassemble the regulator!* Place the contaminated regulator on a cylinder and free-flow air through the regulator for several minutes. If serious or health-threatening contamination is suspected, do not use the regulator until it has been disassembled and cleaned by a professional repair person.

During storage and transport, protect regulators from abuse, physical damage and exposure to high ozone levels in surrounding air (produces rubber deterioration). A protective container is recommended for carrying regulators in the field. Regulators should be stored in a cool, dry, dark place. Placing the regulator in a plastic bag will protect the regulator's rubber parts from ozone, especially if you live in an industrial area. Do not store the regulator in the same room with water heaters or furnaces.

Careful inspection of the high-pressure inlet filter is an excellent indicator of potential type and source of foreign material that may be entering the regulator. This filter is designed to exclude large particles of foreign material (generally 40 microns and larger) ; however, it will not prevent all materials from entering the regulator. The following indicators of cylinder contamination or regulator mishandling are noted:

* A black, wet substance is an indicator of salt water inside a steel cylinder.

* A black dust or powder may indicate contamination of the cylinder interior with activated charcoal from a compressor filter.

* A reddish-brown accumulation indicates fresh water inside a steel cylinder; dry accumulations are indicative of rust and

wet materials suggest the presence of fresh water in the cylinder.

* A greenish or turquoise accumulation indicates that salt water has come into contact with the filter and suggests potential internal contamination of the regulator. This is usually a result of carelessness.

* A white crystal accumulation indicates that salt water, possibly from the dust cap, has evaporated and left a deposit of salt.

* Small flakes of paint-like substance may indicate that the interior lining of the cylinder is coming off (only for early model scuba cylinders with coated interiors).

* Sand and dirt indicate abusive handling of the regulator by dragging it through sand or dirt and/or that the dust cap fits improperly.

Any of these particles can enter the regulator and impair performance or possibly cause serious malfunctions. Particles smaller than 40 microns may actually pass through the regulator to the diver's lungs. If these substances are present, have the regulator inspected and, if indicated, the cylinder inspected by a professional scuba service person.

Periodic Inspection and Overhaul

Scuba regulators should be inspected by a qualified technician annually. In the event of even minor malfunction, immediate repair is essential. Annual maintenance procedures involve inspection (and possible replacement) of all rubber parts, pressure-setting adjustments, and evaluation of the internal condition of the regulator. Periodically, the regulator must be completely overhauled, including disassembly, cleaning, and replacement of worn or defective parts. If the regulator has been subjected to abuse and physical shock, it should be inspected by a qualified technician prior to use. A record of all inspections and repairs should be maintained in the diver's logbook.

Scuba Regulators Must Be Inspected Annually!

Keep in mind that periodic inspection of a regulator also includes the auxiliary second-stage (octopus), BCD inflator, and pressure gauge. Today, many divers use combination BCD-auxiliary second stage assemblies. Many of these divers leave this unit on the BCD and fail to submit it for periodic maintenance. Serious mishaps have resulted from BCD-auxiliary second-stage failure. One diver was swimming at a depth of 80 feet when he depressed the inflation button to add air to his BCD, it apparently stuck or the unit malfunctioned and rapidly inflated the high capacity BCD. The diver was carried out-of-control to the surface in a few seconds and more than 1200 psi of air drained from the scuba cylinder before he could disconnect the hose. Only quick thinking, skill, and experience prevented serious injury or death.

HIGH-PRESSURE CYLINDERS

Air cylinders and high-pressure manifolds should be rinsed thoroughly with fresh water after each use to remove all traces of salt and other deposits. The exterior of the cylinder should be periodically inspected for abrasion, dents, and corrosion. If the cylinder has been subjected to severe damage resulting in deep abrasion or denting, it should be professionally inspected and hydrostatically tested before refilling.

External cylinder corrosion (rusting) is rare with modern aluminum and galvanized steel cylinders. However, there are still a few old steel cylinders that require continuous inspection and maintenance in use today. If any corrosion is detected on the cylinder exterior it should be removed and a protective coating applied to these areas to prevent further deterioration of the cylinder wall. Realistically, old unGALVANIZED steel scuba cylinders should be removed from service and replaced with properly protected cylinders.

The cylinder boot should be removed periodically. The portion of the cylinder under the boot is particularly subject to corrosion since the boot, regardless of design, may retain moisture next to the cylinder. Galvanized steel cylinders can exhibit significant corrosion. Aluminum cylinders are less likely to exhibit corrosion in this area. Modern self-draining cylinder boots to minimize moisture retention are recommended.

The interior of scuba cylinders is also subject to corrosion. About 20 years ago some scuba repair facilities claimed that approximately 80 percent of the steel scuba cylinders submitted for hydrostatic testing had to be tumbled to remove excessive rust from the interior of the cylinder. Care must be taken to prevent moisture accumulations in high-pressure cylinders. Moisture can enter scuba cylinders in several ways. First, if a cylinder is completely emptied and the valve is left open atmospheric moisture can enter the cylinder. If the cylinder is stored in a moist location with the valve open, internal corrosion can be significant.

Second, when a cylinder is completely drained of air underwater, water may enter the cylinder through the regulator if the purge button is depressed allowing the second-stage valve to open [1]. The obvious solution to this problem is never to allow the cylinder to be completely drained of air. Always terminate the dive with a small amount of air remaining in the cylinder. Also, never depress the purge button underwater when snorkeling with an empty cylinder.

Third, moisture may enter the cylinder during charging. The cylinder should never be completely submerged prior to attachment of the filler assembly. Small amounts of water may be trapped in the valve orifice and injected into the cylinder. Furthermore, the filler assembly is often carelessly submerged in the water bath and small amounts of water may enter the end of the assembly. When it is placed on a cylinder this water is injected into the cylinder. This may be the most common sources of cylinder water today. Also, inadequate removal of moisture from air by high-pressure compressor filter systems is another source of internal moisture. Be certain that the compressed air filter system has an adequate moisture separator that is regularly emptied.

You can check for moisture in your cylinder by opening the valve, discharging a small stream of air, and inspecting the air stream for a whitish mist; dry air is clean. Keep in mind that you can cause condensation of atmospheric air at the discharge point if you rapidly release a large volume of air on a humid day and thus give a false indication. Carefully smell the air. Moist rust and corrosion has a damp and metallic odor. To preform this test, turn the air on first and carefully lower you nose to the air stream. Also, you only need a gentle flow of air, not a large blast of air. *Do not place you nose against the valve orifice and then open the valve; this is hazardous.* A high-pressure blast of air into your nostril could change your entire outlook on life. If a large quantity of water has entered a cylinder it may be detected as a sloshing sound as the cylinder is tipped back and forth.

It is extremely important that the cylinder interior remains absolutely dry. Rust and corrosion are obvious problems. Regulator malfunction as a result of particle contamination is also possible. The cold water diver faces the additional hazard of internal regulator freezing and subsequent malfunction.

Internal Inspection

Because of concerns with cylinder contamination, moisture accumulation, and corrosion, all scuba cylinders, steel or aluminum, should be internally inspected at least once a year. A special rod-type light that illuminates the entire inside of the cylinder should be used for this visual inspection. Most diving equipment suppliers and repair facilities provide this service. Standards and procedures for visual inspection of compressed gas cylinders are discussed in detail in an excellent book, *A Guide for Visual Inspection of Scuba and Scba Cylinders* [2].

**The Interior of
Scuba Cylinders Must Be
Visually Inspected
Annually!**

The internal visual cylinder inspection program began about two decades ago in the recreational scuba diving community. There are, to my knowledge, no local, state, or national laws that require periodic inspection of personally owned scuba cylinders. However, the diving community has voluntarily imposed this safety standard on itself. A study conducted by the University of Rhode Island in about 1970 revealed the significance of internal corrosion in steel cylinders [1, 3]. The explosion of a scuba cylinder was among the cases used to illustrate the seriousness and danger of cylinder deterioration. People have been seriously injured and killed when filling apparently unsafe, rusted cylinders.

Most instructors and professional persons that fill cylinders support the annual internal inspection program. Visual inspection by a qualified examiner will detect nearly all unsafe cylinders prior to hydrostatic testing. There are now approximately 2,300 trained scuba cylinder inspectors in the world. Most air suppliers will not fill a scuba cylinder that lacks a current inspection sticker. Unfortunately, many inspectors are untrained and not qualified to inspect the inside of cylinders. Although there is an excellent inspector training and certification program available [2], most dive shop inspectors are not certified for cylinder inspection at this point in time.

Some divers feel that aluminum cylinders do not need to be inspected annually since they do not rust. Aluminum corrosion is usually less severe that steel corrosion, however it can produce a destructive galling at the cylinder threads [1]. Furthermore, room temperature grain boundary creep and manufacturing deficiencies, commonly and inaccurately referred to stress cracking, has occurred in the neck and threads of aluminum cylinders and there is currently concern about pinhole leakage in the shoulder of aluminum cylinders manufactured by Luxfer (January 1990). This condition or flaw could be quite dangerous. All Luxfer cylinders manufactured between 1971 and 1987 should be subjected to an annual crack inspections. The same applies to all W. Kidde aluminum cylinders. If such leakage is detected, the cylinder should not be filled and it should be returned to the manufacturer for replacement.

If internal inspection of a steel cylinder reveals corrosion, the cylinder may be cleaned by tumbling. The tumbling process involves filling the cylinder approximately one-half full with an abrasive material such as palet abrasive, carbide chips, or aluminum oxide chips and allowing the cylinder to rotate. The abrasive materials remove corrosion and polish the inside surface of the cylinder. Aluminum cylinders are cleaned in a similar fashion using a special "washing tumble" procedure developed by PSI, Incorporated [2]. The cylinder is then rinsed to remove loose material and dehydrated internally to remove all traces of moisture.

In extreme cases, rust chips may be detected by rocking the steel cylinder through its horizontal axis while pressing it next to the ear and listening for foreign matter. Also gently tapping an empty steel cylinder with a hammer may reveal internal rust and corrosion. A clean cylinder will have a clear bell-like metallic ring and a corroded or structurally weak cylinder gives a dull wooden sound. These procedures are not to be considered as a substitute for visual internal inspections.

Hydrostatic Testing

High-pressure cylinders are subject to Department of Transportation (formerly, Interstate Commerce Commission) regulations. These regulations require that high-pressure cylinders transported from state to state by commercial carriers be hydrostatically tested at least once every five years. Most states and cities have ordinances that cover transportation of high-pressure cylinders requiring adherence to Department of Transportation regulations.

It is interesting to note that, to my knowledge, there are no official state or federal laws that require periodic hydrostatic testing of a personal recreational scuba diver's air cylinder. However, local laws may expand on the federal regulations. Also, cylinder testing has been an accepted standard of the community since the earliest days of scuba diving. Diving equipment suppliers and air station personnel will generally never recharge out-of-date cylinders.

**Scuba Cylinders
Must Be
Hydrostatically Tested
Every 5 Years!**

The water jacket method of hydrostatic testing is commonly used for scuba cylinders. In this method the valve is removed and a special test fitting inserted. The cylinder, filled with water, is placed in a water-filled pressure chamber and all air is evacuated. A high-pressure water line is attached to the test fitting and pressure is applied to the inside of the cylinder using a high-pressure hydraulic pump. Before pressure is applied, a burette reading is taken. The burette, attached to the test chamber by a water line, allows the tester to measure the amount of cylinder expansion in terms of water column displacement.

The pressure is increased to five-thirds (5/3) (or 3/2 for the new Genesis cylinders) the rated pressure of the cylinder, or in the case of the standard scuba cylinder with a rated pressure of 2250 psi, the test pressure is 3750 psi. This pressure is held for 30 seconds. A second burette reading is taken under full pressure. The water column rises due to expansion of the cylinder. The hydraulic pressure is released and the water column starts to drop, indicating that the cylinder is returning to its original diameter. After all pressure is released, a third burette reading is taken. Based on these burette readings, the permanent expansion, if any, of the cylinder is determined. According to DOT regulations, permanent expansion of 10 percent or more of total expansion indicates that the cylinder is unsafe for use. Cylinders that fail hydrostatic testing and show signs of structural damage must be condemned. This can be accomplished by stamping out the DOT specification symbols and figures or boring a hole in the cylinder. A cylinder cannot be restamped for a lower pressure.

Hydrostatic testing facilities are authorized to retest a steel cylinder to determine if the wall *elastic expansion* is low enough to retain the 110% (+) fill designation. However, most elect to not used the more complex test. Some facilities do not have the proper equipment, are not willing to expend the extra effort, or do not understand the process required to determine this elastic expansion factor. Generally, they only evaluate the cylinder for *permanent expansion.* Consequently, divers seldom see a "+" on cylinders after the original test.

The cylinder valve assembly and low-pressure warning mechanism should be periodically inspected. Immediate repair is necessary if it is determined that assembly is malfunctioning or faulty. Routine valve inspection and preventive maintenance includes checking and replacing, if necessary, O-rings and packings. The proper operation of the low-pressure warning valve is verified. Divers are discouraged from disassembling the valve mechanism and applying lubricants. The entire valve assembly should be rinsed with fresh water after diving, and protected from unusual abuse. Frequently, the reserve lever is damaged when hit against the roof of a cave or a ship's hull, or when the cylinder assembly is left unsecured on a boat deck in rough seas or in the back of a car during transport. Use a protective shield for cave diving and properly secure cylinders at sea and during transport. Cylinders should be tied down, blocked, or otherwise fastened to prevent shifting during transport in vehicles.

When not in use, the valve orifice should be covered with masking tape or a special plastic protector to prevent loss of rubber O-ring and accumulation of foreign material. Divers should carry extra cylinder valve orifice O-rings attached to the regulator or in the diving equipment bag.

Cylinders containing high-pressure compressed gas can be extremely dangerous if abused or misused. If the pressure of 2250 psi is multiplied by the number of square inches of surface inside a standard cylinder, the force is found to be approximately 433.3 tons. Property damage, physical injury, and even death have resulted from the explosion of high-pressure cylinders.

Scuba Cylinders Storage

Scuba cylinders may be stored at full pressure for short periods of time. However, most authorities suggest that the pressure be reduced to about 50 to 300 psi for storage periods exceeding a month or so. In the event that there is moisture in the cylinder, the higher pressures (high partial pressure of oxygen) accelerate rusting and corrosion. Also, in the event of fire or physical damage, the low pressure constitutes a lesser hazard. Leaving some air in the cylinder with the valve closed is the best protection against contamination of the cylinder interior. Steel high-pressure cylinders should be stored in an upright position. Should moisture collect inside the cylinder, corrosion will be less detrimental on the thicker bottom than on the walls. Aluminum cylinders may be stored on their side or in an upright poistion. Strap or secure the cylinder in the upright position.

Although compressed air normally does not show signs of contamination after storage for long periods, it is advisable to discharge the cylinder and recharge it. If a cylinder containing some water is stored at high pressure, the oxygen in the air may be depleted to a significantly low level in the corrosion process since oxygen is consumed in the chemical reaction. Scuba diving fatalities have been attributed directly to this cause [4, 5]. A scuba cylinder was filled about three months prior to its use one fatal dive. The victim apparently lost consciousness and drowned approximately 5 minutes after entering the water. Analysis of the residual air in the cylinder revealed an oxygen concentration of only 2 to 3% instead of the normal 20%. Inspection of the interior of the cylinder revealed significant corrosion. The investigators concluded that the oxygen concentration had been depleted as a result of corrosion.

Charging Scuba Cylinders

High pressure cylinders used with open-circuit scuba should be filled only with pure compressed air. Some special activity divers may fill scuba cylinders with pure oxygen to be used in decompression or for first aid. *This practice is discouraged.* First, if pure oxygen is to be used with a standard scuba, the entire unit — cylinder, valve, and regulator — most be cleaned for oxygen service. The possibility of oil contamination is always present. Pure high-pressure oxygen in contact with oil can, under the right conditions, cause an explosion and fire. Secondly, unless the cylinder is clearly marked *"OXYGEN ONLY"* and color coded, an unsuspecting diver might attempt to use it for conventional scuba diving. Below a depth of 25 feet oxygen toxicity could lead to a fatal accident.

Some divers are also now using mixtures of nitrogen and oxygen for special purpose open-circuit scuba diving. The mixture may contain up to 40 percent oxygen. Ideally, these scuba must also be cleaned for oxygen service. Technically, special oxygen service cleaning is not required until the cylinder is to be used with mixtures containing 40% or higher concentrations of oxygen. Furthermore the cylinders must be clearly identified as containing a mixture other than air and, ideally, color coded. Diving to depths beyond 80 feet using a mixture containing 40 percent oxygen could lead to oxygen toxicity and serious consequences.

The rated cylinder pressure should not be exceeded by more than 10 percent if over pressure is indicated by a plus (+) following the hydrostatic test date (steel cylinders); otherwise, never exceed the pressure stamped on the cylinder. Overfilling places extreme stress on the cylinder walls and may result in metal fatigue. I am aware that many special activity divers (especially cave and shipwreck divers) charge their cylinders to significantly higher pressures. Many either plug the pressure relief mechanism on the cylinder valve or insert doubled or special thick burst disks. Cylinders designed for 3000 psi pressure are often charged to 3800 psi or more in order to increase dive duration. This is, in my opinion, a high risk procedure that can cause serious metal fatigue and significantly shorten the safe life of the cylinder. The added risks to persons charging and handling these over pressureized cylinders are obvious.

Never allow the cylinder to overheat during charging. Cylinder temperature should not exceed 120° F; Excessive heat, especially involving temperatures above 350° F, can result in significant structural damage.

BUOYANCY CONTROL DEVICES

The buoyancy control device is part of the scuba system and must be maintained with as much care as any other scuba component. Subjectively, I would estimate that more divers are compromised each year by BCD malfunctions than scuba regulator malfunctions. BCDs should be inspected and verified to be fully operational prior to each dive. Periodic inspection by the diver should include a leakage test. I always inspect my unit prior to any major diving trip and after long periods of storage. The initial test involves inflation to full capacity until the over pressure or relief valve begins to discharge air. The unit should then hold inflation for approximately two hours without significant loss of air. Tiny leaks may be detected by systematically submerging parts of the unit in a large container of water.

The periodic test also includes operating the inflation and deflation valve several times to assure proper function and no leakage. If the inflation valve continues to leak air into the BCD when the button is released, it is malfunctioning and must be repaired or replaced before diving. Accidental overinflation of the BCD while submerged could lead to an uncontrolled ascent. I recall one incident where a BCD inflation valve stuck in an open position and carried the diver out-of-control to the surface from 80 feet in a few seconds.

The manual deflation valve must also be inspected and assured functional. I recall an incident where a divers BCD deflation valve apparently stuck in an open position. Consequently, when the diver apparently attempted to put air into the BCD, it immediately flowed out of the deflation hose. Unfortunately the diver drowned and we will probably never know the true sequence of events. It appears that the diver, unable to compensate for buoyancy changes, panicked. In a struggle to swim back to the surface he may have held his breath and experienced pulmonary barotrauma. He was found on the bottom. Ironically, his weight belt was still in place. If the diver had simply dropped his weight belt he may have very well surfaced without distress and survived. Furthermore, the BCD was at least two years old. To my knowledge there was no record of inspection or maintenance. Most divers submit scuba cylinders and regulators for annual inspection but few pay any attention to their BCDs. *In my opinion, the BCD valve systems must be subject to professional inspection annually and overhauled or replacement as indicated.*

CONCLUSION

Diving equipment must be inspected and assured to be operational prior to every dive and following each dive the equipment must be properly washed and stowed. A diver must never use an item of equipment that appears to be malfunctioning. Furthermore, if inadequate performance or suspected malfunction is noted during the dive, the dive must be terminated immediately and the equipment repaired or replaced prior to future diving.

Periodic inspection and repair by professional service persons is required for all scuba components. Regulators, BCD valves, and cylinders must be inspected annually. Scuba cylinders must also be hydrostatically tested every five years.

Dive injury or fatality is seldom caused by equipment malfunction. However, when equipment is indicated as the probable cause, it generally exhibits evidence of diver abuse or neglect and lack of periodic preventive maintenance.

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ACKNOWLEDGMENTS

I wish to express my sincere appreciation to William L. High for reading this manuscript and for his many helpful comments and correction.

Manuscript completed: 3 February 1990
Manuscript revised: 21 June 1990

CHAPTER 3-4

BUOYANCY AND THE SCUBA DIVER

INTRODUCTION

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

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

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

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

> To overcome this [buoyancy] it is necessary to add weights to the diver. As he submerges, water compresses the air in the suit reducing the buoyancy. A relatively safe method is to add a few pounds of weights, then submerge to twenty or thirty feet and check to determine if an excess positive buoyancy still exists. More or less weights can be added as needed to obtain neutral buoyancy at the desired depth.

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

> One pleasant characteristic of free diving is the weightlessness in water, which enables the swimmer to proceed in any direction with surprisingly little effort. The same neutral buoyancy allows various submarine acrobatics and maneuvers, to the beginner's delight.
>
> A standard 70 cubic foot Aqua-Lung tank charged to 1800 pounds per square inch and with the regulator attached - selected at random by the author - weighed 36 pounds in air and 2.1 pounds in water. The same tank, when effectively exhausted, had a positive buoyancy of about 4 ounces in sea water.
>
> In addition to the weight of the 70 cubic foot Aqua-Lung (2.1 pounds) the author requires another 3 pounds ballast for approximately neutral buoyancy in sea water while using swim trunks. In fresh water, however, the author is slightly heavy (negatively buoyant) with no ballast. A cold water exposure suit will require much more ballast, perhaps 15 pounds, for neutral buoyancy in sea water, because of the diver's changed displacement.
>
> It must be kept in mind that the individual buoyancy and ballast requirements will vary greatly, depending on the body build (or specific gravity) of the diver. Some people even tend to sink in salt water, without a suit, and with lungs full of air. Negatively buoyant

swimmers, perhaps 3% of individuals, should be aware of their peculiarity.

Ballast adjustment may depend on the type of activity planned. If much stationary or heavy work on the bottom is anticipated, the diver may prefer to be quite heavy. For most underwater activities, however, the free diver will prefer approximately neutral buoyancy and the following adjustment procedure is recommended:

With the cylinder(s) about 50% exhausted and wearing full equipment, the diver should enter water about 9 feet deep. While upright in the water, with arms and legs motionless, the diver exhales as much as possible. If neutral, he will sink slowly to the bottom, only to begin rising at the same rate as a full breath is taken. If this is not the case, he adds one pound at a time until this balance is achieved. Often, a beginner will find his buoyancy apparently "changing" after diving for a time. This will happen if he did not completely exhale or inhale, as described, during the buoyancy test.

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

Well, that is the way it was near four decades ago for an earlier generation of diver. Take note of two considerations: (1) the very careful adjustment of ballast (to the pound), and (2) breath control. Today, after nearly 40 years of evolution in scuba diving and equipping the diver with nearly $400 worth of power-inflated buoyancy control equipment, one of the pleasant characteristics of free diving is the weightlessness in water which enables the swimmer to proceed in any direction with surprisingly little effort.

To quote a line from a TV commercial, "You've come a long way, Baby!" So true! Scuba diving has come a long way in these 40 years. Easy breathing single-hose regulators, pressure gauges, "octopus" regulators, decompression microprocessors, thin fabric dry suits, and buoyancy control devices (BCD) [or buoyancy compensators (BC)] are all common items for the modern scuba diver. It's great to be a scuba diver today!

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

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

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

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

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

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

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

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

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

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

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

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

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

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

If we combine the compression of the wet suit and the weight of a full cylinder of air, the diver will be about 8 to 9 pounds *heavier* at the beginning of a 120 foot dive than at the end of the dive when swimming at 30 feet. If the diver plans to decompress at 10 feet, then he/she will be about 3 pounds more buoyant than at 30 feet. In the final analysis, the diver may experience a 14 to 15 pound buoyancy variation over the course of the dive.

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

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

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

Experience is a great "changer of buoyancy." I have seen divers remove as much as 8 pounds of weight from their weight belt during their first year or so of diving. One dive guide told of an individual who, with proper retraining, removed 22 pounds of lead from their belt during a one week dive trip. They simply become more relaxed, their breathing pattern evens out (reduced tidal volume and RMV), they gain skill in handling themselves in the water, and finally received proper instruction in diving.

WEIGHTING THE DIVER

As previously stated, the amount of weight required to achieve proper buoyancy depends on a number of factors and should be re-evaluated on a regular basis. Every time the diver changes suits and size of cylinder weights must also be adjusted.

Many instructors tell their students to use 10 to 15% of there body weight as a base figure. However, they occasionally fail to emphasize that this is only a "rough" estimate for a diver wearing a 1/4-inch wet suit. Other instructors will weight the student to be essentially "neutral" at the surface at the beginning of the dive. The diver will be about 5 pound "lighter" at the end of the dive because of air consumed and may have difficulty maintaining control during the last 20 feet of ascent.

Today, the trend is moving toward very careful weighting of divers. Finally, the haphazard approach to diver weighting associated with the promotion of BCD sales is behind us. Divers and instructors are also more environmentally sensitive. Consequently, proper weighting in order to prevent damage to delicate corals is now becoming fashionable. There is also more awareness of the significance of control during ascent and making precautionary decompression stops at 10 to 30 foot depths.

Many authorities now recommend that a diver be weighted so that he/she is neutrally buoyant at approximately 15 feet with 300 to 500 psig of air remaining. This should accommodate a controlled ascent. Many divers will be able to adjust for minor buoyancy changes using breathing techniques alone, especially when diving in thinner wet suits or dive skins. Others will use a small amount of air in the BCD.

Unfortunately, dive guides still tell horror stories of over-weighted divers demolishing coral reefs. Some divers arrive in the tropics and insist that the need 10 to 20 pound more lead that the guide deems reasonable. Many victims of diving accidents prove to be significantly over-weighted.

When all is said and one proper weight selection becomes a matter of trial and error. The prudent diver will develop "weight awareness" and continuously adjust weights until they establish perfect buoyancy control.

COMPENSATING FOR BUOYANCY CHANGE

By now it should be evident that a number of factors control diver buoyancy. The diver, in turn, has three major mechanisms of compensating for buoyancy change — weights, breathing, and buoyancy control device. In addition, the diver can change swimming position in order to direct some component of the kicking force upward or downward and thus assist in maintaining a give depth level. However, this is a haphazard and energy demanding technique that should not be substituted for proper buoyancy adjustment.

In my opinion, the first and most important factor is proper weight selection. Unfortunately, many dive shops rent large hip-weights to divers for open water training. It is easier to deal with two large weights than 6 or 8 two and three pound weights. A one pound weight is hardly ever seen today.

Once the diver has determine the appropriate amount of weight for a given configuration of equipment, changes in buoyancy associated with air consumption can generally be made by slightly altering breathing patterns (slightly deeper or shallower breath). However, many people will introduce a small amount of air into their BCD.

Buoyancy changes associated with 1/4-inch wet suit compression are generally neutralize by injecting small burst of air into the BCD. Keep in mind that this air will expand and dramatically change buoyancy as you ascend to shallow water; air must be discharged in a controlled fashion (shorty burst) as one ascends. Some individuals with large lung capacities can even compensate for wet suit compression by slightly altering their breathing pattern.

LEARNING BUOYANCY CONTROL

Before you can master buoyancy control you must learn to *relax and breathe normally* underwater. Breathing rapidly and deeply can cause significant changes in buoyancy with each breath. Beginning divers should control their descents and ascents by using an anchor line or descent line. This practice allows for precise control and increased diver confidence. You can make mistakes and have time to correct them because of your hold on the line. Soon you will learn to "feel your buoyancy" change with each inflation or deflation of the BCD and eventually each time you inhale and exhale. With experience you will gain a anticipation — you will anticipate what will happen as you inflate and deflate your BCD. You will anticipate what will happen as you change depth. You will instinctively adjust buoyancy as you ascent by discharging air from your BCD.

As you gain experience you will find that you can "fine tune" your buoyancy by adjusting your breathing pattern. If you are properly weighted and essentially neutral, you will find that if you stop breathing in the middle of a normal inhalation or exhalation you will remain motionless in the water. Keep in mind that it is better to learn this skill at 50 or 60 feet rather the 30 feet because slight changes in depth will not produce as dramatic of changes in volume. *Do not practice this skill in shallow water!*

Once you master buoyancy control, you will rarely have to touch your BCD during a dive. Proper weight adjustment, the initial compensation, and relaxed breathing is the key. Simply stop in the water column and breathe. Keep in mind that kicking momentum and body angle may be covering poor buoyancy control. Do you sink if you stop swimming? If so, you have not mastered buoyancy control. Many of the above were emphasized in an excellent article in *Skin Diver Magazine* from which the following quotation was also taken[10]:

> If you are a master of buoyancy control, you will rarely touch you BC during the course of a dive. The ultimate test! In 60 feet of water, wearing the correct amount of weight and

> being neutrally buoyant, cross your legs. Have your vest inflator in your left hand as you would normally during an ascent. But instead of kicking gently to ascend, try to control your ascent with your breathing. Breathe in, ascend a foot or so, and stabilize yourself at this new depth by exhaling. Repeat these steps, again and again. When you reach 30 feet, descend to 60 feet and do it again. Never fill your lungs completely and don't hold your breath. It will take time to master this skill.

I have included this quotation since many of you will read it or similar items in magazines. Please be careful if you decide to try such tests of skill. The above procedure is truly a demonstration of buoyancy control masterly. However, it does have a slight element of risk. I encourage you to master hovering at a fixed depth, ideally adjacent to a line which you may grab for control, if necessary, as a measure of your masterly of buoyancy control.

HISTORICAL NOTES ON BUOYANCY COMPENSATION

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

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

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

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

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

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

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

In about 1970 the At-Pac appeared on the scene. This unit consisted of a horseshoe-shaped bag fitted to a scuba backpack. The backpack was hollow and could be filled with lead pellets for ballast (to replace the weight belt). A quick-release door on the bottom of the back pack enabled the diver to jettison his ballast in an emergency. This was a significant departure from the conventional BCD design and developed as a second evolutionary path. In fact, the entire diving community started dividing into two camps, the At-Pacers and "otherwise." A segment of the recreational diving community accepted and aggressively promoted the "At-Pac" training and diving philosophy. I remember standing on the shore of Salisbury Quarry and being to that I was an unsafe diver because, "Any diver that did not use an At-Pac was an unsafe diver!" At least seven diving equipment companies marketed the back-mounted or buoyancy compensating pack (BCP), generic names for this design, by the mid-70s.

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

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

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

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

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

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

Throughout the 1970s the divers, instructors, and manufacturers debated the merits (and demerits) of different BCDs. Lift capacity seemed to be important to some debater-divers and ranged from 15 to 57 pounds. One scholar suggested that only about 10 pounds of lift was required to hold a diver's head out of the water and that a BCD with 18 to 20 pounds of buoyancy would be more than adequate. A noted national training director felt that it should be at least twice that figure and another expert gave a range of 25 to 50 pounds. Lift capacity is still with us today. At least one BCD currently available has a rated buoyancy lift of 80 pounds.

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

Many divers and instructors were concerned about *surface flotation position*. Would the inflated BC hold the diver's head "out-of-the-water" or "under water" at the surface? What if the diver was panicked? What if the diver were unconscious? Generally, what if? This debate raged through the 70s and into the 80s. All of this seems rather elementary now. My new "Super Duper Mark XIII Mod 4" BCD purchased in 1985 includes the following *disclaimer* printed directly on it,

"EMERGENCY FACE UP FLOTATION MAY NOT BE PROVIDED FOR ALL WEARERS AND CONDITIONS."

A quick review of the manufacturer's instruction manual that came with my other BCD revealed (1) "The XXX YYY ZZZ is not an emergency life vest, but is a means of compensating buoyancy." and (2) "Be aware that the XXX YYY ZZZ may not float a diver on his back with his head and mouth out of the water." Well, there it is, in print, *"the BCD is a BCD, not a life saving device."*

Now that that little issue has been resolved, let's get back to 1977. That was the year Scubapro revolutionized buoyancy compensation with the introduction of the "Stabilizing Jacket." In some ways it was the beginning of the end for front-mounts and back-mounts. The *jacket-style* BCD combined the best of both worlds into a single unit. The diver was now literally surrounded by a buoyancy bladder. Radical in design, aggressively promoted, widely accepted, and expensive — all the key ingredients to success if you add one more. Highly copied! Today, the jacket-style BCD probably represents 90% or more of the BCD sales in the United States. Some dive stores only sell front-mounts and back-mounts by special order; they don't even stock samples. However, the back-mounted BCD is now making a comeback (1990).

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

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

TODAY'S BCD

Today, the BCD evolution continues. The bulky "bag-in-a-bag" models of a few years ago are yielding to the trimmer single bag units. Compact designs with limited drag characteristics (resistance to movement through the water) and smaller size for packing are increasing in appeal to the traveling diver. Dry suit divers and an increasing number of tropical divers favor open-front models with adjustable and separating front shoulder straps. The diver is looking for comfort and freedom of movement.

Some BCDs now incorporate weight pockets directly into the BCD waist assembly. The weights may be dropped independently on some models by opening quick-release Velcro closures or simultaneously with a cable release mechanism. The ideal of weights as an integral part of the BCD-scuba system is still a subject for debate.

One manufacture has made a radical departure from traditional BCD design by developing a very small "donut" shaped BCD that fits between a conventional scuba backpack-harness assembly and the cylinder. The BCD inflation hose is approximately 1/4-inch inside diameter rubber hose with a unique power inflation-deflation device. There is no oral inflation capability! A small rubber inner tube (motor scooter type) is contained in an outer nylon bag which controls the amount of inflation and distribution of air within the BCD. The unit is absolutely wonderful for limited buoyancy compensation (ideally, 10 pounds or so; maximum 18-20 pounds). Unfortunately, the unit is a significant enough departure from conventional units that most trained divers will have to retrain in its use. *It is not a lifesaving device!* Persons using this BCD will have to rethink and retrain in diver assistance and lifesaving procedures.

BUOYANCY COMPENSATION VS. LIFESAVING FLOTATION

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

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

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

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

The report further stated:

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

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

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

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

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

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

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

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

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

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

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

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

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

MAINTENANCE

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

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

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

I recall one incident where a diver using a two year old BCD apparently could not get the BCD to hold air underwater. Upon loosing buoyancy he apparently struggled to ascend and/or sank uncontrolled to the bottom. The diver died! The BCD was identified as the "cause" and damages were awarded to the surviving widow. The BCD had apparently functioned well for two years. Had the BCD even been professionally inspected? Had the valve been tested for satisfactory operation before the dive? Why didn't the diver simply discard his weight belt (it was still in place when the body was recovered)?

I recall another incident where an instructor was hurled out-of-control to the surface as his BCD inflator-regulator unit stuck and instantly inflated his BCD to full capacity (about 50 pounds buoyancy). The diver was carried to the surface "in a few seconds" an lost over 100 pound of air from his scuba before he could disconnect the BCD hose. Interestingly, he had had trouble with the unit before.

It is absolutely essential that you maintain your BCD in accord with the manufacturer's instructions and test it for proper operation prior to each dive. Use common sense and do not become a BCD dependent diver!

BCD DEPENDENCY

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

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

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

SELECTING A BCD TODAY

When you go to a large dive shop to purchase a BCD you may be confronted with 20 to 30 different models. A BCD will range in cost from $285 to $500. Ideally, before you purchase a BCD you should have an opportunity to diver with that BCD, at least in a swimming pool. Many divers will purchase the same model BCD that they use in training while others look for newer and more innovative designs. I certainly encourage divers to "shop around" and try various models before making a final (and expensive) selection.

Keep in mind that most dive shop employees and instructors will have personal biases. These biases may reflect anything from their prior training and the type of diving that they do to the fact that they are overstocked on a particular BCD that is going out-of-style next year or a BCD that gives the greatest profit margin.

Be certain that the BCD fits properly. Some salespersons have a tendency to recommend too large of size BCD. For example, two of my former students were both sold BCDs that were one size too large. No doubt the salesperson anticipated that the would use them for dry suit diving. These individual only plan to use them with a wet suit and dive skins.

I too have my personal biases! The following are factors that I would consider in selection a BCD today. These opinions may or may not be shared by other instructors or sales persons.

What type of diving do you intend to do? If most of your diving is going to be in the tropics in a thin neoprene suit or dive skin, you may wish to select a low profile, low capacity unit. If you intend to use a dry suit for cold water diving you should certainly consider an open-front model with adjustable shoulder straps that can be unbuckled for donning and doffing. If you are planning to do skin dive you should also consider a low-profile collar style BCD. Some "all-around" divers own as many as three BCDs.

What general characteristic should you consider? I feel that current trends favor a BCD that has a *low in-water profile* which offers minimum resistance to movement through the water. For this reason *single bladder* or bag BCDs appear to be favored over double bladder units. However, there are excepts. Some manufacturers of back-mount units use an elastic outer bag that compresses the inner bladder in order to maintain a low profile. This system seems to work well. More divers seem to be selecting BCDs that are less restricting and have an *"open-front"* for tropical diving as well dry suit diving. The *adjustable, separating shoulder strap* complements securely fitting the BCD to the diver's body as well as donning and doffing scuba. Finally, the traditional "hard pack" models appear to be loosing ground to the newer "soft-packs." Many people feel that *soft packs* are more comfortable and they certainly pack more compactly for the traveling diver. Others reflect concern about cylinder movement. Soft packs have improved significantly over the past year.

BCDs also have a number of different attachment devices (for consoles, safe-seconds, and the like), pockets, changeable color panels, inflator mechanisms, and so on. These items will have to be judged on an individual basis and diver preferences.

A CO_2 cylinder was mentioned previously. Should I select a BCD with a CO_2 cylinder? The concept of an independent emergency inflation system is sound. However, modern trends in BCD design have precluded to CO_2 inflation system. Only a few manufacturers still offer it as an option. The modern BCD is (1) only a buoyancy control device, (2) is, for all practical purposes, not intended to be be uses for skin diving, and (3) is designed for air inflation from the scuba. Modern trends in diver education have (1) ridiculed and condemned the CO_2 system, (2) de-emphasized skin diving, and (3) promoted diving procedures that rely strictly on the air inflation system. Consequently, the diver has little choice in the matter.

Earlier information in this chapter was very supportive of front-mount BCDs. Should I buy a front-mount BCD? The front-mount BCD is versatile, safe, and inexpensive (in comparison to a jacket-style BCD). However, good front-mount BCDs are difficult to find and seldom see in scuba diving today. Admittedly, they are less satisfactory as a buoyancy control device. However, they excel for skin diving and rescue (skin or scuba diving). Keep in mind that a separate back pack is required for the scuba and equipment preparation and donning requires additional steps. The diving industry and educational agencies have so favored the jacket-style BCD that the modern diver has little choice in the matter.

If you do plan to skin dive I recommend that you seriously consider purchasing a compact front-mount snorkelers unit in addition to your jacket-style BCD used for scuba diving. However, use of the snorkelers buoyancy unit for scuba diving is discouraged.

CONCLUSIONS

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

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

* Do not substitute a "buoyancy system" for swimming skill and physical fitness.
* Inform the student of both the advantages and limitations of various buoyancy systems.
* Encourage students and divers to personally evaluate the performance and capabilities of their buoyancy system relative to various diving equipment configurations and conditions in a controlled environment.
* Encourage divers to establish a regular maintenance program for their buoyancy equipment and to replace components as necessary.
* Encourage divers to complete conventional lifesaving training in addition to scuba diver rescue training.
* Divers must select buoyancy equipment that is appropriate for their individual size and diving requirements. An improperly fitted or adjusted BC may actually compromise the diver's comfort and safety. A person who anticipates doing a considerable amount of skin diving may wish to consider the benefits of a front-mount BC. If this means purchasing more than one BC, then so be it!
* Encourage divers to properly weight themselves, "to the pound," taking into account individual variables. Divers should continuously evaluate their weight (ballast) requirements and make adjustments when appropriate.

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ACKNOWLEDGMENTS

This chapter, in part, was take from *Buoyancy and the Scuba Diver*, a publication in the Diver Education Series published by the Michigan Sea Grant College Program with grants form the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and funds from the State of Michigan.

Original manuscript: 1986
Manuscript revised: 6 July 1990

NOTES:

CHAPTER 3-5

DIVER INSTRUMENTATION

INTRODUCTION

A scuba diver must monitor specific information in order to properly execute a safe underwater excursion. First, the diver must be continuous aware of the amount of breathing gas remaining in the scuba cylinder(s). Secondly, the diver must be able to compute that amount of nitrogen that has been absorbed. This can be accomplished by accurately determining maximum depth and exposure time and consulting dive tables or by a diver-carried computer which automatically reads depth (pressure) and time and, using a mathematical model of the human body, determines gas absorption status. In both cases the diver is informed of no-decompression time or decompression time requirements. Finally, the diver must be capable of determining direction and navigating an appropriate course underwater using a compass. Many divers also carry thermometers for measuring temperature at various depths.

Two decades ago most divers mounted a depth gauge, watch, and compass on their wrist and attached a pressure gauge to their scuba regulator. A slate and/or set of dive tables was attached to the scuba harness or carried in a pocket on the BCD. The depth gauge and watch was generally positioned on the left wrist and the compass on the right wrist. The pressure gauge hung freely or was attached at one of several possible points on the cylinder, waist belt, or buoyancy unit. Through a series of arm and hand movements the diver would monitor vital information throughout the dive. Each monitoring event consisted of two or more specific tasks.

As divers became more sophisticated they discovered that the amount of effort (physical and mental) required to monitor critical dive information could be greatly reduced by integrating these separate components into a single unit — a console. Now the diver could read depth, time, and cylinder pressure simultaneously with one visual scan. Compasses and information slates were often placed on the back side of the console making directional information available through a simple turning motion.

What is so significant about the integration of components? Scuba diving involves a number of "time-sharing tasks." A diver must remain vigilant to infrequent events for long periods of time and simultaneously monitor a wide range of status indicators to note change in status of any indicator. These task must be time-shared with continuous attention to ongoing tasks associated with breathing, moving, and, in general, functioning in an environment where physical concepts of sight, sound, and thermal comfort have been altered and an artificial means of life-support is requires.

The use of various instruments involves information-gathering and effective decision-making. The diver scans or observes the instrument(s) to gather information that will then be interpreted or evaluated. The interpretation of this information is based in part on present status and in part on past experience (memory). Based on the evaluation, the diver must make a decision as to an appropriate response — the action.

The previous discussion may seem a bit "heavy" to someone who simply thinks in terms of reading a gauge or timer. However, ultimately the diver's safety and well-being depends on successful information-gathering and effective decision-making. Using simpler and more efficient the information-gathering (scanning) process (i.e., the console concept) reduces the number of time-shared tasks.

There are two major weaknesses in gathering and using the information provided by diver instruments. First, the diver must assign "high priority status" to monitoring instruments. Some divers simply appear to lack the training and experience to appreciate the importance of information monitoring. In "fast-scuba training" they are told to monitor their instruments, but gain only limited insight as to the adverse consequences of failure to do so. In some cases divers become distracted by other events or tasks, experience thermal-related mental degradation, or experience the effects of nitrogen narcosis. All of these factors interfere with both information-gathering and decision-making.

Secondly, the diver must be able to evaluate or interpret this information and take an appropriate action. Today, as we enter the age of computerized living, diving is becoming more sophisticated than ever before. Divers must have a solid academic background in diving theory in order to correctly use the information provided. Many divers do not receive the in-depth academic training that is required for effective decision-making. Furthermore decision-making is also based on acquired experience. Today, many divers rely on dive masters and dive guides for dive planning, environmental analysis, problems resolution, and so on. Consequently, they often fail to gain the experience that is so vital to the interpretation and decision-making process.

When all is said and done, divers must use their various instruments to gather vital information. This information must then be interpreted and the diver must take an appropriate action.

DEPTH MEASUREMENT

Self-contained divers must continuously monitor their depth. Accurate measurement of maximum diving depth is essential for use in reading dive tables. Often, depth will vary significantly for the self-contained divers during a single submergence.

Under conditions of constant depth in a limited working area, some divers rely on the use of a hand sounding line or a sonic depth sounder on board the support vessel for depth information. These method of depth measurement are excellent for dive planning purposes. However, measurements made from the surface are not to be considered as a substitute for use of a diver's depth gauge.

Self-Contained Diver's Depth Gauge

Over the years, the self-contained diver's depth gauge has been one of the least understood pieces of diver equipment. How accurate is a depth gauge? How accurate is it supposed to be when delivered by the manufacturer? What are the effects of use, abuse, and age? Most divers cannot answer these questions. Many accept the gauge reading as accurate without question. I wonder if some divers really appreciate how critical this depth reading is to their health and safety? An error of a few feet could result in using the wrong decompression schedule, This, in turn, could result in the diver suffering from decompression sickness.

The introduction of electronic instrumentation has significantly improved the accuracy of depth measurement. Depth is measured using a temperature compensated pressure transducer. The pressure reading is converted into a voltage reading and this reading is then processed by the analog to digital converter which changes it into a digital signal that can be displayed or "read" by the microprocessor. Accuracy of electronic or digital depth gauges is either expressed in "±" number of feet or percentage of full scale. For example, most of today's dive computers specify a depth measurement accuracy of ± 1 to 2 feet or ± 1%.

Many divers continue to use analog depth gauges. Gauge quality, performance, capability, and accuracy vary significantly, however, not necessarily in direct relation to price. The novice diver is faced with a critical decision in selecting a depth gauge, however, very little information on gauge accuracy and testing is provided by many manufacturers. All too often selection is made on external appearances alone.

The standard of denoting analog gauge accuracy may be expressed in several different ways. The simplest measure of accuracy is in terms of plus or minus (±) a percentage of the entire depth scale and is used over the entire scale range. The standard of accuracy ranges from 1 to 5%. This would mean that a ± 3% depth gauge with a 300 foot scale could have an acceptable accuracy tolerance of ± 9 feet at any point on the scale when new. Consider a diver who must make a 10 foot decompression stop. In theory, at 10 feet the actual water depth could conceivably be any depth from one to 19 feet. Let us further consider a depth gauge based on a tolerance of ± 5% of full scale; the scale reads to 320 feet. The diver's depth gauge reads 100 feet; the actual depth may be 84 to 116 feet. The Recreational Dive Planner no-decompression limit for 100 feet is 20 minutes and at 116 feet this limit is only 13 minutes. At this point it becomes apparent that a knowledge of depth gauge accuracy is critical to the diver's safety.

In order to overcome this problem, some manufacturers selected a graduated accuracy standard or tolerance. For example, a gauge movement can be designed, manufactured, and tested on a basis of ± 1% of full scale for the first one-quarter of the scale, ± 2% of full scale for the second and third quarters, and ± 3% of full scale for the last quarter. On this basis the actual depth range at a gauge reading of 10 feet for a 300 foot scale gauge would be 7 to 13 feet. At a gauge depth of 100 feet the actual depth range could be 94 to 106 feet. For further information on specific manufacturer depth gauge accuracy, the reader is advised to consult the information pamphlet supplied with a depth gauge by the manufacturer, The diver must know the accuracy tolerance of a depth gauge in order to aid in safer dive planning.

The standard of accuracy or tolerance stated above are for new gauge movements tested at the factory. What about accuracy in used depth gauges? Before addressing this issue, how many divers actually test their depth gauges on a periodic basis? Very few! My experience with testing in-service analog depth gauges is less than satisfactory. Variations of ± 5% are not uncommon. However, of even greater concern, is the fact that very few divers ever test their gauges after purchase. The diver cannot really be held at fault since most instructors do not discuss depth gauge maintenance (testing) and very diving equipment retailers offer a gauge testing service.

Furthermore, even where depth gauge testing services are available, the accuracy of the test equipment is a matter for concern. Simply placing a depth gauge in a pressure vessel beside another self-contained diver's depth gauge that is supposed to be "factory tested" or accurate is not a satisfactory test. The use of small two-inch dial pressure gauges and a conversion chart for pounds per square inch to feet of sea water is generally also equally inadequate. How accurate is the test gauge? In my opinion, a test gauge should have an accuracy of at least ± .25% of full scale. Generally, a 6-inch diameter dial size is minimum and a 12-inch diameter is more desirable. Dial graduation of one foot of sea water are most acceptable. These large gauges are periodically calibrated by dead weight testing procedures.

Divers can check the accuracy of their own gauges using an accurately measured line or chain in calm water. A lightweight metal chain is better since it is not subject to stretching and shrinking. Suspend the weighted chain from a surface float, structure, or vessel. If a boat is used, the water should be flat calm in order to avoid up and down movements of the chain. The chain is marked at 10 foot intervals (or less if the diver desires). The diver descends beside the chain and reads the depth gauge in comparison to the actual depth indicated on the chain. These results are recorded on a slate. The diver cannot mechanically adjust the gauge. However, a small correction chart can be taped to the side of the gauge indicating true depth compared to gauge depth. As a word of caution, this testing procedure is not as accurate as precision testing in a laboratory and the results should be considered as a relatively good approximation only. Also, this is not an excuse to make a deep dive. The diver need not exceed the range of normal diving depth. Measurements made between the surface and 60 feet will generally be sufficient to give accuracy in the normal range of self-contained diving and an estimate of the gauge's performance at greater depths if you know the manufacturer's tolerances. For those who use their depth gauges at greater depths, professional testing is recommended.

Persons diving in fresh water should be aware that depth gauges generally read in terms of pressure converted to a sea water depth equivalent scale, although some models are fresh water calibrated. Consult manufacturer's manual for this information. If your gauge is salt water calibrated keep in mind that at a depth of 34 feet of fresh water the mechanical depth gauge will read 33 feet. Decompression tables are based on feet of sea water; therefore, conversions are not necessary. Considering the normal accuracy tolerance of the diver's depth gauge, the difference between fresh water and sea water is relatively insignificant when reading a depth gauge. If the you wish to determine actual diving depth in fresh water when using a sea water calibrated gauge, multiply the gauge reading by 1.03.

Depth Gauge Design

Depth gauges available at present are generally of the open or sealed bourdon tube, diaphragm, capillary, or electronic type. The bourdon tube appears to have been used in the majority of self-contained diver analog depth gauges. In this type of gauge the ambient pressure is transmitted hollow C-shaped spring; pressure variations change the curvature of the spring. The three types of C-spring bourdon tubes used are open tube, oil-filled tube, and sealed tube with an oil-filled compartment.

The open bourdon tube depth gauge consists of a beryllium brass or copper C-shaped tube contained in a pressure-proof housing. The tube is connected to a small hole in the housing and water is allowed to enter the tube. The closed end is connected, by linkage, to a pointer which rotates around a calibrated dial. The water, entering the open end of the tube, pressurizes the bore. The pressure differential between the bore and the sealed housing causes the tube to deflect or straighten; this movement is transmitted to the pointer. The oil-filled bourdon tube has a sealed, inverted neoprene cup which ambient water pressure depressed and transmits the pressure to the oil, As in the open tube, the pressure differential causes the tube to deflect from the original shape and move the pointer. The oil-filled tube has an advantage over the standard open tube in that water does not enter the tube and cause corrosion.

In the classic oil-filled depth gauge, a sealed air-filled bourdon tube is completely enclosed in an oil-filled housing. The liquid generally is silicone or mineral oil, All air is evacuated from the housing during filling. Ambient pressure acts upon the housing and is transmitted by a neoprene diaphragm or the flexible housing structure to the bourdon tube. The pressure differential between the inside of the sealed buordon tube and the ambient pressure causes the tube to curl. The tube is connected to a linkage as described above. This type of depth gauge has proven to retain accuracy longer than some other types. Since water is not allowed to enter the tube, corrosion is not a problem. Also, the oil-filled housing tends to protect the delicate gauge mechanism by dampening any severe shock.

The diaphragm mechanism depth gauge basically consists of a sealed air chamber separated from a water chamber by a metal or silicone diaphragm. When submerged, the pressure differential between the water and the sealed chamber causes the diaphragm to deflect inward, which by linkage moved the pointer. This type of gauge is subject to greater variation due to ambient temperature changes than other types of gauges.

Some depth gauges contain a maximum depth indicator that rotates with the depth pointer as the diver descends. The indicator remains at the maximum depth while the depth pointer returns toward the zero position during ascent. The maximum depth indicator is an important diving safety feature. Although in present models there is occasional sight needle drag, generally physical movement of the diver's arm and depth gauge is sufficient to overcome this drag. The maximum depth indicator must be reset to a shallow depth prior to each dive in order to accurately indicate the maximum depth attained on that dive. Abuse of the gauge (bumping, etc.) can cause the indicator to move slightly.

The simplest and least expensive depth gauges are of the capillary type. These gauges are seldom sold today. The capillary depth gauge consists of a small diameter clear plastic tube that is open at one end and closed at the other. The tube is secured to a calibrated dial. There are no moving parts in this gauge. As the diver descends, ambient pressure forces water into the tube, thus compressing the entrapped air. The gauge operates on the principle of Boyle's Law. A logarithmic calculation of the tube volume determines the points of dial face calibrations.

The capillary depth gauge is relatively accurate at shallow depths, generally 60 fsw or less. The scales are too compressed at greater depths to insure real accuracy. Submerged, the depth is indicated at the leading edge of the solid column of water entering the tube at the zero point.

In using this type of gauge the diver must be certain that the tube opening is positioned exactly at the "zero" mark in accord with the manufacturer's instructions. The diver must also be certain that the tube is clear of water droplets prior to the dive and that air bubbles do not become entrapped in the tube during water entry. Air trapping, evident by a broken water column, is common following jump-type entries, as from a boat. The presence of entrapped air bubbles seriously impairs accuracy and the diver must surface to remove these bubbles prior to relying on the gauge for depth readings.

Depth Gauges and Altitude

Depth gauges are designed to function with the "zero" point at sea level pressure. In more sensitive gauges slight daily variations as a result of barometric pressure changes may even be evident. If the diver intends to use the gauge at higher altitudes, such as diving in mountain lakes, calculations of depth corrections are necessary or the diver may use an altitude adjustable depth gauge. Diaphragm and bourdon tube gauges read shallow at altitude while capillary gauges read deeper than actual depth.

Since bourdon tube and diaphragm gauges are designed to measure ambient pressure with the sea level absolute pressure indicated as "zero." they are calibrated for ocean use. The actual depth reading for a given altitude may be calculated using the formula

$$D = \frac{144}{d}\left(\frac{d_s}{144} D_i + P_o - P_a\right)$$

where,

D_i = depth indicated by gauge,
D = actual depth (water density d) ,
d = density of fresh water (62.4 lbs/ft^2) ,
d_s = density of sea water (generally 64.0 lbs/ft^2) ,
P_o = sea level atmospheric pressure (14.7 psia) , and
P_a = actual atmospheric pressure at altitude of dive (psia).

Using this formula one can calculate the actual dive depth at a given altitude. For example, at Lake Tahoe, Nevada (approximately 6000 feet above sea level) the atmospheric pressure is 11.7 psia. When a bourdon gauge indicates 30 feet, the actual depth is equivalent to about 38 feet (with fresh water correction). For additional information on depth gauge correction requirement when diving at higher elevations, consult a manual of altitude diving procedures. Keep in mind that some analog depth gauge allows for mechanical adjustment of the mechanism to facilitate use at higher altitude.

Selection of a Depth Gauge

When selecting a depth gauge, the diver should consider the following factors:

* high standard of accuracy in the normal range of diving;
* large, easy to read dial face, numbers, and pointer;
* luminous markings are easier to read under low light conditions;
* special features including temperature compensation, altitude adjustment, and maximum depth indicator;
* periodic calibration or accuracy evaluation services available from the supplier; and
* record of gauge performance in the field as indicated by other divers.

One might ask, "With all of the modern day technological advancement, why can't a highly accurate self-contained diver analog depth gauge be produced?" A very accurate depth gauge can be produced! However, at present the "cost" of such a gauge would be prohibitive for the average diver. Electronic depth gauges and dive computers have basically resolved the accuracy issue.

Use and Maintenance

Any depth gauge is only as good as the person using it. The diver can not expect the depth gauge or any other item of equipment to "do it all." The diver must consider the following:

* Know the accuracy of your gauge. Insist on being provided with the manufacturer's standard of accuracy when purchasing a new gauge. Many manufacturers provide excellent instruction booklets with their products.

* Ideally, you should check your gauge against an accurate standard at the time of purchase and periodically thereafter (every 6 to 12 months).

* Protect your gauge against abuse and shock. Dropping a gauge on the ground or floor will most generally damage the internal mechanism and affect the gauge accuracy.

* Secure your console so that it does not drag across the bottom during the dive or strike the side of the boat when you enter the water. Not only do you stand the chance of damaging several hundreds of dollars in instruments and endangering your personal well-being if they subsequently read inaccurately, you are also damaging the environment.

* Transport the gauge in a padded container. For air travel I encourage divers to remove consoles from there regulators and carry them in their carry-on luggage.

* If you drop your gauge, have it checked for accuracy.

* Avoid prolonged exposure to excessive heat and sun.

* Carefully rinse the gauge in fresh water after each dive and dry prior to storage. Open-bourdon tube gauges should be soaked in fresh water to aide in the removal of salt deposits and corrosion that might clog the mechanism.

* Use a margin of safety! Even if your gauge is tested and shown to be relatively accurate, be conservative in computing the no-decompression limit and do not push the limits.

* Remember to read the gauge! Knowledge of the maximum diving depth is absolutely necessary for selecting the proper no-decompression time limit.

* If your gauge reads shallower than your buddy's gauge at a given depth, use the deeper of the two readings for determining the dive schedule or limit. You cannot afford to assume that the shallower reading is correct.

* The depth gauge and the diver's watch or timer should be positioned immediately next to each other whether on the wrist or in a console. If the diver is not using the electronic depth gauge that includes an ascent rate indicator, coordinated viewing of both the watch and the depth gauge is the only other method of maintaining a relatively accurate rate of ascent.

Surface Swimmer's Sounding Line

A simple, inexpensive, diver-carried sounding line consisting of a lightweight line (1/16- to 1/8-inch) marked at one foot intervals, a small lead weight (a few ounces) on the end, and a compact hand reel is useful for surface swimmers (snorkelers) in shallow water areas. The swimmer lowers the weight until he/she "feels" it touch the bottom and reads the measurement at the water's surface.

Pneumofathometer

For precise depth measurements as in scientific research, the self-contained diver may wish to use the surface-supplied diver's pneumofathometer. This, of course, necessitates having a vessel overhead, surface personnel to record depth readings, and some sort of diver to surface communications unit. The pneumofathometer system consists of a precision depth gauge, an air source, a lightweight air hose, and appropriate fittings. Air is introduced into the air hose at the surface, displaces the water, and forces it out the diver's end of the hose. When the hose is clear of water, the air escapes. The gauge connected to the hose on the surface indicates the pressure measured in feet of sea water, required to clear the hose of water and, consequently, the diver's depth. The diver holds the end of the hose at the exact level of desired measurement. High quality calibrated gauges with a full scale accuracy of 0.25% are generally used for this purpose.

WATCHES AND TIMERS

A water-resistant watch or timer is essential to the scuba diver for determining bottom time, controlling rate of ascent, and navigation procedures. In recent years scores, possibly hundreds, of water-resistant watches have appeared on the market ranging in price from about $35 for a popular digital model to more than $1500 for the traditional analog (dial-type face) Rolex chronograph.

Some models incorporate both analog and digital time display. Digital watches incorporate a number of features such as time, day, and date function, stop watch, count down timer, alarm functions, and face illumination. Various watch and timing functions are initiated by activating a button on the side of the watch. Most are depth rated or water resistant to at least 100 meters (330 feet).

A dive watch (or timer) must be highly water resistant, reliable, accurate, robust, capable of withstanding thermal stress, readable under a variety of conditions, and capable of standing up to normal dive use. The watch band, generally constructed of nylon, plastic, or metal, must also be capable of standing up under normal dive use. For divers who wear their watch on their wrist, the band must be adjustable and of sufficient size to were on a bare wrist or over a diving suit sleeve.

In 1982 the U. S. Navy selected and evaluated a representative sample digital and combination digital/analog dive watches available in the United States at that time. They conducted a series of test suitability (human engineering and durability), luminescence, readability, comfort, button activation (with and without gloves), pressure (330 feet), thermal stress (water temperatures of approximately 30 to 90 F°), and magnetic signature. All watches tested were found to be effective in normal use by a diver. All watches requiring button activation were found difficult and time consuming to operate when wearing gloves or mitts. Watches with analog display and a rotatable bezel in conjunction with a digital display were found more convenient to use for dive time recording. However, bezels may be accidentally moved underwater. In selecting a bezel-type watch the diver must consider bezel security and resistance to movement once set.

A review of the catalog of one major diving equipment distributor indicated the availability of analog dive, combination analog/digital dive watches, and digital display dive watches (with a 'pressure activated dive timer feature), pressure activated digital dive timers (some integrated with depth gauges) and full function dive computers. Based on this and subjective observations in various diving equipment retail stores, it appears that the analog style watch is still popular among divers although I feel that most divers wear them as a status symbol rather that for serious dive timing. The vast majority of dive watches today have Quartz movements. Most dive watches are acceptable for every day use.

Dive timers are generally designed only for underwater use. Many dive timers are pressure activated stopwatches; both analog and digital models are available. The timer automatically activates as the diver descends below a given depth (generally 4 to 6 feet) and stops when the diver ascends above that depth. When the dive timer stops during ascent, it automatically begins to time the surface interval, and indicates the number for dives completed within a given time period (usually 12 hours). Most dive times do not incorporate standard time of day functions. Dive timers are available as independent units or may be incorporated into other instruments such as a depth gauge or pressure gauge.

Dive timers are now incorporated into multifunction microprocessors which are attached to the high-pressure port of scuba regulators. These units provide the diver with numerical display of cylinder pressure, bottom time, surface interval, maximum depth, and current depth. More sophisticated models provide digital analysis of air consumption and no-decompression status (dive time remaining).

Finally, the dive timer may be incorporated into a even more sophisticated decompression microprocessor that provides a continuous status display of current depth, maximum depth, and no-decompression dive time remaining. The no-decompression and decompression status is updated ever three seconds based on current depth, bottom time, and previous theoretical nitrogen absorption-elimination factors. Theoretical nitrogen status is also displayed graphically. Theoretical nitrogen absorption and elimination status calculation is based on integrating depth-time factors with twelve tissue model of the human body. The microprocessor also provides the diver with decompression time status and ceiling depth for decompression dives.

Again, the novice diver must often make critical and costly decisions with a very limited amount of available information. Let's examine the absolutely necessary requirements for safe diving and some of the alternatives for meeting these requirements. Consider the following:

* A scuba diver must be able to accurately determine bottom time and surface interval time.
* A scuba diver must document the maximum depth of the dive and be able to continuously monitor depth throughout the dive.
* Depth and time information is necessary in order to determine no-decompression/decompression status using standard tables or a microprocessor.

A scuba diver may accomplish the above with a simple diver watch ($35), a depth gauge ($70), plastic decompression tables ($8), and a slate/pencil to record dive data ($7) for a total cost $120. Keep in mind that the diver must set or activate the dive watch/manual timer, read and record maximum depth, read the tables accurately, and record all information on a slate for proper calculation of repetitive dives. The diver can not rely on personal memory or data from other divers for making these vital determinations. Digital dive timers that will maintain a record of dive time and surface interval range in price from about $75 to $130.

For sake of comparison, a combination depth gauge and digital dive timer cost about $200 and a console unit that also includes a analog scuba cylinder pressure gauge sells for about $280 (a separate pressure gauge cost about $100). These units are relatively compact and very convenient to use; some also include a compass (additional cost of about $40). However, keep in mind that such items are strictly limited to scuba diving applications and may not be used for other recreational or everyday activities.

In recent years dive and sport watches have become fashionable of general wear. However, a decade ago John T. Molloy stated the following in his book Dress for Success:

> A gentleman's watch is thin, plain and gold, with either a gold or leather band. Gentlemen do not wear skin-diver watches or astronaut's watches or Mickey Mouse watches to the office. Gentlemen do not wear cheap expansion bands; they are a symbol of the lower class.

With these thoughts in mind, you can now ask yourself a series of questions regarding the selection of a dive watch or timer:

* How much diving do I realistically anticipate doing each year? One or two days? Five days? Twenty-five days?
* Will I use my watch for tropical diving (bare hands or very thin gloves) or cold water diving (thick gloves)? Will I ever wear the watch over a thick wet or dry suit sleeve?
* Will the watch band be suitable for all intended use situations (diving, aquatic sports, business, dress, etc.)? Will I want to select a watch with more than one band or purchase an extra band and an appropriate tool to change bands easily?
* How long will the battery last? How often must the watch be serviced by the factory or an authorized agent in order to maintain a valid warranty? How much does routine service and battery change cost (servicing a Rolex can run from $75 to $250)?
* Do I participate in other sport activities where a water-resistant watch would be useful? Do I need a stopwatch for physical fitness activities such as jogging, bicycling, or swimming?

* Do I have an appropriate everyday watch or do I need a new one? Do I need a dress watch? Do I wish to select a watch that will be appropriate for dress, work, recreation, and diving? Will stainless steel, plastic, gold (plating), or black (external finish) be most appropriate for my intended use.

* How much money do I wish to invest in scuba diving? Can I afford to select a timing device that will be used only a few days each year? Will the type and frequency of my diving activity be too extensive or harsh for a watch that I would also wear on a daily basis?

* Do I want to wear my dive watch as a status symbol? Would wearing a dive watch be considered tacky by my colleagues at work or in my social circle? Do I care?

The choice is yours! There are scores of very beautiful and stylish dive watches that would be appropriate for everyday wear as well as most diving activities. They are available in both mens and womens sizes at cost of $35 to $1500 (some gold Rolex diving watches sell for more than $15,000). Digital models may be purchased on sale at discount stores for as low as $17.97. Cost is no excuse for a diver to not have a personal dive watch or timer.

I personally use a decompression microprocessor for all of my scuba diving. However, I wear a good dive watch that has both digital and analog display 365 days per year as well as for all dives. In addition to dive timing, I routinely use the digital timer for timing fitness activities, parking, test, lectures, and a variety of other activities.

Maintenance

All watches and timers must be handled with care and protected from shock or abuse. The time piece should be washed or soaked in fresh water after use in salt water or chlorinated pool water. Protect these units against prolonged exposure to direct sunlight and excessive heat. Watches and timers should be serviced regularly in accordance with manufacturer's recommendations.

DIVE COMPUTERS

The modern, sophisticated diver may wish to purchase a dive computer that sells for $300 to $700. These devices will add a new dimension to an individuals diving activities. By continuously updating the diver's nitrogen status, the diver may take advantage to multilevel diving capabilities to increase underwater time and range.

Modern dive computers are truly marvelous instruments. The computer consist of a power source, a pressure transducer, an analog to digital converter, an internal clock, a microprocessor (with both ROM and RAM), and a display screen. Depending on the make and model, the is computer activated (or powered up) a manual switch, scuba cylinder pressure, or contact with water. Once activated it automatically checks all of its computing circuits and sequentially lights all segments of the screen (and warning lights) to verify that they are working. Some models then display battery voltage. The computer reads and displays ambient "surface reference pressure" in feet of sea water. Some computers will automatically adjust for diving at altitude.

Most computers will now display a *scrolling dive table* which gives the no-decompression dive time at 10 foot depth intervals over a range of depths. When you submerge the computer's internal timer automatically activates in the dive timing mode and changes in pressure are measured by the pressure transduce. *Dive time and depth* are shown on the display. This information is entered into the microprocessor where it is integrated with stored information (for repetitive dives) and a mathematical model that simulates nitrogen absorption and elimination rates in various theoretical tissue compartments. Using this information the computer displays *remaining no-decompression time*. The computer updates diver status approximately every three seconds taking into account depth changes and diver on-gassing and off-gassing.

In the event that the diver remains at depth for a sufficient enough time to exceed the no-decompression limit of the model, a *ceiling depth* is displayed. This is the shallowest depth to which the diver can safely ascend. The diver must stop at or below this depth to allow for nitrogen off-gassing or decompression.

As the diver ascends the computer continuously adjust the no-decompression limit for the new depth. For example, at a depth of 95 feet your computer may indicate that you have 4 minutes of no decompression time remaining. You ascend slowly to a depth of 60 feet and the computer may indicate that now have 37 minutes of no-decompression time remaining. Ascend to 40 feet and you have even more time. Consequently, the 95 foot dive that has a diver table limit of 20 minutes can be extended to an hour or more using a computer and progressively ascending to shallower dive levels. Current and maximum depth is also displayed throughout the dive. In addition, most dive computers have an ascent rate warning. If you ascend too rapidly a flashing light or screen indicator will warn you to slow the ascent.

When you reach the surface you computer switches to a surface mode to provide you with the maximum depth and duration of the previous dive (some units scroll the three previous dives), surface interval time, and a scrolling dive table indicating no-decompression time allowance for a repetitive dive. In addition, many computers display a numerical value or a symbol indicating the time you must wait before flying. You computer also stores a series of dive profiles. Some computers may be manually accessed to provide depth information at 3 minute (for example) time interval throughout several previous dives. Others will store more detailed dive profile data for 35 hours of underwater time that may be accessed by the manufacturer and downloaded into a large computer for analysis and printing.

Several compact wrist model computers are available. However, an increasing number of computers now include both digital and graphic scuba cylinder pressure displays. Several dive computers now estimate and display the remaining amount of dive time available based on present air consumption.

All divers must remember that any mechanical/electronic device is subject to failure or malfunction. Most frequently these failures are a result of human error, carelessness, or physical abuse. A microprocessor will fail if the battery compartment floods because the diver did not clean the o-ring or properly close the compartment. A careless diver may accidentally turn the device off while putting it on or taking it off. Consequently, all dive information for previous dive is lost. The diver must wait at least 12-24 hours for nitrogen levels to be reduced to the point where the device can again be properly and safely used for it's intended purpose.

As a safeguard, many dive carry a backup timer/depth gauge, document all dives on a slate throughout the day, and carry the slate and a set of dive tables in their BCD pocket. There is a considerable amount of diving community interest with regard to being able to continue diving safely, or at least safely ascend, in the event that a dive computer fails.

Keep in mind that there are numerous different dive computers and dive tables, all based on different mathematical models of the human body. Any attempt to combine one with another could lead to serious adverse consequences. Procedures are being evaluated for using a specific dive table in the event that a specific computer "crashes," however, determining the exact position to enter the table in this transition is no minor task. Realistically, if your computer crashes you are out of diving for a period of time specified in the manufacturer's instruction manual for that computer.

Some serious individuals now dive with two computers. In the event that one crashes the can safely ascend and make subsequent dives using the backup unit.

Maintenance

Dive computers should never be left in direct sunlight or exposed to potentially high temperature environments. This could result in display fading and damage to electronic components. Following each dive the computer should be rinsed in fresh water. The computer mus be protected from excessive should. Take care in handling computers to avoid dropping or striking against solid objects. Secure the computer so that it does not "drag" across rocks and coral as you swim underwater.

Batteries should be replaced when low power warnings are displayed. Some models are designed for diver battery replacement and others must be returned to an authorized service center. Manufacturer manuals give detailed information on maintenance of specific computers.

Using a Dive Computer

Instructions for the use of specific dive computers are beyond the scope of this manual. Divers purchasing computers must reading instruction manuals in detail and, ideally, obtain instruction in the use of the computer from a qualified instructor. *Several manufacturers provide instructional videos. Do not dive with a* *computer until you completely understand its operation and display characteristics.*

COMPASSES

Self-contained divers commonly use a liquid-filled magnetic compass for underwater direction finding and navigation. Generally, the compass is part of the instrument console that is attached to the scuba regulator. However, some divers will secure the compass to their wrist or to a compass board. A diver's compass should have the following features: (1) correct dampening action, (2) liquid filled, (3) the compass rose marked in degrees, (4) lubber's line showing direction over the face, (5) a course setting line or reference markers, and (6) a movable bezel. A good compass will respond rapidly to even slight course changes and have a high degree of luminescence for use in dark water.

CONCLUSION

Information provided by the various diver instruments is critical for decision-making in safe diving. However, the diver must use judgment and knowledge in interpreting this information. Keep in mind that depth gauges, times, pressure gauges, and computers are only instruments. These instruments are subject to malfunction. If you enter the water and descend to a depth of approximately 50 feet (based on prior knowledge of the area) and your depth gauge or computer only reads 12 feet, it is you responsibility to abort the dive or use backup information systems. If you fail to act in a reasonable an produced manner and develop decompression sickness, you have no one else but your self to blame.

Manuscript completed: 9 July 1990

NOTES:

CHAPTER 3-6

SELECTING YOUR PERSONAL SCUBA DIVING OUTFIT

INTRODUCTION

Selection of scuba diving equipment use to be so simple. In those early years there were only a few brands and models of masks, fins, and snorkels. There was a single-stage or two-stage U. S. Diver regulator and a J-valve. The were no buoyancy control devices. The popular color was basic black. Today, the diver must sort through literally scores of mask, fins, snorkels, regulators, BCDs and suits. One manufacturer alone offer a product line which includes 40 different underwater knives. Once the diver has determined the make and model, fashionable coordination is often a major considered in the final selection. Scuba cylinders are now available in more colors than most automobile models.

The selection dilemma is further complicated by the fact that there is very little, if any, current independent and objective consumer product testing information available on diving equipment. Products are tested by manufactures and the results of those test are published in the form of *promotional* materials, advertisements, and catalogs.

The U. S. Navy's Experimental Diving unit does test selected diving equipment and publish reports on those test. Unfortunately, these tests do not include all of the available makes or models of diving equipment. During the past decade the Navy has reported on the tests of selected regulators, depth gauges, pressure gauges, dry suits, under garments, BCDs and watches. However, very few divers ever see these reports and some of the models tested are obsolete before the reports surface in the sport diving community. For example,the U.S. Navy published a report on regulators in 1987. However, prior to that time the most recent U.S. Navy report on regulators was published in 1980 and only addressed selected models manufactured prior to that year.

Each month readers of popular sport diving magazines have an opportunity to study *descriptive* reports on new products. With few exceptions, the information contained in these reports appears to come directly from the manufacturer's promotional materials and the subjective experience of a writer/diver who has had an opportunity to use the particular item of equipment. These equipment "test(?)" seem to lack any significant objectivity, specific evaluation or study design, and competitive product comparison. It is very difficult to publish an objective and critical report on an item of diving equipment on one page of a magazine and collect advertising dollars to promote that item on another page.

In the earlier years of dive magazine publishing some attempts at product comparison from a standpoint of cost, size, and features, however, topics such as performance comparison were seldom addressed. However, in all fairness to sport diving magazines, summaries of some of the U. S. Navy's test have been published.

SCUBA DIVER EQUIPMENT REQUIREMENTS

Each individual diver must select the appropriate diving equipment the meet safety and environmental requirements for their specific geographic area and diving activities. The most obvious variable is in thermal protection requirements. However, there are still some regional variations in the type of auxiliary air supply system (i.e., standard octopus vs secondary scuba or pony system) and special equipment requirements for cave and under ice diving. It is often difficult for a beginning diver to anticipate future diving activities and equipment requirements. However, a prudent individual will identify if they anticipate most diving to be in northern or tropical waters, the time of year they intend to dive (especially in the north), and when they intend to begin active diving. For example, a college may wish to delay major equipment purchased until they have selected their geographic region of employment. On the other hand, a college student may find ample opportunity to travel to tropical waters during vacation periods. In this case, it would be wise to begin assembling a diving outfit during training or soon thereafter.

The following list is considered to be the *minimum* equipment requirement for safe scuba diving:

* Mask, fins, boots, and snorkel
* Net equipment bag
* Buoyancy control device (BCD)
* Knife/sheath
* Environmental protection garment
* Weight belt
* Waterproof decompression tables and slate
* Underwater watch or timer
* Depth gauge
* Scuba regulator with pressure gauge and auxiliary breathing unit
* Scuba cylinder/valve

The above list also represents an order of purchase priority for a beginning diver. The order may differ from the recommendations of others. The mask, fins, and snorkel area basic items that will be required for most instructional courses. In the event that an individual later decides to discontinue scuba diving, these items still represent a relatively sound recreational equipment investment since they can used for skin diving, passed on to other family members/friends, or sold. With proper care, high quality rubber goods should serve the individual/family for many years. A prudent individual will also purchase a pair of boots for use with the fins during training and in later diving. If you plan to do dive primarily in the tropics, lighter weight boot are excellent. Some people prefer "low-cut" models. However, keep in mind that some dive stores will not rent boots for open water training. If you are completing open water training in a northern quarry during the months of April, May, or June, the low-cut models will generally not be satisfactory.

When purchasing mask, fins, and snorkel the student/diver should also consider selecting an intermediate-size net bag. This bag is excellent for use in carrying equipment to class, drying/storing equipment, and in later diving activities. I select a bag of adequate size to carry all of my equipment to the boat at a Caribbean resort. This includes my 1/8-inch foamed neoprene diving suit. However, if I am using a 1/4-inch wet suit or a dry suit, I carry it separately.

The buoyancy unit (buoyancy control device or BCD) is my personal selection for the next item to be purchased. A student diver should use a BCD throughout the entire training program in order to be completely familiar with it's operation, capabilities, and limitations before advancing to open water. Ideally, the BCD should be included as part of the equipment package provided for training.

The highly promoted jacket-style BCD is currently used by the majority of divers. These units represent a sizable investment in the range of $250 to $500 (including power inflation systems). The less popular collar-style BC cost $125 to $200 with comparable inflation features. BC design and selection will be discussed later. However, keep in mind that jacket-style BCDs are specifically designed for scuba diving and not skin diving. Select a model that fits comfortably and has a low profile. Be certain that it is not too large. Many northern salespersons tend to size BCDs large so that they can be worn over a dry suit. If you plan to do primarily tropical diving and wear only a dive skin or 1/8-inch suit, it is likely that this larger BCD will be unacceptable. Be careful with manufacturer BCD size designations. For example, I were a 46 Long sport coat and extra-large sport shirts. However, I am quite comfortable in a medium BCD for tropical diving.

For the skin diver many of these units are bulky, cumbersome, and of questionable value for emergency surface flotation. On the other hand, the less popular collar-style BC is more compact, affords less resistance for surface swimming/movements, and many be very valuable as an emergency flotation unit. It is also potentially more versatile for use in other aquatic activities and less bulky for the traveling diver to pack.

I have selected this as a higher priority item to be purchased before the scuba since I feel that the diver's safety may be more directly linked to complete familiarization and competence with a selected buoyancy unit than other items such as a regulator. Although many resorts do now rent BCDs, a diver is less likely to find the specific BCD that he/she used in training. By having a personal BCD the diver does not have to risk the uncertainty associated with the use of unfamiliar equipment.

Many authorities will suggest that the next item, an underwater knife, should be lowest on the list of priorities and many divers do not even carry one. I consider the knife as an item of safety equipment for both skin and scuba divers. Although underwater entanglements are very rare occurrences, I suggest that all divers should carry a knife as a safeguard in the event of entanglement. This is especially important for divers swimming in limited visibility water and at night. Synthetic fish line is difficult, if not impossible, to see even in clear water.

A knife could well be the life factor for a skin diver who becomes entangled in fish line while diving in limited visibility water. In lakes, bays, and coastal fishing areas, lost commercial fishing nets constitute potential entanglement hazards for scuba divers, especially wreck divers. Fatal diver entanglement accidents have included a river diver who apparently becoming entangled in his surface float line and a diving student diver who became entangled in an underwater guideline during a training exercise. In a nonfatal incident, a lake diver was snagged by a fisherman's hook and pulled to the surface from a depth of about 60 feet. The diver was subsequently treated for decompression sickness. I carry a small, inexpensive sharp knife, especially when diving in limited visibility water, around shipwrecks, or near piers (increases possibility of discarded fish line).

I have placed thermal protection garments ahead of scuba in purchase priority. The prudent selection of a thermal protection garment (or system) will provide the diver/sportsperson with an item of equipment that may be used for any number of aquatic activities ranging from sailing to scuba diving. Furthermore, this is a more personal item that must be fitted to the diver. Many divers prefer to purchase custom tailored suits in order to assure proper fit, optimum comfort, and maximum thermal protection. Many dry suit divers prefer to wear personal undergarments for assured sanitation.

If you plan to dive primarily in the tropics you do not need a heavy 1/4-inch neoprene suit. For example, I wear either a 1/8-inch (3 mm) or 1.5 mm full length foamed neoprene one-piece suit for tropical diving. I northern Ohio I wear the same suit with the addition of a 1/8-inch hooded sleeveless vest and 1/8-inch gloves from early July through the end of September. I simply limit my excursion time below the thermocline and ocassionally dive duration or number of repetitive dives to maintain optimum comfort.

Since I also dive year around in the north I also have a dry suit with a layered undergarment system. On the other hand, I find that summer diving off southern California requires a full 1/4-inch wet suit. A prudent diver will carefully analyze future diving plans and select an environmental protection system accordingly. If you plan to complete your open water training in a northern quarry and do most of your future diving in the tropics, then the lighter suit and late summer open water training might be the most prudent choice.

If you own a thermal protection garment or even if you dive in salt water with out a diving suit, you will need a weight belt. Some "buoyant" individuals even require one for training and freshwater diving. Traveling divers generally do not have to carry lead weights to dive resort. These are included in the dive package. However, some resorts do require diver to supply their own belt.

Every item of diving equipment to this point may be used for skin diving and a variety of other aquatic sport. Only the jacket-style BC is more or less limited to scuba diving. Consequently, if an individual elects to not continue active scuba diving, this equipment has many other applications as well as relatively sound resale value and market (i.e., a potentially large user population engaging in other aquatic sports). The wise investor will analyze present, future, and alternative requirements when selecting diving equipment.

If you plan to participate in open water scuba diving ownership of a set of waterproof decompression tables is, in my opinion, mandatory. Many divers rely on the dive guide or other divers to supply decompression tables and calculate dive schedules. This is an unacceptable practice.

The last items of equipment that many divers purchase are a depth gauge and timer. All scuba divers, regardless of dive depth and conditions, must have the capability of documenting their depth and underwater time in order to lessen the risk of a decompression accident. Relying on another diver or the dive guide is not a recommend practice. No two divers dive the exact same profile or schedule.

Some authorities consider the use of a timer and depth gauge to be optional if the diver does not exceed a depth of 30 to 40 feet. Keep in mind that some of the new decompression tables do specify as low as 135 minutes no-decompression time for 40 feet. An active diver performing several repetitive dives with minimum surface interval could possibly exceed no-decompression limits 40 feet. Sixty to one hundred foot dives appear to routine at many dive resorts today. A diver is less likely to find these items available for rent.

Do I purchase a dive computer or conventional instruments? Again it is wise to analyze your future dive plans. If you intend to only make a few shallow dives annually, a dive computer is a fairly expensive item to hang in the closet 360 days per year. Furthermore, dive computers are improving each year. You may wish to shop around and compare the cost of a conventional console (scuba pressure gauge, depth gauge, dive timer, and plastic decompression tables) to a computer that provides the same information.

I have placed scuba last on the above list. The reasons for selecting other items of equipment have first have already been stated. Be aware that many diving authorities may not share the same opinion. I would purchase a scuba regulator before the cylinder. You can easily rent cylinders and most traveling divers do not travel with cylinders.

Regulator ownership is somewhat of a diver status symbol. It also represents a significant profit for vendors and a annual income for equipment repair facilities. For the individual diver, ownership and proper maintenance of a good regulator probably assures a higher level of performance and safety.

The scuba regulator represents a considerable capital investment and a commitment to annual maintenance cost. The retail value of a a high quality scuba regulator with a pressure gauge and auxiliary second stage (octopus) is $400 to $620. Annual maintenance costs range from $15 to $50 depending on the repair facility and model, age, and condition of the regulator. Assuming an initial investment of $500 and seven years of annual maintenance costs at only $30 per year, the average annual cost of owning your own regulator approximately $101. Although rental cost vary considerable from one geographic area to another, one dive facility operator recently quoted a rental price of $14 per day and $42 per week for a regulator with pressure gauge and octopus.

If you only dive a few days each year or take one or two one-week diving vacations per year, rental may be a feasible consideration. On the other hand, when using rental equipment you must depend on the integrity of the supplier to provide you with a well-maintained, high quality regulator. Furthermore, some Caribbean resorts may have very few or no rental regulator. If you elect to rent a regulator be certain to verify availability at the resort or acquire one from a local vendor on a weekly rental basis. Sometimes the latter alternative is less expensive.

Ownership of other items of equipment will depend on an individual's diving requirements. Persons who routinely dive in their home area will want to purchase one or more scuba cylinders. However, a person who limits their diving to resort vacations will have little need for a cylinder since nearly all resorts include cylinders as part of the dive package.

A diver may select any number of attractive accessories for purposes of convenience and fashion. Many tropical divers consider gloves as a necessity for protecting the hands from marine life injury. On the other hand, when you arrive at some dive resorts they will aggressively discourage the use of gloves as a mechanism of reducing environmental impact. I never wear gloves in the tropics. Many instructors and dive vendors highly recommend that every diver have a spare parts/repair kit (often referred to as a "save-a-dive" kit) which includes an extra fin and mask strap, dive suit repair materials, and so on.

All divers should consider assembling a personal first aid kit. However, many resorts provide excellent first aid kits and oxygen delivery units on their boats. In most states, scuba divers are required to tow a float and display a dive flag. Many coastal divers consider a surf mat-style or inner tube surface float to be necessary for safety. *However, divers seldom tow a surface float in the Caribbean. In assembling a personal diving outfit, a diver must take into account geographic traditions and safety practices, their instructor's recommendations, availability of group/club equipment, and the type of diving activity.*

SPECIFIC OF SELECTION

Which regulator should I purchase? Is SCUBA-DO equipment the best? The salesperson at Wet Place Scuba said that all Smith regulators breathe hard! Why do you still wear that obsolete collar-style BCD? Are wet suits really obsolete? Do I really need an air moisturizer? The MQ-84 is the only safe regulator on the market! Rocket! Jet! It is a minor miracle that a beginning diver does not experience a level-one nervous breakdown when attempting to select a good diving outfit.

There are many excellent, professionally trained salespersons working in dive shops today. On the other hand, most divers and many diving equipment sales persons and instructors are highly opinionated. Really! Subjectivity and emotions often dominate objectivity when it comes to selecting and endorsing specific items of diving equipment.

Some salespersons and instructors simply lack the knowledge and experience to objectively assist a novice diver in the selection of their equipment. Several of my basic course diving students have been employed to sell diving equipment with in a few weeks after completing their basic course. And, keep in mind that there is always the "fall-back" philosophy of diving instruction and marketing, *"If you can't dazzle them with brilliants and facts, baffle them with bull!"*

As previously discussed, objective product evaluations and comparisons is simply not available to the prospective buyer. Most buyers rely on the endorsements of friends, salespersons, and instructors as a guide to selecting equipment. Many beginning divers will purchase the same equipment that they see their instructor use during the training course. This may or may not be a reliable guide. Many instructors will carefully and objectively select their personal diving outfit. Others will simply use the equipment that their dive shop has elected to "push" during that course.

Some independent diving instructors continue to use equipment that is "out-of-date" and/or purchased through discount mail order outlets. They claim that they simply cannot afford to buy new equipment all the time. The "good old regulator" may still do the job, however, a conscientious instructor will generally use a regulator that meets a high standard of the of performance and is currently available in the local market place. A student may become confused and even flustered if they go shopping and find that the regulator that their role-model uses is unavailable. The instructor has an obligation to his/her students to "set a proper example." An instructor should be able to prepare an objective list of criteria to support the selection of each item of their personal diving equipment.

Specific criteria for selection will be given for each item of diving equipment discussed below. However, there are certain fundamentals that a consumer must consider in the selection of any item of diving equipment:

* Many diving equipment vendors elect to promote one or two specific manufacturers' equipment lines. From a standpoint of business, inventory management, wholesale discounts for quantity buying, marketing and so on this makes a lot of sense. However, the simple fact that a given shop promotes that specific item/brand of equipment is absolutely no assurance to the consumer that it is the best quality or value.

* A vendor may aggressively promote a specific make and model regulator. This may or my not mean that it is the best

regulator in value or quality. Manufacturer's often offer specials to their dealers. A dealer who buys 100 regulators at a reduced price is naturally going to promote that regulator, regardless of it's comparative quality. In some cases, that model may be tagged for phase out or replacement with a much improved model next year. Generally, the consumer is unaware of this fact. On the other hand, if the regulator has had a good reputation and performance record, it many represent an excellent investment. Unfortunately, the consumer may not have a satisfactory basis to make such a determination.

* The diving industry is becoming increasingly fashion oriented. The consumer apparently wants and pays for colorful fashion coordination. Keep in mind that you many have to sacrifice some basic quality to achieve color coordination.

GENERAL CRITERIA

The consumer must consider a number of factors when selecting an item of diving equipment. The following factors apply to all items of diving equipment:

Performance and Durability. Unfortunately, it is difficult to obtain comparative performance evaluations on diving equipment. This information may be suppressed by vendors or manufacturers or simply unavailable. Some manufacturers provided detailed performance information in their catalogs and others do not. The SCUBAPRO catalog is an excellent example of one containing a considerable amount of technical and performance information. Others may only emphasize their extensive color selection. Unfortunately, modern trends in diver education leave the basic diver unprepared to objectively interpret equipment performace data. The diving industry relies, to some degree, on dealing with a poorly informed consumer.

The diver must make every effort to obtain and interpret objective technical performance information. A salesperson simply stating, "This is the easiest breathing regulator that I have ever used!" or "This is the regulator that I use!" is not a sufficient basis for selecting a regulator. Furthermore, price is not necessarily a measure of performance. Several years ago one of the most expensive depth gauges on the market consistently gave less accurate depth reading in laboratory test than less expensive models. Don't be afraid to request on performance evaluations such as air flow volume and breathing resistance. You may not get it, but it doesn't hurt to ask.

Potential durability may be very difficult or very easy to evaluate. Some new items of diving equipment simply look flimsy. You can spot them across the room. Unfortunately, many product seem to be designed and manufactured of materials which will deteriorate in one to two years of average diving, sooner if you are an extremely active diver. Not too may years ago a diver could purchase a black rubber mask that would give 10 years of excellent service. Today, many black rubber mask will deteriorate to gum in one to two years. Consequently, most mask are now made of silicone. Unfortunately, there are some grades of silicone that will also deteriorate to gum.

Encumbrance and Resistance. A diver who is encumbered with excessively bulky equipment will experience more resistance to movement in the water that a diver equipped with streamlined, properly fitted equipment. For example, some buoyancy compensators are extremely bulk. Lost fitting equipment will shift on the diver's body and tight fitting equipment may be very restrictive and uncomfortable. In addition, some divers will encumber themselves with far more equipment than is needed to perform the dive safely. This additional and unnecessary equipment may increase resistance to movement. *Select equipment that fits properly and comfortably and do not encumber yourself with unnecessary items of equipment.*

Cost and Quality. As previously stated, cost is not necessarily an objective indicator of performance or quality. On the other hand, the American market place is being flooded with cheap, poor quality diving equipment. The consumer must use great care in selecting quality diving equipment. For example, one mask, fins, and snorkel outfit might sell for $100 and another for $135. Many beginning divers will attempt to save money and select the cheaper items. Inspect these cheaper items closely. For example, compare the fin and mask strap retaining/adjusting system on the cheaper model with that of the more expensive model. Some cheaper models are extremely difficult to adjust and/or may easing disengage during diving. This could lead to the loss of a fin underwater and even compromise the safety of a diver. A $35 savings is not worth risking your life!

Keep in mind that rubber products are produces in different grades. In general, higher grade materials are more resistant to deteriorating forces than lower grade materials. And, higher grade products are generally more expensive. On the other hand, some manufactures/vendor may market lower grade products with a higher grade price. Shop around, make comparisons, and talk to other divers. Study and analyze the equipment that is used during training and by other divers that you encounter. If you hear a diver complaining about a deteriorating mask or wet suit or constantly experiencing difficulty with a fin strap retainer, make a note of the make and model in you class notes or logbook. This information may be very helpful in making your future equipment selection.

EQUIPMENT MALFUNCTION AND MANUFACTURER'S RECALLS

A University of Rhode Island report identified 761 nonoccupational underwater diving fatalities over the five year period, 1976 – 1980. Based on information available in this report not a single accident can be clearly attributed to the malfunction or failure of a properly used and maintained piece of diving equipment. Equipment related causes such as depletion of air supply at depth, overweighting of the diver, poor regulator maintenance, regulator freezing, and so on are better classified as diver or procedural errors rather than equipment malfunctions. Only three fatal accidents even remotely suggest true equipment malfunction and even these could be attributed to to improper maintenance or user abuse of the equipment.

On the other hand, there are reports of alleged equipment malfunction incidents which *could* have resulted in serious injury or fatality. Unfortunately, many of these reports circulate through the diving community as rumors or unsubstantiated allegation.

Like the automobile industry, the diving industry does manufacture and distribute items of diving equipment that must later be recalled to corrected specific defects or problems. In addition, manufactures may direct repair facilities to "upgrade" or replace specific equipment components when that equipment is presented for routine periodic maintenance. The consumer may or may not be informed of this action or the reason for it. In the event that specific hazards that might result in mishap or injury are identified, an official recall is issued. Examples of diving equipment recalls over the past few years include:

* A pneumatic spear gun that might inadvertently and without warning discharge a spear, possibly impaling anyone standing in a direct line of fire.

* A shot filled weight belt that had "come apart" during a dive and released the lead shot.

* A new BC bladder that may come apart or burst.

* A underwater propulsion vehicle that has exploded during the recharging procedure and seriously injured a diver.

* A regulator second stage assembled with an incorrect size retainer in which the diaphragm could dislodge and allow the diver to breathe water.

Sometime a manufacturer or the Diving Equipment Manufactures Association (DEMA) will simply release a statement regarding potential problems with an item of equipment rather than recalls. These statements often emphasize or upgrade maintenance procedures. For example, one manufacture released a statement regarding the fact that the trigger switch on the handle of a diver propulsion vehicle could "stick" in an "ON" position, posing a possibly dangerous situation. Apparently, sand lodged in the handle and trigger mechanism caused this malfunction.

A few years ago DEMA issues a notice to divers and vendors identifying a potential problem with the piercing pin attached to the CO_2 inflation mechanism on certain buoyancy control devices. Due to potential breaking of piercing pins (which may not be apparent), the CO_2 inflator mechanism might fail to activate the CO_2 cartridge. DEMA encouraged each diver to "immediately cut the lanyard or string activator attached to the CO_2 inflation mechanism so that the mechanism is not readily available for use" and emphasized that buoyancy control devices are not lifejackets and must not be relied upon for that purpose. Apparently, no official recall was ever issued.

The consumer can easily take precautions and measures to protect themselves from risk that may result from potential equipment problems. The prudent diver should:

* Establish a good relationship with a local diving equipment supplier. By periodically "dropping-in" at the local dive shop the diver will often be personally informed of any such problems and requested to bring the item in for repair or replacement. This is one of the real values of purchasing your equipment at a local vendor.

* Immediately complete and mail any manufacture warranty documents. This will provide the manufacture with your address and identify the specific item of equipment (including serial number and purchased date) that you own. Consequently, in the event of recall or special notification you can be contacted immediately.

* Subscribe to one or more of several diving periodicals. Manufactures publish recalls and special notices in various popular diving magazines and newsletters. *Undercurrents* is a divers newsletter that provides a considerable amount of consumer information.

* If you hear a rumor regarding a possible safety problem with an item of equipment that you own, immediately contact your local dive shop or the supplier/manufacturer of the equipment in order to determine if there is any substance to that rumor. Do not simply continue the equipment.

* If an item of equipment appears to be malfunctioning, discontinue the use of the equipment immediately, even if you must abort a dive. Do not wait for the situation to become more critical. Do not simply disconnect the equipment and continue to dive. For example, a popular combination BCD inflator/octopus regulator begins to leak air during a dive. Many divers will simply disconnect the air supply hose and continue the dive. These divers have now lost the options of BCD power inflation and octopus breathing. Lack of either of these options could be critical in an emergency situation. Many divers do not submit the unit for repair and repeat the same scenario dive after dive.

* If you do not receive a satisfactory response to your inquiry or complaint from the local dive shop, contact the manufacturer's customer service department directly. If there is a potential safety problem with any item of diving equipment, the manufacturers want to know about it immediately.

Do keep in mind that the standard response from both manufactures and dealer may be, "This is the first time that we have ever heard of a problem with this item of equipment. We will be glad to replace or repair it immediately." Fantastic! However, your malfunctioning item may very well be added to the box of 32 others in the back room with a similar problem. That's simply good business. You don't necessarily advertise you weaknesses unless you have to.

The above information is not intended to be overly critical of the diving industry. Nothing is perfect! Mistakes in design and manufacturing may pass undetected until the equipment is in the field. There is no testing laboratory that can completely duplicate the use and abuse of diving equipment afforded by the general diving public.

In order to make every item of diving equipment "diver-proof", pass it through a length testing program, and subject it to extremely rigid quality control standards during manufacturing, the cost of that item of equipment might have to be increases by 25% to 100% or even more over present market value. On the other hand, every diver has a right to expect the highest reasonable standard of performance and quality control, especially in life-support equipment.

CONCLUSIONS

A prudent diver will carefully analyze his/her future diving plans and select equipment according. If you intend to only dive in the tropics you do not need a 1/4-inch wet suit, an extra large BCD, thick neoprene gloves that extend up to your elbow and so on. Recently, a profit motivated, cold water diving employee sold one of my students a pair of "super gloves" for her open water training dive. Based on her current diving plans she will probably never use them again.

Divers should develop a "purchase priority" list, discuss equipment with friends, instructors, and sales persons, and study catalogs and literature prior to making major purchases. Once they have decided on a specific make and model of equipment, they should "shop around" for the best purchase price and service incentives.

Manuscript completed: 9 July 1990

NOTES:

SECTION 4

DECOMPRESSION

INTRODUCTION TO DECOMPRESSION THEORY & MODELS

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INTRODUCTION

The problem of decompression sickness (DCS), also known as "the bends" or caisson disease, has plagued humans ever since they first subjected themselves to hyperbaric (elevated pressure) environments. During a hyperbaric exposure the increased gas pressures cause more gas molecules to be transported through the lungs and become dissolved in the body tissues. Inert gas pressures (such as that of nitrogen [N_2] when air is being breathed) in the tissues gradually increase until they equal the ambient partial pressure of the inert gas. At this point the tissue is considered saturated. As pressure is decreased the flow of gas is reversed and off- gassing occurs (Figures 1). If the pressure of the inert gas exceeds the total ambient pressure a situation of supersaturation occurs and conditions exist for the gas to come out of solution. DCS is the result of bubble formation from inert gas coming out of solution in the tissues when there is a rapid decrease in the surrounding pressure, just as carbon dioxide bubbles are released from solution when a carbonated beverage is opened. This gas bubble release within the blood and tissues can produce a wide range of physiological problems. Pain and neurological detriment are the most common symptoms associated with DCS.

How the inert gas is absorbed and eliminated by the body throughout a dive is what the majority of decompression theory constitutes of. There are many different theories that exist to explain the phenomena of decompression and many decompression models have been developed from those theories. These models are used to calculate decompression tables or are programmed into dive computers. All the models do is attempt to approximate a very complex system with mathematics. They calculate depth-time envelopes that are hopefully safe for most of the divers most of the time.

Haldanian Model

The most common decompression model in use today is the Haldanian model, after the English physiologist J.S. Haldane who first proposed this type of model in 1907 [2]. The model assumes that the body can be approximated by a group of compartments that absorb and eliminate nitrogen at different rates. Furthermore, each of these compartments can hold a certain level of excess nitrogen (supersaturation) in them at the surface without bubbles forming and DCS occurring.

The absorption and elimination rates of nitrogen from the compartments are expressed in terms of half-times. One half-time is the time it will take the compartment to reach the half way point between its initial nitrogen pressure and the ambient nitrogen pressure. For example, a 5-minute compartment will be half-way between its initial pressure and ambient pressure (50% saturated) after five minutes. After ten minutes it will be 75% saturated, after 15 minutes 87.5% saturated, etc. Mathematically this describes and exponential curve (Figure 2) which indicates that the compartment will never become fully saturated. In practice a compartment is considered saturated after six half-times, or when it is 98.44% saturated.

The level of "safe" supersaturation for a compartment can be represented in different ways. For example consider a compartment that could be saturated at a depth of 33 feet of sea water (fsw) and safely returned to the surface. The ambient pressure at sea level is 1 atmosphere (ATA) which is equivalent to the pressure exerted by 33 fsw so the total ambient pressure at a depth of 33 fsw is 2 ATA or 66 fsw. The various ways to represent the allowable supersaturation in this compartment are shown below:

A. Equivalent Saturation Depth:Ambient Pressure Ratio = 2 ATA / 1 ATA = 2:1

B. Nitrogen Pressure:Ambient Pressure Ratio = (2 ATA x 0.79) / 1 ATA = 1.58:1

C. Total Allowable Nitrogen Pressure = 2 ATA x 0.79 = 1.58 ATA N2 or 52 fsw N_2

D. Total Pressure Differential = 2 ATA – 1 ATA= 1 ATA or 33 fsw

E. Nitrogen Pressure Differential = (2 ATA x 0.79) – 1 ATA = 0.58 ATA N_2 or 19 fsw N_2

The most commonly used representations are B, the Nitrogen Pressure to Ambient Pressure (PN_2:P_a) Ratio, and C, the Total Allowable Nitrogen Pressure generally referred to as the M-value. In most models a faster compartment can withstand a greater level of supersaturation than a slower compartment. By varying the number, half-times, and allowable supersaturation levels of compartments a large number of models can be created. From each of these models it is possible to create many different sets of tables based on various assumptions that need to be made when converting a dynamic model into a static table.

U.S. Navy Model & Tables

The present U.S. Navy tables were developed in the 1950s to accommodate the introduction of scuba and to improve the U.S. Navy tables, published in 1937. The older tables had no acceptable provisions for performing repetitive dives, since most dives were done in the surface-supplied hardhat mode with an unlimited air supply. The model that was used in the computation of the newer tables was a modified Haldanian model [3, 4, 5].

Six compartments were used in the model with 5-, 10-, 20-, 40-, 80-, and 120-minute half-times. The 120-minute tissue assumes a saturation, or desaturation, time of 12 hours (six half-times). [Note: An easy way to determine six half-times for a compartment is to divide the minute half- time by ten to get the hours required.]

The U.S. Navy model assumed the allowed supersaturation ratio for the compartments decreased with depth. This led to the development of the "M value" system to determine the allowable nitrogen pressure (in fsw) for a compartment at a specific depth. The M value for a compartment that corresponds to the supersaturation ratio permitted at sea level is referred to as M_0. M_{10} is the nitrogen pressure that the compartment can hold at a depth of 10 fsw. The change in the M value per foot of sea water is referred to as Delta M.

TABLE 1

U.S. NAVY M_0 AND DELTA M VALUES

TISSUE 1/2-TIME	SS RATIO	M_0 Value	DM	MAXIMUM NO-D DEPTH
5 min.	3.15	104 fsw	2.27	99 fsw
10 min.	2.67	88 fsw	2.00	78 fsw
20 min.	2.18	72 fsw	1.71	58 fsw
40 min.	1.76	58 fsw	1.40	40 fsw
80 min.	1.58	52 fsw	1.29	33 fsw
120 min.	1.55	51 fsw	1.27	31 fsw

The M_0 and Delta M values for the six compartments are listed in Table 1 with the corresponding supersaturation ratios for surfacing. As you can see the M_0 value is just the supersaturation ratio times 33. The table also shows the maximum no-decompression depth for each of the compartments. This is the depth where the inspired nitrogen pressure is equal to the M_0 value. In the case of the 5-minute compartment the M_0 value is 104 fsw N_2. Since the nitrogen percent in air is 79% then the 104 fsw nitrogen pressure is exerted when the total ambient pressure is 132 fsw (104 fsw / 0.79). Since this is a total pressure of 132 fsw the depth at which this pressure is experienced is 99 fsw (132 fsw – 33 fsw surface pressure). This says, according to the model, that the 5-minute compartment could be saturated at 99 fsw or shallower and not require any decompression.

Using the six compartments and their M values the U.S. Navy Standard Air Decompression Tables were developed. These tables are presented in Appendix B.

FIGURE 1

GAS DIFFUSION

OVERALL GAS MOLECULE MOVEMENT IS FROM AREAS OF HIGH CONCENTRATION TO AREAS OF LOW CONCENTRATION

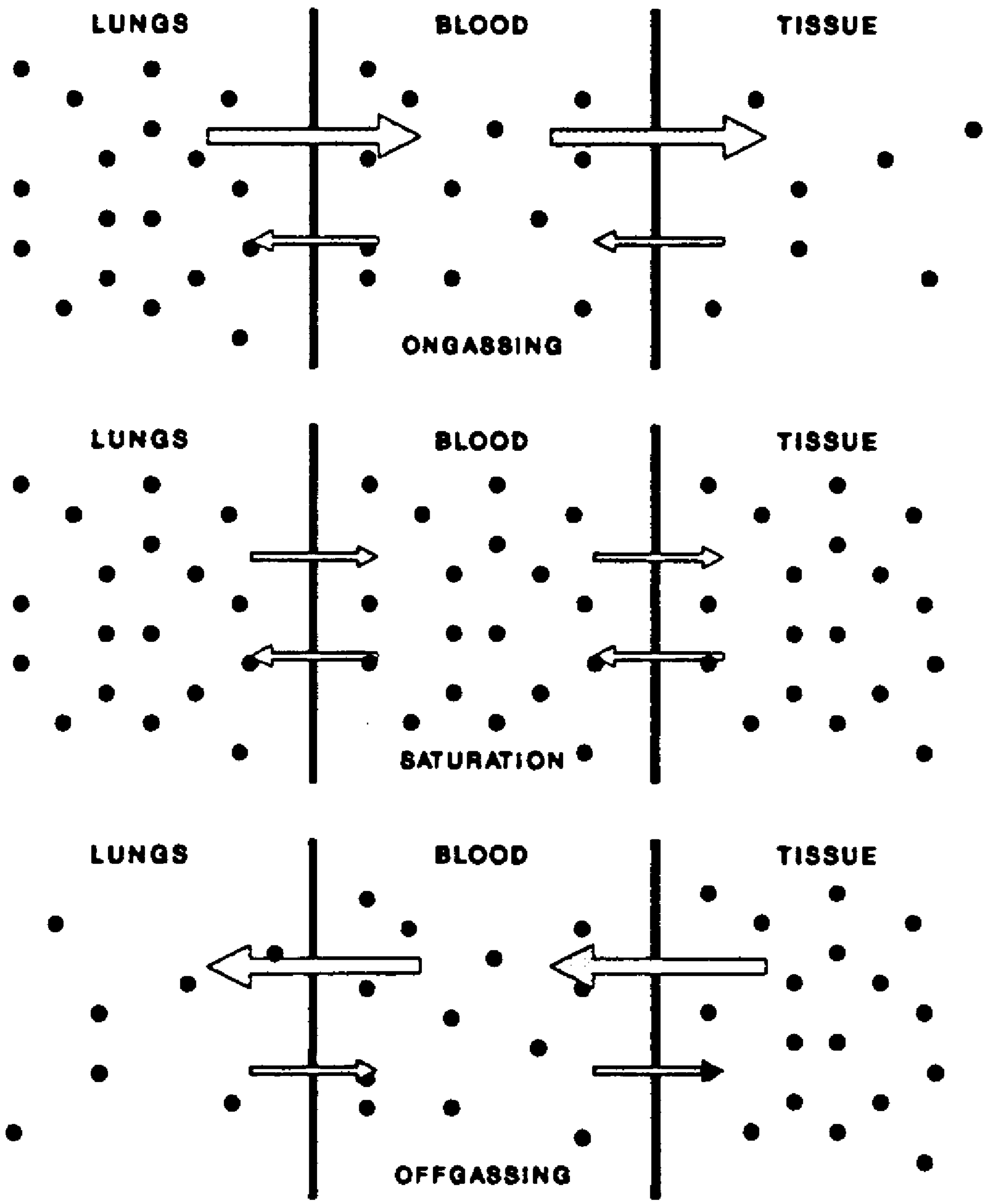
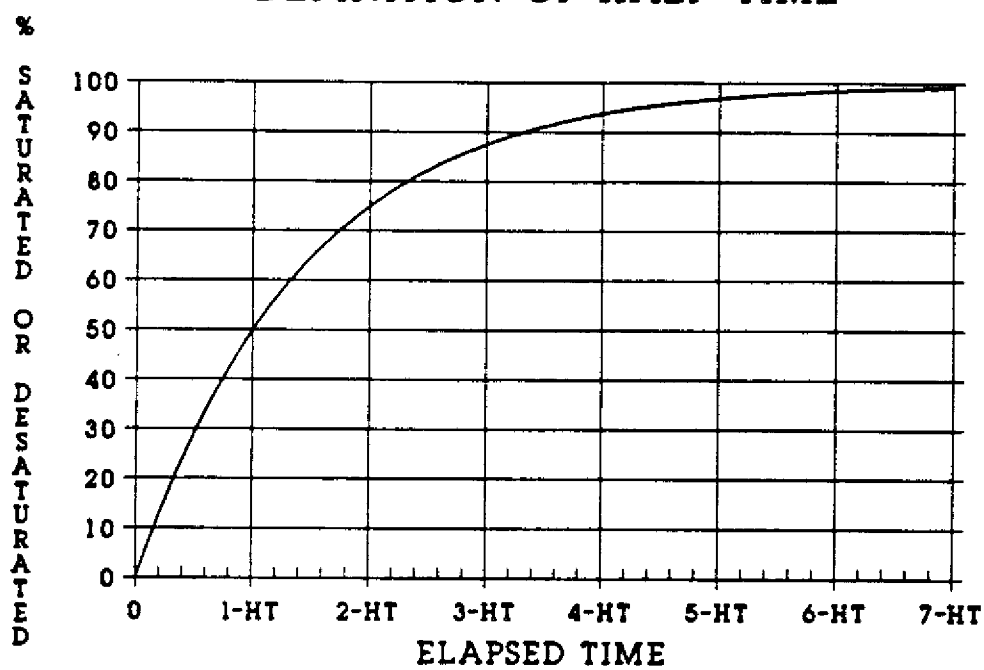


FIGURE 2
DEFINITION OF HALF-TIME



The no-decompression limits for the tables were determined using the half-times and their respective M_0 values. To calculate the no-decompression limits for a specific depth the compartments, which are initialized at surface pressure, are "exposed" to the depth in question. The first compartment that reaches its M_0 value is the one that controls the no-decompression limit. It can be seen that at depths shallower than 78 fsw there is no need to consider the 5- and 10-minute compartments since they will never reach their M_0 values. The no-decompression limits for the shallower depths are controlled by the slower compartments while those at the deeper depths are controlled by the faster compartments.

In addition to the standard decompression tables, it was necessary to create a set of tables that would allow divers to perform repetitive dives. If a repetitive dive was performed using the 1937 tables, the bottom times of the two dives would be added together, no matter how long the surface interval was, without considering the off-gassing that occurred during the surface interval.

The initial idea was to have repetitive dive tables for all six compartments. However, it was decided that six sets of tables would probably have been too complex for normal diving operations. A simple technique needed to be devised that would be easy to use in field operations. The technique also had to prevent any of the other five compartments from controlling a repetitive dive. Calculations were made to see how long a surface interval was required for the other five compartments to off-gas to levels where they would no longer have a controlling effect on a repetitive dive, following any dive profile allowed by the tables. The longest time generated was 9.7 minutes for the 40-minute compartment. For this reason the Surface Interval Table cannot be entered unless the surface interval is greater than 10 minutes. Any repetitive dive done within 10 minutes of surfacing is considered part of the original dive.

The solution used for computing repetitive dives was the Repetitive Group Designation system. The Repetitive Group Designators "A" to "O" and "Z" represent increasing levels of residual nitrogen in the 120-minute half-time compartment. Each group represents a nitrogen pressure range of approximately 1.58 fsw. Following a dive (either no-decompression or decompression), the diver's status is represented on the table by a Group Designator. By using the initial Group Designator and the time spent at the surface, a new Group Designator is obtained using the Surface Interval Table. To obtain the time penalty the first dive places on the second dive, the Residual Nitrogen Time table is used. This translates the new Group Designator to the time it would have taken at the repetitive dive depth to reach the nitrogen pressure in the 120-minute compartment that is equivalent to the present Group Designation. This residual nitrogen time (RNT) is then added to the actual bottom time (ABT) of the dive to determine an equivalent single dive time (ESDT), which is then used in computing the decompression requirements of the second dive (ESDT = RNT + ABT). A third dive can be computed by following the same procedure since the ESDT in essence combines the first and second dive into a single dive used to enter the tables.

The wedge shape of the no-decompression table can now be understood with the information we have. Since the no-decompression limits for the deeper depths are controlled by the fast compartments, the 120-minute compartment does not have much time to build up extra nitrogen, hence the low RGD even though the no-decompression limit has been reached. As the depths get shallower the medium speed compartments start to control, giving the 120-minute compartment more time to build up nitrogen, producing a larger RGD. At 35 fsw the 120-minute compartment has enough time to nearly reach its M_0 value, giving the highest RGD on the table. At depths of 30 fsw and shallower there is not enough nitrogen pressure to reach the M_0 value of the 120-minute compartment so the RGDs of the maximum times decrease with depth.

To test the tables, sixty-one repetitive dive combinations were devised. One hundred-twenty-one test dives, resulting in 3 cases of decompression sickness, were completed before the tables were released for Navy use. They were picked up by the fledgling sport diving community and have since been used by millions of divers around the world.

A recent recalculation of the current U.S. Navy tables by the Navy Experimental Diving Unit found some computational and transcriptional errors [16]. This was a surprise to some divers since they assumed that the U.S. Navy tables were "carved in stone". But it must be remembered that in the 1950s only the earliest computers existed and most of the numerical entries of the U.S. Navy tables were derived through manual computations. The major transcriptional error occurs in the no-decompression table (Table B-1, Appendix B). Every value in the table at a depth of 30 fsw and shallower is shifted one column to the left. If after a dive to 30 fsw the Repetitive Group Designation was G, it should actually be Repetitive Group H. Even with these transcriptional and computational errors, the U.S. Navy tables have served divers well for over 30 years.

Silent Bubble Limits

In 1976 Dr. Merrill Spencer of the Institute of Applied Physiology and Medicine in Seattle published a report recommending that the present no-decompression limits be reduced, based on Doppler ultrasonic bubble detection studies [15]. He found that divers who were exposed to the U.S. Navy no-decompression limits developed large counts of venous gas emboli (VGE) or "silent bubbles". These bubbles are thought to be nitrogen bubbles that have been released from solution during ascent. They are detected with an ultrasonic probe that distinguishes gas bubbles by the reflection of the ultrasonic wave off the bubble surfaces. Further studies by Dr. Andrew Pilmanis at the Catalina Marine Science Center [13] confirmed the presence of high degrees of VGE following "no-decompression" dives in open water. Pilmanis found VGE formation in all his subjects who were exposed to 100 fsw for 25 minutes (the U.S. Navy no-decompression limit for that depth). Spencer presented the following formula to compute reduced no-decompression limits that would hold the occurrence of VGE formation below 10% to 20%:

$$\text{No-D Limit}_{min} = (465/\text{Depth}_{fsw})^2$$

This information, along with additional information from Bassett [1], was used to produce modified no-decompression limits for sport divers. These limits (Table 2) have been used as a basis for numerous new tables that have spread throughout the diving communities.

TABLE 2

U.S. NAVY VS.
SPENCER NO-DECOMPRESSION LIMITS

Depth	USN	Spencer
30	none	225
40	200	135
50	100	75
60	60	50
70	50	40
80	40	30
90	30	25
100	25	20
110	20	15
120	15	10
130	10	5

Jeppesen Tables

Jeppesen, publishers of diving education materials, decided to modify the U.S. Navy tables based on the new no-decompression limit recommendations. They took the new limits and drew a red line on the tables to represent the limits that sport divers should follow. If the recommended limit did not match a table entry then the next lower entry was used as the limit. The tables are used the same as the standard U.S. Navy tables.

NAUI Tables

NAUI has used a similar approach to the development of their new tables and dive planner [7]. The no-decompression limits were modified to be closer to the Spencer limits and they corrected the errors that had been discovered by the Navy in 1983. The total desaturation time (the time it takes to consider a dive new as opposed to repetitive) was changed from 12 hours to 24 hours in an attempt to add conservatism to multi-day diving and some of the data on the repetitive dive timetable were removed to discourage repetitive dives deeper than 100 fsw. A recommendation of a 3 – 5 minute stop at 15 fsw after every dive was also included, although not printed on the tables. The depth of 15 fsw is also used for decompression in case the no-decompression limits are exceeded.

Huggins Tables

In 1981, Huggins computed a set of Repetitive Dive Tables using a model based on the new no-decompression limits [8].

TABLE 3

M0 VALUES FOR HUGGINS MODEL

TISSUE 1/2-TIME	M_0 VALUE (fsw)	TISSUE 1/2-TIME	M_0 VALUE (fsw)
5 min.	102.0	40 min.	54.5
10 min.	85.0	80 min.	47.5
20 min.	67.5	120 min.	43.0

The model uses the same six half-time compartments as the U.S. Navy model. The M_0 values for the compartments were determined by computing the maximum pressures produced in the compartments following exposure to the new no-decompression limits. No Delta M values were necessary since the tables were computed exclusively for no-decompression diving. The new M_0 values are listed in Table 3, along with the compartment half-times.

The tables are presented in the same format as the U.S. Navy Tables. The major computational difference is that the Repetitive Group Designators represent nitrogen levels in all six compartments instead of just the 120-minute compartment. Each repetitive group represents a 3% range of the M_0 values of the compartment. For example, group "E" represents 72% to 75% of the M_0 value of any of the six compartments. This type of representation allows all six compartments to be considered in repetitive dive calculations and permits certain types of multi-level diving procedures to be performed without any of the compartments exceeding their Mo values.

The Huggins Tables are presented in Appendix A. The only difference in reading the tables involves the arrows "—>" in the first table. These arrows indicate that the diver must move to the right to obtain the repetitive group designator for the dive.

These tables have not been officially tested. However, they are more conservative than the U.S. Navy Tables when they are used to compute no-decompression limits and repetitive no-decompression limits. These tables have been published by the Michigan Sea Grant College Program, and have gained in popularity and use.

PADI Recreational Dive Planner

PADI's Recreational Dive Planner (RDP) has taken a different approach to the development of tables based on Spencer's limits. Ray Rogers, DDS, the developer of the RDP used Spencer's limits to derive M_0 values for his model (Table 4) but then made the assumption that the U.S. Navy's use of the 120-minute compartment to control repetitive dives was too conservative for the type of dives recreational divers perform. He concluded that a 60- minute half-time compartment could adequately control their needs. This means that the 26 repetitive groups in the PADI RDP indicate nitrogen levels in a 60-minute compartment, not a 120-minute one like the U.S. Navy tables, leading to total table desaturation in 3 to 6 hours. The result of this decision is that residual nitrogen, represented by the tables, is eliminated more rapidly and divers may be able to enter the water sooner and/or perform longer repetitive dives.

TABLE 4

RECREATIONAL DIVE PLANNER MODEL COMPARTMENT HALF-TIMES AND M_0 VALUES

1/2-Time	M_0 Value	1/2-Time	M_0 Value
5	99	80	49
10	82	120	47
20	67	200	45
30	59	240	44
40	55	360	43
60	51	480	43

The RDP comes in two formats, the Table and the Wheel. The table is used in the same manner as the U.S. Navy table. The Wheel is basically a circular slide ruler that calculates nitrogen build-up in the 60-minute compartment and assigns the result a repetitive group letter. The Wheel can also be used to compute Multi-Level dives, which allow divers to eliminate the restriction of assuming they have spent their entire dive at their deepest depth.

PADI has been conducting tests on the RDP for the past few years. The first phase of their testing involved three multi-level dives on a single day [14]. Over 400 person-dives conducted with no symptoms of DCS (except for occasional skin itching which is normal in chamber dive) and an overall silent bubbles occurrence of 7.1%. PADI is in the middle of their second phase of testing which consists of four dives a day for six days in a row.

DCIEM Model & Tables

Over the last decade the Defence and Civil Institute of Environmental Medicine (DCIEM) in Canada has been modifying their decompression model based on ultrasonic Doppler studies. In September of 1984 DCIEM released their new No-Decompression and Decompression Tables [11]. A version of the DCIEM tables has been adapted for recreational divers and is experiencing expanded use. The DCIEM model is a serial model with four compartments [12]. The previously presented Haldanian models are parallel models, which assume all the compartments in the model are exposed to the ambient pressure with no interaction between the groups. A serial model assumes the compartments are connected in a series with only one tissue group exposed to the ambient pressure. Figure 3 compares the serial and parallel models.

Each of the four compartments in the model have the same half-time of approximately 21 minutes. The allowable surfacing supersaturation ratios considered are 1.92 and 1.73 for the initial two tissues in the series. The pressure levels in the last two tissues are not considered in the computation of the diver's safe ascent depth.

The DCIEM tables are based on thousands of man-dives that were evaluated using ultrasonic Doppler detection [9, 10]. DCIEM's primary goal with the modifications was to upgrade the decompression model that is programmed into their decompression computers.

New BSAC Tables

BSAC, the British Sub Aqua Club, recently introduced a new set of tables that used a reworking of data used to compute the Royal Navy Physiological Laboratory tables. The model that was used is called a "slab diffusion" model, which involves the linear bulk diffusion of gas into a tissue slab [6]. This model represents the body as a tissue slab that ambient nitrogen pressure diffuses into from one face (Figure 4). As the inert gas pressure increases on the exposed side, the pressure will migrate through the slab. As long as the inert gas pressure does not exceed a specific level with respect to the ambient pressure, decompression sickness theoretically will not develop. The BSAC tables tend to be more conservative than the U.S. Navy tables.

Comparison of Tables

Table 5 shows a comparison of the no-decompression limits of the various tables mentioned above. The resulting times are more conservative than the U.S. Navy limits which have been the "standard of the community" for years. Even though the models may differ in their hypotheses, the no-decompression limits for the more recent tables correlate quite well for depths deeper than 50 fsw. Therefore the author recommends the use of the more conservative limits, especially in sport diving. However this does not mean that the other tables will be more conservative than the U.S. Navy tables in all situation. The assumptions used to create the tables from the U.S. Navy model may create a more conservative table than the RDP table which is created from a more conservative model. Figures 5 and 6 show comparisons of allowable repetitive dive times from the various tables.

TABLE 5

COMPARISON OF SINGLE DIVE NO-DECOMPRESSION LIMITS

Depth	USN	PAD	NAU	Huggins	DCIEM	BSAC
40	200	140	130	135	150	122
50	100	80	80	75	75	74
60	60	55	55	50	50	51
70	50	40	45	40	35	37
80	40	30	35	30	25	30
90	30	25	25	25	20	24
100	25	20	22	20	15	20
110	20	16	15	15	12	17
120	15	13	12	10	12	14
130	10	10	8	5	8	13

FIGURE 3

PARALLEL vs. SERIAL MODEL

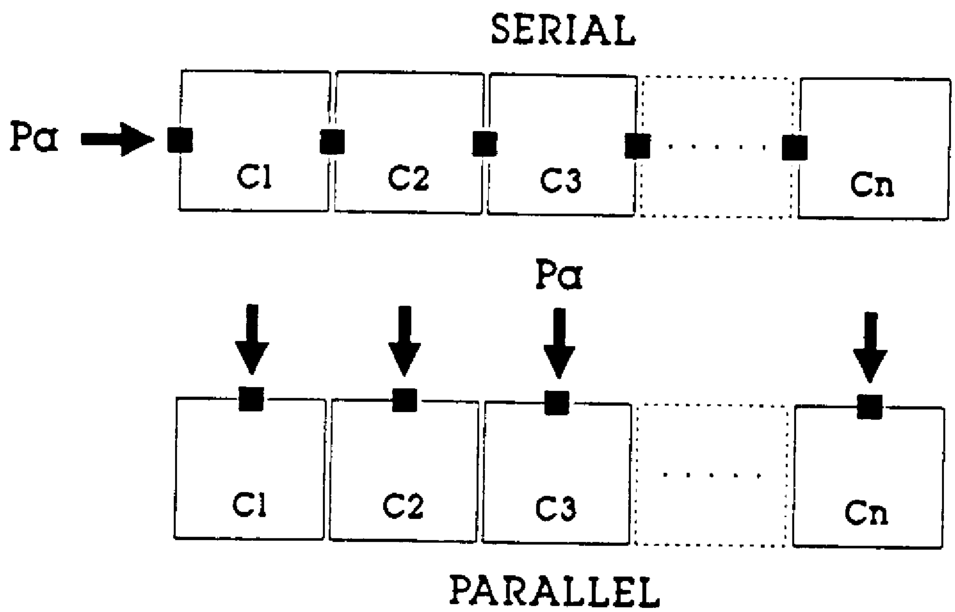


FIGURE 4

TISSUE SLAB MODEL

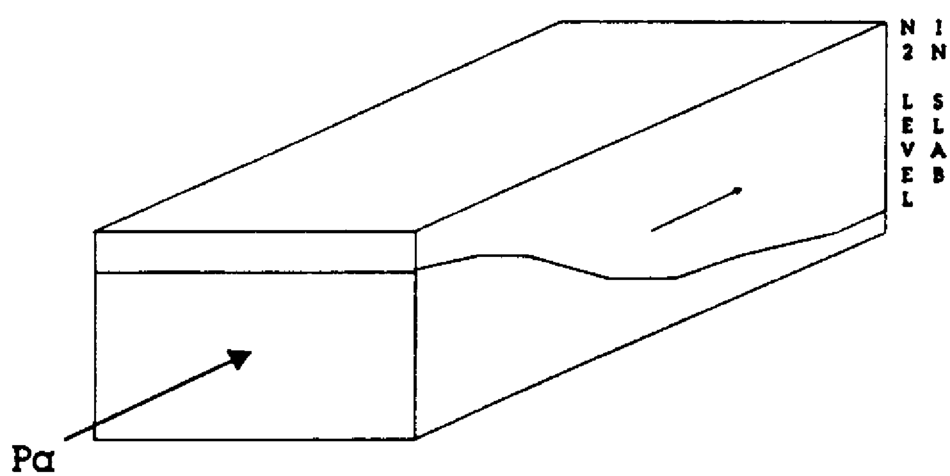


FIGURE 5

NO-D LIMIT FOR DIVE TO 60 FSW FOLLOWING DIVE TO 80 FSW FOR 25 MIN.

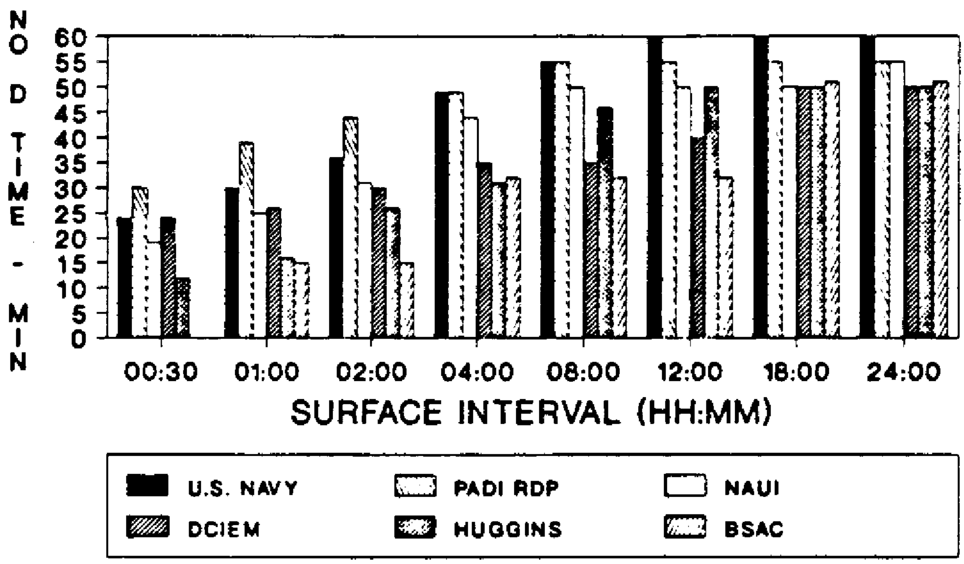
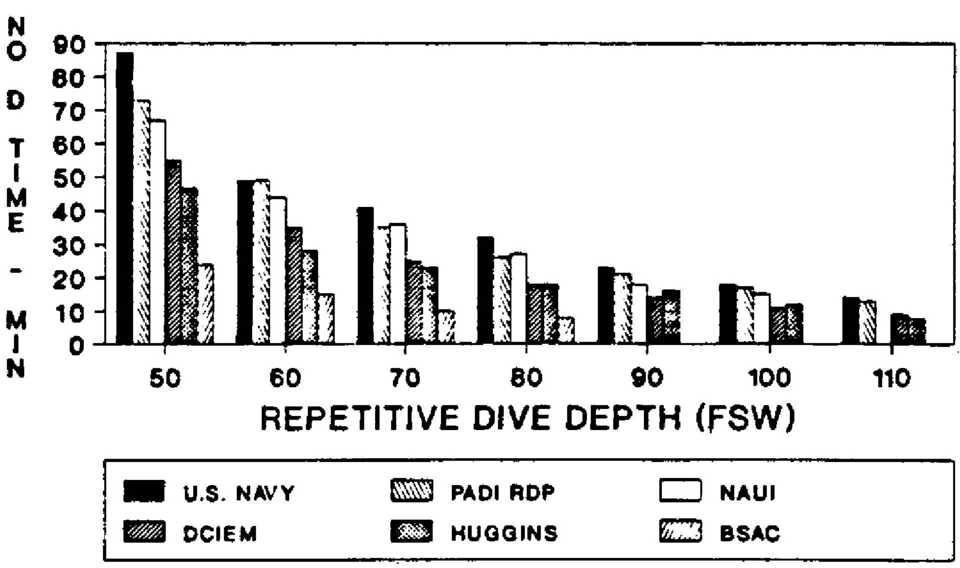


FIGURE 6

NO-D LIMITS FOLLOWING 120 FSW/10 MIN. DIVE AND A 3 HOUR SURFACE INTERVAL



SUMMARY

The basic limitation of any set of tables, no matter which set is used, is that only a limited number of the depth/time dive combinations can be presented. Most tables present information in depth/time matrixes with normal depth increments of 10 fsw and time increments of five or ten minutes. To enter these matrixes, depths and times are rounded up to the next higher table entry. For example, a 41 fsw dive for 32 minutes must be entered into the table as a 50 fsw dive for 40 minutes. The other basic limitation of tables is that most are based on the assumption that the diver has performed a "square wave" dive profile; that is, the diver has spent the entire dive time at the maximum depth achieved. These assumption lead to added conservatism when used on dives where the maximum depth was achieved for only a fraction of the dive time and where divers do not dive to exact depth represented on the table.

It must be remembered that all any of these models and tables are attempting to do is minimize the risk of DCS occurring. They are not panaceas. No model or table can guarantee a 0% occurrence of DCS. All they attempt to do is provide a diver with a depth-time "envelope" that will be safe for most of the people most of the time.

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Manuscript completed: 21 August 1990

APPENDIX A

DANGER – READ WARNINGS!

These tables have been developed mathematically and have *not* been subjected to testing to validate them. This table is more conservative than the United States Navy tables. If this table is used in the same manner as the U.S. Navy tables you will have less allowed bottom time. The maximum recommended ascent rate is 40 feet per minute when you are between 130 and 20 feet sea water. The maximum recommended ascent rate is 20 feet per minute when you are between 20 feet sea water and the surface. A safety stop at 20 feet for three minutes is recommended when the depth of your dive was greater than 60 feet. If you are within the no-decompression time limits of this table when reaching 20 feet, *and* the 3 minute safety stop causes you to exceed the no-decompression limit, you *will* be a group "N" diver. The recommended time *before flying* is 24 hours after your last dive.

If these or any other diving tables are used incorrectly, it is possible to develop decompression sickness which may result in severe injury or death. Although statistically less likely, it is also possible to develop decompression sickness even if these or any other diving tables are used correctly. The use of these tables, or any other tables for multi-level diving is discouraged until testing has validated multi-level diving as an acceptable technique. In case of a scuba diving emergency, call the Divers Alert Network at Duke University in Durham, North Carolina U.S.A. Emergency 24-Hour Diving Accident Phone: 919-684-8111. Table graphics designed by Kenneth A. Ascher, NAUI 9200L. The table data is based on research by Karl E. Huggins, NAUI 5900, and financed in part by the Michigan Sea Grant College Program.

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Revision 4 – Issued May 2, 1989
OTG Official Publication # A-13 – Printed in U.S.A.

COMMUNICATIONS ELECTRONICS INC.

Ocean Technology Group

HUGI

No-Decompression Dive Tables
for 0 – 2,000 feet (*0 – 610 m.*) above sea level

Table 1 – End-of-Dive Letter Group
Total Underwater Time in Minutes

Start Depth in sea water m.	FEET	A	B	C	D	E	F	G	H	I	J	K	L	M	N
6	20	10	25	40	60	85	110	135	170	215	275	325	569	∞	
9	30	5	15	25	40	50	65	75	95	110	130	150	175	205	225
11	35	5	15	20	30	40	50	60	70	85	100	120	135	155	185
12	40	5	10	20	25	35	40	45	55	60	70	85	100	120	135
15	50	–	10	15	20	25	30	35	37	40	50	55	60	70	75
18	60	–	5	10	15	20	23	25	27	30	35	40	45	47	50
21	70	–	6	10	13	15	17	20	23	25	27	30	33	35	40
24	80	–	5	7	–	10	13	15	17	20	–	25	27	–	30
27	90	–	–	5	7	–	10	–	13	15	17	–	20	23	25
30	100	–	–	–	6	7	–	–	10	–	–	13	15	17	20
34	110	–	–	–	–	5	–	7	–	–	10	–	–	13	15
37	120	–	–	–	–	–	5	–	–	7	–	–	10		
40	130	–	–	–	–	–	5								

Table 2 — Surface Interval Time Table
Time Ranges in Hours & Minutes

New Group	A	B	C	D	E	F	G	H	I	J	K	L	M	N
N														0:10 0:17
M													0:10 0:23	0:18 0:32
L												0:10 0:23	0:24 0:39	0:33 0:48
K											0:10 0:25	0:24 0:41	0:40 0:57	0:49 1:06
J										0:10 0:28	0:29 0:44	0:42 1:00	0:58 1:18	1:07 1:25
I									0:10 0:29	0:29 0:50	0:45 1:08	1:01 1:21	1:17 1:38	1:26 1:47
H								0:10 0:33	0:30 0:53	0:51 1:14	1:07 1:30	1:22 1:49	1:38 2:02	1:48 2:11
G							0:10 0:33	0:34 1:01	0:54 1:21	1:15 1:42	1:31 1:58	1:46 2:13	2:03 2:30	2:12 2:38
F						0:10 0:42	0:34 1:06	1:02 1:34	1:22 1:54	1:43 2:15	1:59 2:31	2:14 2:48	2:31 3:03	2:40 3:12
E					0:10 0:48	0:43 1:23	1:07 1:47	1:35 2:15	1:55 2:35	2:18 2:58	2:32 3:12	2:47 3:27	3:04 3:44	3:13 3:53
D				0:10 1:03	0:50 1:43	1:24 2:17	1:48 2:41	2:16 3:09	2:36 3:29	2:57 3:50	3:13 4:06	3:28 4:21	3:45 4:38	3:54 4:47
C			0:10 1:18	1:04 2:20	1:44 3:00	2:18 3:34	2:42 3:58	3:10 4:26	3:30 4:48	3:51 5:07	4:07 5:23	4:22 5:38	4:39 5:55	4:48 6:04
B		0:10 2:30	1:20 3:41	2:21 4:42	3:01 5:22	3:35 5:56	3:58 6:20	4:27 6:48	4:47 7:08	5:08 7:29	5:24 7:45	5:38 8:00	5:56 8:17	6:05 8:28
A	0:10 12:00	2:31 12:00	3:42 12:00	4:43 12:00	5:23 12:00	5:57 12:40	6:21 13:10	6:48 13:30	7:08 14:00	7:30 14:20	7:48 14:40	8:01 14:50	8:18 15:10	8:27 15:30

Table 3 — Residual Nitrogen Time Table
Repetitive Dive Depth in Sea Water – Time in Minutes

m.	6	9	11	12	15	18	21	24	27	30	34	37	40	
FEET	20	30	35	40	50	60	70	80	90	100	110	120	130	NEW GROUP
	–	225	185	135	75	53	41	31	28	21	18	13	11	•N
	–	207	158	124	71	52	40	30	25	20	15	12	10	•M
	569	178	139	103	64	47	35	28	22	18	13	11	9	•L
	369	154	122	88	57	43	32	26	20	15	12	10	8	•K
	279	132	103	75	51	38	29	23	18	13	11	9	8	•J
	219	113	86	65	45	34	26	21	16	12	10	8	7	•I
	175	96	73	57	40	30	24	19	14	11	9	8	7	•H
	140	80	62	49	36	27	22	17	12	10	8	7	6	•G
	111	66	53	43	32	24	19	14	11	9	7	6	5	•F
	86	53	44	37	28	22	17	12	9	8	7	6	5	•E
	65	41	34	30	23	19	15	10	8	7	6	5	5	•D
	45	29	25	21	17	14	12	9	8	6	6	5	5	•C
	28	18	16	14	11	9	8	7	6	6	5	5	4	•B
	12	8	7	6	5	4	4	3	3	3	3	2	2	•A

NOTES:

APPENDIX B

TABLE B-1

U.S. NAVY NO-DECOMPRESSION LIMITS AND REPETITIVE GROUP DESIGNATION TABLE FOR NO-DECOMPRESSION AIR DIVES

Depth (feet)	No-Decompression Limits (min)	Group Designation														
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
10		60	120	210	300											
15		35	70	110	160	225	350									
20		25	50	75	100	135	180	240	325							
25		20	35	55	75	100	125	160	195	245	315					
30		15	30	45	60	75	95	120	145	170	205	250	310			
35	310	5	15	25	40	50	60	80	100	120	140	160	190	220	270	310
40	200	5	15	25	30	40	50	70	80	100	110	130	150	170	200	
50	100		10	15	25	30	40	50	60	70	80	90	100			
60	60		10	15	20	25	30	40	50	55	60					
70	50		5	10	15	20	30	35	40	45	50					
80	40		5	10	15	20	25	30	35	40						
90	30		5	10	12	15	20	25	30							
100	25		5	7	10	15	20	22	25							
110	20			5	10	13	15	20								
120	15			5	10	12	15									
130	10			5	8	10										
140	10			5	7	10										
150	5			5												
160	5				5											
170	5				5											
180	5				5											
190	5				5											

TABLE B-2

U.S. NAVY SURFACE INTERVAL AND RESIDUAL NITROGEN TIME TABLES FOR REPETITIVE AIR DIVES

Repetitive Group at the beginning of the surface interval

Repetitive Group	Z	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A
A																0:10 12:00
B															0:10 2:10	2:11 12:00
C														0:10 1:39	1:40 2:49	2:50 12:00
D													0:10 1:09	1:10 2:38	2:39 5:48	5:49 12:00
E												0:10 0:54	0:55 1:57	1:58 3:22	3:23 6:32	6:33 12:00
F											0:10 0:45	0:46 1:29	1:30 2:28	2:29 3:57	3:58 7:05	7:06 12:00
G										0:10 0:40	0:41 1:15	1:16 1:59	2:00 2:58	2:59 4:25	4:26 7:35	7:36 12:00
H									0:10 0:36	0:37 1:06	1:07 1:41	1:42 2:23	2:24 3:20	3:21 4:49	4:50 7:59	8:00 12:00
I								0:10 0:33	0:34 0:59	1:00 1:29	1:30 2:02	2:03 2:44	2:45 3:43	3:44 5:12	5:13 8:21	8:22 12:00
J							0:10 0:31	0:32 0:54	0:55 1:19	1:20 1:47	1:48 2:20	2:21 3:04	3:05 4:02	4:03 5:40	5:41 8:40	8:41 12:00
K						0:10 0:28	0:29 0:49	0:50 1:11	1:12 1:35	1:36 2:03	2:04 2:38	2:39 3:21	3:22 4:19	4:20 5:48	5:49 8:58	8:59 12:00
L					0:10 0:26	0:27 0:45	0:46 1:04	1:05 1:25	1:26 1:49	1:50 2:19	2:20 2:53	2:54 3:36	3:37 4:35	4:36 6:02	6:03 9:12	9:13 12:00
M				0:10 0:25	0:26 0:42	0:43 0:59	1:00 1:18	1:19 1:39	1:40 2:05	2:06 2:34	2:35 3:08	3:09 3:52	3:53 4:49	4:50 6:18	6:19 9:28	9:29 12:00
N			0:10 0:24	0:25 0:39	0:40 0:54	0:55 1:11	1:12 1:30	1:31 1:53	1:54 2:18	2:19 2:47	2:48 3:22	3:23 4:04	4:05 5:03	5:04 6:32	6:33 9:43	9:44 12:00
O		0:10 0:23	0:24 0:36	0:37 0:51	0:52 1:07	1:08 1:24	1:25 1:43	1:44 2:04	2:05 2:29	2:30 2:59	3:00 3:33	3:34 4:17	4:18 5:16	5:17 6:44	6:45 9:54	9:55 12:00
Z	0:10 0:22	0:23 0:34	0:35 0:48	0:49 1:02	1:03 1:18	1:19 1:36	1:37 1:55	1:56 2:17	2:18 2:42	2:43 3:10	3:11 3:45	3:46 4:29	4:30 5:27	5:28 6:56	6:57 10:05	10:06 12:00
New --> Group Designation	**Z**	**O**	**N**	**M**	**L**	**K**	**J**	**I**	**H**	**G**	**F**	**E**	**D**	**C**	**B**	**A**

Repetitive Dive Depth	Z	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A
40	257	241	213	187	161	138	116	101	87	73	61	49	37	25	17	7
50	169	160	142	124	111	99	87	76	66	56	47	38	29	21	13	6
60	122	117	107	97	88	79	70	61	52	44	36	30	24	17	11	5
70	100	96	87	80	72	64	57	50	43	37	31	26	20	15	9	4
80	84	80	73	68	61	54	48	43	38	32	28	23	18	13	8	4
90	73	70	64	58	53	47	43	38	33	29	24	20	16	11	7	3
100	64	62	57	52	48	43	38	34	30	26	22	18	14	10	7	3
110	57	55	51	47	42	38	34	31	27	24	20	16	13	10	6	3
120	52	50	46	43	39	35	32	28	25	21	18	15	12	9	6	3
130	46	44	40	38	35	31	28	25	22	19	16	13	11	8	6	3
140	42	40	38	35	32	29	26	23	20	18	15	12	10	7	5	2
150	40	38	35	32	30	27	24	22	19	17	14	12	9	7	5	2
160	37	36	33	31	28	26	23	20	18	16	13	11	9	6	4	2
170	35	34	31	29	26	24	22	19	17	15	13	10	8	6	4	2
180	32	31	29	27	25	22	20	18	16	14	12	10	8	6	4	2
190	31	30	28	26	24	21	19	17	15	13	11	10	8	6	4	2

RESIDUAL NITROGEN TIMES (MINUTES)

TABLE B-3

U.S. NAVY STANDARD AIR DECOMPRESSION TABLE

DEPTH (fsw)	BOTTOM TIME (min)	TIME TO FIRST STOP (min:sec)	DECOMPRESSION STOPS (fsw) 50	40	30	20	10	TOTAL ASCENT (min:sec)	REPETI-TIVE GROUP
40	200						0	0:40	N
	210	0:30					2	2:40	N
	230	0:30					7	7:40	N
	250	0:30					11	11:40	O
	270	0:30					15	15:40	O
	300	0:30					19	19:40	Z
	360	0:30					23	23:40	*
50	100						0	0:50	L
	110	0:40					3	3:50	L
	120	0:40					5	5:50	M
	140	0:40					10	10:50	M
	160	0:40					21	21:50	N
	180	0:40					29	29:50	O
	200	0:40					35	35:50	O
	220	0:40					40	40:50	Z
	240	0:40					47	47:50	Z
60	60						0	1:00	J
	70	0:50					2	3:00	K
	80	0:50					7	8:00	L
	100	0:50					14	15:00	M
	120	0:50					26	27:00	N
	140	0:50					39	40:00	O
	160	0:50					48	49:00	Z
	180	0:50					56	57:00	Z
	200	0:40				1	69	71:00	Z
	240	0:40				2	79	82:00	*
	360	0:40				20	119	140:00	*
70	50						0	1:10	J
	60	1:00					8	9:10	K
	70	1:00					14	15:10	L
	80	1:00					18	19:10	M
	90	1:00					23	24:10	N
	100	1:00					33	34:10	N
	110	0:50				2	41	44:10	O
	120	0:50				4	47	52:10	O
	130	0:50				6	52	59:10	O
	140	0:50				8	56	65:10	Z
	150	0:50				9	61	71:10	Z
	160	0:50				13	72	86:10	Z
	170	0:50				19	79	99:10	Z

* Exceptional Exposure Dive — No Repetitive Dive Allowed

TABLE B-3 (CONTINUED)

U.S. NAVY STANDARD AIR DECOMPRESSION TABLE

DEPTH (fsw)	BOTTOM TIME (min)	TIME TO FIRST STOP (min:sec)	DECOMPRESSION STOPS (fsw) 50	40	30	20	10	TOTAL ASCENT (min:sec)	REPETITIVE GROUP
80	40						0	1:20	I
	50	1:10					10	11:20	K
	60	1:10					17	18:20	L
	70	1:10					23	24:20	M
	80	1:00				2	31	34:20	N
	90	1:00				7	39	47:20	N
	100	1:00				11	46	58:20	O
	110	1:00				13	53	67:20	O
	120	1:00				17	56	74:20	Z
	130	1:00				19	63	83:20	Z
	140	1:00				26	69	96:20	Z
	150	1:00				32	77	110:20	Z
	180	1:00				35	85	121:20	•
	240	0:50			6	52	120	179:20	•
	360	0:50			29	90	160	280:20	•
90	30						0	1:30	H
	40	1:20					7	8:30	J
	50	1:20					18	19:30	L
	60	1:20					25	26:30	M
	70	1:10				7	30	38:30	N
	80	1:10				13	40	54:30	N
	90	1:10				18	48	67:30	O
	100	1:10				21	54	76:30	Z
	110	1:10				24	61	86:30	Z
	120	1:10				32	68	101:30	Z
	130	1:00			5	36	74	116:30	Z
100	25						0	1:40	H
	30	1:30					3	4:40	I
	40	1:30					15	16:40	K
	50	1:20				2	24	27:40	L
	60	1:20				9	28	38:40	N
	70	1:20				17	39	57:40	O
	80	1:20				23	48	72:40	O
	90	1:10			3	23	57	84:40	Z
	100	1:10			7	23	66	97:40	Z
	110	1:10			10	34	72	117:40	Z
	120	1:10			12	41	78	132:40	Z
	180	1:00		1	29	53	118	202:40	•
	240	1:00		14	42	84	142	283:40	•
	360	0:50	2	42	73	111	187	416:40	•

• Exceptional Exposure Dive – No Repetitive Dive Allowed

CHAPTER 4-2

INTRODUCTION TO DIVE TABLES

INTRODUCTION

Diving used to be so simple. In those early years there were only a few brands and models of masks and regulators. There were no BCDs. And basic black was the color. Today, the diver must literally sort through scores of masks, fins, snorkels, regulators, BCDs and diving suits. Once the diver determines the make and model, fashionable color coordination may also be considered in final equipment selection.

The selection dilemma is not just limited to diving equipment. Considering that the average individual dives only 10 days per year, it is possible to use a different decompression table or device for each day. At present, there are approximately seven distinctly different decompression tables and numerous electronic dive computers available to the diver. All of the available tables and many of the dive computers are based on *different* decompression models.

The U. S. Navy Standard Air Decompression, No-Decompression, and Repetitive Dive tables published in the 1958 edition of the U. S. Navy Diving Manual served as the standard for recreational and scientific scuba diving for nearly three decades [6, 7, 24]. Even though they have been highly criticized in the past decade and errors have been discovered [23], they have served the diving community well.

Several excellent format *rearrangements* simplified the use of the Navy tables for repetitive scuba diving. The tables were marketed under names such as PADI Tables, NAUI Tables, Nu-Way Tables, Dacor Tables and so on, however, they were all just rearrangements of the U.S. Navy tables. In those early years it was considered unacceptable to deviate from the exact procedures prescribed in the Navy manual for using the tables. There was no allowance for table interpolation. Many scuba divers felt *limited* by the fact that a dive schedule had to be based on the maximum depth attained during the dive, even if the diver only stayed at that depth for a few minutes. If a diver spent only three minutes at 100 feet, the no-decompression time for that dive was 25 minutes.

In the mid-70s a technique of *stepping-the-tables*, similar to one that had previously been used in oil field diving, emerged in the recreational diving community. Using this new technique a scuba diver could dive to a maximum depth of 100 feet at the beginning of a dive and progressively move to shallower depths without exceeding a no-decompression limit. The no-decompression time for a 100 foot maximum depth dive could now be extended to 60 or more minutes. Although this technique never received an official endorsement by the Navy or training agencies, it was used for thousands of scuba dives each year, especially in the Caribbean. The recreational scuba diver is by nature a multilevel diver.

Meanwhile, there appeared to be increasing controversy as to the safety of the U. S. Navy tables for a sport diving population. In 1976, Dr. Spencer published the results of his work on ultrasonically detected bubbles in the blood following U. S. Navy no-decompression dive exposures and proposed new, more conservative limits [22]. In 1981, Karl Huggins of the University of Michigan developed a complete set of no-decompression repetitive dive tables based on Spencer's values [9]. Other authorities also endorsed a more conservative approach to no-decompression diving and several new no-decompression limits appeared in recreational diving literature. Sport divers and instructors now had to decide what no-decompression limit to use.

Although electronic dive computers had been available for many years, it was not until the early 1980s that two electronic decompression microprocessors successfully entered the recreational and scientific diving market at an affordable price. Each of these computers was based on a different *decompression model*. In a review of one of these devices, the EDGE, Dr. Bassett (Skin Diver Magazine, July 1983) wrote "an innovation to sport divers equal to the original introduction of scuba." Since then other electronic devices based on still other decompression models have been released.

Not every diver will be able to afford an electronic dive computer. Consequently, today the majority of the diving community must still rely on a table for determining proper and safe dive schedules. In the United States, most instructors begin to be teaching a conservative approach to use of the U. S. Navy tables in the 1980s. Some groups have adopted the Huggins tables. A few use the British or Royal Naval tables.

In 1983 Florida dentist Ray Rogers proposed a new dive table model based, in part, on the earlier work of Spencer. Diving Science and Technology Corporation, a corporate affiliate of the Professional Association of Diving Instructors (PADI), funded a project to finalize and test tables based on this new model [1, 2, 16, 17, 19, 20]. The Rogers Tables were tested by the Institute of Applied Physiology and Medicine in Seattle under the direction of Michael Powell, PhD [15]. The test population was selected to include typical recreational divers based on sex, age, and physical condition and all testing included Doppler monitoring.

In the mid-1980s the PADI Recreational Dive Planner, based on Rogers' work, was released to the general public. These tables are designed solely for *no-decompression diving* [19]. This table provides the diver with a more conservation initial dive no decompression limit (compared to the US Navy tables). However, the diver will soon discover that these tables allows must shorter surface intervals and longer repetitive dive times than the US Navy tables. This results from the fact that Rogers uses a 60 minute half-time compartment for computing surface interval credit and residual nitrogen as compared to the 120 minute compartment used by the US Navy.

The Recreational Dive Planner is available in two formats — a Table and The Wheel. The Table format is identical to PADI's prior US Navy rearranged table format however it has 26 pressure (repetitive) groups rather than 14. The diver must still select the *exact or next higher* time and depth figure. The Wheel format allows for dive time selection to one minute intervals and has five foot depth increments to a depth of 100 feet (compared to 10 foot increments on most other tables). The Wheel may also be used to make multilevel dive calculations.

In 1985 the Canadian Defense and Civil Institute of Environmental Medicine's (DCIEM) released new air diving tables. These tables resulted from a continuous 15 year evolution of the Kidd-Stubbs decompression model. The tables are simple, easy to use, included correction factors for diving at altitude, and appeared to be more conservative than the U. S. Navy tables. From technical reports, it was evident that the tables had been calculated on a relatively conservative decompression model *and* subjected to considerable human subject testing before release. These tables are used in Canada today, however, they have not been adopted by any of the United States training agencies.

Today, there are basically two air dive tables used by the United States recreational and scientific diving communities — the US Navy and the PADI Recreational Dive Planner. Currently, the National Association of Underwater Instructors (NAUI) has designated that their instructors will teach a *conservative use* of the US Navy dive tables. NAUI has published a rearrangement of the Navy tables and redefined dive time and repetitive dive. The Professional Association of Diving Instructors (PADI) requires that all students be trained in the use of the Recreational Dive Planner.

The YMCA and Scuba Schools International (SSI) apparently remain with the US Navy tables. SSI apparently endorses the Jeppesen arrangement of the US Navy dive tables with conservative no-decompression limits based on doppler research. The Jeppesen/US Navy dive table was used in University of Michigan training programs until June 1990. At that time the University instructors elected to provided instruction in the use of the NAUI/US Navy dive table and the PADI Recreational Dive Planner in order to compliance with the requirements of these recreational diver training agencies.

The dive table controversy continues into the 1990s! Unfortunately, the controversy may be more political than physiological. The US

Navy table have 30 years of in field use with hundreds of thousands of dives. People have experienced decompression sickness using the US Navy tables, however, the incidence is not nearly as serious as some individuals would lead you to think. *When used properly* the incidence of decompression sickness on US Navy tables is said to be less than 0.01 percent [28]. It is too soon to establish an incidence of decompression sickness for the Recreational Dive Planner. Although the initial test results were apparently excellent, the true test lies in long term use by the general diving population.

All divers must keep in mind that no decompression model, no dive table, or no dive computer can assure complete freedom from incidence of decompression sickness. There are simply too many variables. The best that we can hope for is to keep the incidence to an absolute minimum through proper training, understanding basic diving physiology, and common sense diving procedures.

At the present time we are all a bit confused by the number of alternatives in dive tables and computers available to the beginning diver. Today it is possible for a group of 10 divers to enter the water and for each to be using a dive table or computer that is based on a different mathematical model. In this training program you will be introduced to the basic physiological principles of nitrogen absorption and elimination, instructed in the use of both US Navy and Recreational Dive Planner tables, provided with an overview of diver computers, and provided with insight into the proper application of dive tables and computers in routine diving activities.

DECOMPRESSION: WHY AND HOW!

When air is breathed under pressure the inert component, nitrogen, diffuses into the various tissues of the body. Nitrogen uptake by the body continues at various rates as long as the partial pressure of the nitrogen in the inspired gas is higher than the partial pressure of the nitrogen already absorbed in the tissues. The amount of nitrogen absorbed is primarily dependent upon the partial pressure of the inspired nitrogen (depth) and the duration of exposure to pressure (time).

When the diver begins to ascend, the process is reversed as the partial pressure of nitrogen in the tissue exceeds that in the circulatory and respiratory systems. The pressure gradient between the tissues and the blood and lungs must be carefully controlled in order to prevent too rapid of a diffusion of nitrogen. If pressure changes take place too rapidly and a sufficiently steep gradient develops, nitrogen bubbles can form in the blood and tissues. These bubbles ultimately can lead to the development of decompression sickness.

To minimize the possibility of decompression sickness, special tables and procedures have been established. These tables, based on the amount of nitrogen absorbed by various theoretical compartments at various pressures for given time periods, are designed to maintain a pressure gradient that, *in theory*, prevents harmful bubble formation. They allow for natural elimination of nitrogen through normal circulation of dissolved gases in the blood stream and normal gas diffusion in the lungs.

Today, no-decompression is the buzz word of recreational diving. Divers are encouraged to never exceed the no-decompression limits of dive tables. One popular dive table is based solely on no-decompression dive limits. In reality, there is no such thing as a no-decompression dive. Basically, you decompress from any exposure to pressure when you ascend — even in a swimming pool. The British use the term *no-stop dive*. This is probably a more appropriate term.

There are three primary methods of decompression or pressure reduction following exposure to depth. *Linear decompression* is probably the oldest form of decompression. In linear decompression the rate of pressure change is constant. Linear decompression is used today for dives which do not exceed the no-decompression depth-time limits. In this case the diver is permitted to ascend directly from depth to surface pressure at a constant rate not to exceed 60 fpm.

Modified linear decompression is sometimes used for ascent from a saturation dive. Saturation dives involve extremely long exposure to pressures, generally exceeding 24 hours. The body tissues become fully saturated with inert gas at a pressure equivalent to the depth of exposure. One approach to decompression of saturated divers is a very slow constant rate of pressure reduction. In reality, such a decompression is generally modified to involve up to three different rates through three depth ranges.

Curvilinear decompression is one in which the rate of pressure change is constantly decreasing. Essentially, a curvilinear decompression attempts to follow the model's nitrogen elimination curve. Theoretically, it provides a fixed, optimum gradient between tissue inert gas tension and alveolar inert gas partial pressure. Curvilinear decompression is the optimal technique that can be executed when using some dive computer.

In simple terms, the dive computer is designed to simulate nitrogen absorption and elimination during exposure based on a mathematical model and provides the diver with decompression information based on this model. Using the curvilinear decompression technique the diver may ascend directly to the ceiling, or safe ascent depth, indicated by the computer. This establishes an optimal gradient for nitrogen elimination. The diver continues to decompress (ascend) by keeping the actual depth equal to the ever-decreasing ceiling depth. Although this technique produces the optimal decompression profile, it does maintain the diver at the limits of model throughout decompression. Consequently, the diver experiences the highest level of decompression stress allowed by the model.

Stage decompression is the most widely used method of decompression from a dive where linear ascent directly to the surface (a no-decompression or no-stop dive) cannot be accomplished due to the amount of exposure. Stage decompression involves ascending, at a fixed rate, from the maximum depth of the dive to a decompression *stop* at some shallower depth. After a given period of time at the stop depth, the diver ascends to the next decompression stop. This process is repeated until the diver reaches the surface. In air diving, the decompression stops are usually at 10 fsw (3msw) depth intervals. Stage decompression represents an attempt to follow the body's nitrogen elimination curve in a stepwise fashion. Stage decompression ascent profiles are relatively easy to maintain in both the water and chamber as compared to linear and curvilinear profiles.

Recreational and scientific scuba divers are encouraged to remain within no-decompression (no-stop) limits of dive tables and computers. Dive exposure which prohibit direct ascent to the surface are of much higher risk to the diver.

UNDERSTANDING AND USING DIVE TABLES

Dive tables are really quite simple. The diver simply reads the no-decompression time limit or the decompression stop requirements for a given depth. If the diver is making only one dive within a specified time period (.i.e. 12-hours for the US Navy tables, 24-hours for the NAUI tables and 6-hours for the PADI Dive Planner) the procedure is straight forward and uncomplicated. The diver must not exceed prescribed *rates-of-ascent* and is encouraged to make an *ascent control stop* for all dives.

Procedures for using *three* dive tables will be included in this discussion — the US Navy dive tables, the NAUI dive tables, and the PADI Recreational Dive Planner. The procedures for use of the US Navy Dive table are a conservative modification of standard US Navy procedures (as given in the *US Navy Diving Manual*) based on new findings and trends in recreational and scientific diving. The NAUI dive tables is a conservative modification of the US Nay dive tables. *Since the procedures for the use of the Recreational Dive Planner have been published and specifically designated by the Professional Association of Diving Instructors, the procedures designated with that table should be used and are also addressed in this publication.*

Specific procedures and values endorsed by the University of Michigan instructors for using US Navy dive tables are presented in bold type.

No-Decompression Time Limits: Unfortunately, all of the dive tables commonly used by recreational and scientific divers have different no-decompression (no-stop) limits. For some this becomes quite confusing. The following values are the no-decompression limits for (1) Jeppesen modified limits for conservative use of the US Navy dive tables (MN), (2) NAUI modified limits for US Navy Tables (NAU), (3) the PADI Recreational Dive Planner (RDP), (4) the Canadian DCEIM Sport Diver Table (DCEIM), and (5) the original 1958 US Navy dive tables (USN) (depth in feet, time in minutes):

DEPTH	MN	NAU	RDP	DECIM	USN
30	205	-	-	360	-
35	160	-	205	-	310
40	130	130	140	175	200
50	70	80	80	75	100
60	50	55	55	50	60
70	40	45	40	35	50
80	30	35	30	25	40
90	25	25	25	20	30
100	20	22	20	15	25
110	15	15	16	12	20
120	10	12	13	10	15
130	5	8	10	8	10

These are the most common dive tables and limits that you will encounter in United States recreational and scientific diving at this time. The limits designated in under column "NAU" are to be used with the NAUI arrangement of the US Navy dive tables and the limits under column "RDP" are to be used with the Recreation Dive Planner. Most authorities recommend that divers never exceed prescribed limits and whenever possible avoid diving to the limits of the tables.

Avoid Diving to the Limits of the Tables!

Depth: When reading dive tables depth is the *maximum depth attained during the dive* and is expressed in feet or meters of sea water. Most dive manuals and tables published in the United States use feet of sea water (FSW). Since most tables are presented in 5 or 10 foot depth intervals, the diver must use the *exact or next greater depth* to determine the appropriate dive schedule (e.g., if 56 feet is the measured depth, use the 60 foot dive table depth). When using the NAUI dive table consider any dive depth shallower than 40 feet as a 40 foot dive.

Dive Table Depth is the Maximum Depth Attained During the Dive

For cold and/or arduous dives you are encouraged to use a more conservative dive schedule. This is easily accomplished by *adding 10 feet to the measured dive depth* for purposes of determining table entry depth (e.g., if 56 feet is the measured depth, use the 70 foot dive table depth).

Cold and/or Arduous Dive: Add 10 Feet

NAUI has elected to use the next greater bottom time to address cold or strenuous dives. For example, for example if you wish to remain within the no-decompression dive time limit for a depth of 60 feet and you are cold, limit the dive to 50 minutes or less. In order to determine the letter group at the end of the dive read the letter for the next greater bottom time (i.e., use 55 minutes).

Time: The U.S. Navy and PADI (Recreational Dive Planner) define bottom time as the total elapsed time (in minutes) from when the diver leaves the surface in descent to the time that the diver *begins* ascent. NAUI defines dive (bottom) time as the total time spent underwater exclusive of the precautionary decompression stop time. Many scientific and recreational scuba divers now use a more conservative definition of bottom or dive time. They define *bottom time as total dive time or time spent underwater* on any given dive. This is more practical in that most divers now use dive timers or computers that are automatically activated and deactivated by pressure (water depth) at the beginning and end of the dive. Since it is not practical to publish a dive table with minute-by-minute schedules, the diver must use *the exact or next greater time* to determine the appropriate dive schedule (e.g., a 42 minute dive to 60 feet would be read as a 50 minute time on the US Navy dive table).

In the UM training programs and operational diving we use the more conservative definition of bottom time — *basically surface to* *surface* for no-decompression dives. However, time spent at an *ascent control stop* (or precautionary decompression stop), to be discussed later, is considered *neutral time* and need not be included as bottom time for purposes of reading tables.

Bottom Time:
Total Time Underwater
Exclusive of Time Spent at the
Precautionary Decompression Stop

Rate of Ascent. The rate at which the diver returns to the surface is specified for specific tables. Both the US Navy and PADI Recreational Dive Planner specify 60 feet per minute. NAUI specifies the rate of ascent as "not to exceed 60 feet per minute." Rate of ascent has been a controversial topic over the last few years. Some authorities suggest that the dive should ascend at a slower rate such as 30 to 40 feet per minute. Others suggest that ascent rate is not a major factor from a standpoint of bubble formation. US Navy tables used prior to 1958 specified a 25 foot per minute ascent rate for deep-sea or hard-hat divers. As compressed air scuba diving became more popular with special warfare groups, a faster ascent rate was requested. The 60 feet per minute ascent rate was a compromise between hard hat divers and scuba divers.

Presently, most authorities have agreed that the *rate of ascent should not exceed 60 feet per minute* and that the diver may ascend at a slower rate if so desired. Physiologically, it appears that an ascent control stop can be more important than slowed rates of ascent.

Rate of Ascent:
Not to Exceed 60 Feet/Minute

Ascent Control Stop. Researchers have shown that tiny bubbles (venous gas emboli or VGE) form in the divers blood stream during ascent from many, if not most, dives. Although a diver may often develop VGE during ascent, symptoms of decompression sickness may or may not pursue. These tiny bubbles indicate a degree of decompression stress on the diver. Although the VGE-decompresson sickness relationship is still contested, research is revealing a probable correlation between high levels of VGE and decompression sickness. Revised and reduced no-decompression limits initially resulted from this discovery.

Later research suggested that *stopping for a few minutes during ascent* was as likely to reduce or preclude detectable VGE formation than reducing the no-decompression limits [14]. The next subject of controversy was, how long and at what depth? Participants in a workshop on diver ascent sponsored by the American Academy of Underwater Sciences (October 1989) concluded that divers should stop in a depth zone of 10 to 30 feet for 3 to 5 minutes during ascent from all dives. This procedure was taught at the University of Michigan for several years and is still used by many University divers. However, the procedures currently recommended in the instructional program have been adjusted to reflect those prescribed by NAUI and PADI.

From a practical standpoint, allowing the diver to stop in a depth zone is far more realistic than establishing a fixed depth. In typical Caribbean diving, a diver can relax and explore the surroundings and not worry as much about precise depth or depth maintenance. Furthermore, if there are rough (high wave) surface conditions, the diver can more comfortably stop at 25 to 30 feet than 10 to 15 feet. The time flexibility can relate to the nature of the dive, the number of dives, or environment conditions. For example, some divers will stop for 3 minutes during ascent from the first dive of the day and 5 minutes for subsequent dives.

Ascent Control Stop:
3 Minutes at 15 Feet!
(Neutral Time)

For all practical purposes, this stop time may be considered as *neutral time*. In other words, it need not be included as bottom time for purposes of reading dive tables. However, some conservative divers do included it in their surface-to-surface time or bottom time. In our opinion, if the stop time exceeds 5 minutes, the additional time should be considered as bottom time.

At present, divers using the PADI Recreational Dive Planner are required to make a *safety stop* for 3 minutes at 15 feet if the diver comes within 3 pressure groups (defined later) of a no-decompression time limit, and for any dive to a depth of 100 feet or greater. Divers using the NAUI dive tables are encouraged to make a 3 minutes *precautionary decompression stop* at a depth of 15 feet during ascent for any no-decompression dive.

Repetitive Dives

Most scuba divers make more than one dive in any given diving day. Some will make as many as 5 to 7 dives. However, most authorities now agree that three dives per day is a more reasonable limit.

Number of Dives:
Limit to 3 Per Day

Repetitive Dives: A repetitive dive refers to any dive conducted with a specified time of a previous dive. The U.S. Navy repetitive dive tables define *a repetitive dive as any dive conducted within 12-hours of a previous dive.* On the other hand, the Recreational Dive Planner (PADI) defines a repetitive dive as any dive conducted within *6-hours* of a previous dive. To the contrary, NAUI considers any dive conducted within *24-hours* of a previous to be a repetitive dive. The Canadian and British dive tables require repetitive dive calculation procedures up to 18 and 16 hours, respectively, depending on the diver's nitrogen retention level value at the completion of the previous dive. Post-dive inert gas retention and elimination will be discussed in another section of this manual.

In order to be designated as a repetitive dive, the US Navy specifies that a surface interval of at least 10 minutes must elapse. Let's assume that a diver, working at a depth of 50 feet, accidentally releases a buoyant object an it floats to the surface. The diver ascends, retrieves the object within 5 minutes, and wishes to return to the work site at 50 feet. Returning to 50 feet is not considered to be a repetitive dive; *it is a continuation of the current dive!* Why? The dive spent less than 10 minutes on the surface.

By strict US Navy procedure, the ascent time and the surface time need not be included as dive or bottom time. Strictly speaking, the diver could add the bottom times of the two segments of the diver to determine the actual total bottom time for the dive. However, from a practical standpoint, most divers simply include both the ascent and surface time in their bottom times and treat the entire event as a single, continuous dive.

The times (12 hours and 6 hours) are determined by the theoretical half-time compartment on which the Surface Interval Credit Tables calculations are based. For example, the US Navy designates the 120-minute half-time compartment as the controlling compartment. Consequently, in theory, a 12 hour time period is required to rid the body of accumulated nitrogen. In reality, this may or may not be so. It appears that NAUI arbitrarily elected to use 24-hours in a more conservative adaptation of the US Navy dive tables.

On the other hand, the mathematical model used to develop the Recreational Dive Planner assumes that all no-decompression dives can be controlled by a compartment with a faster than 60 minute half-time. Consequently, in theory, a 6 hour time period is required to rid the body of accumulated nitrogen. In reality, this may or may not be true. You will find that the Recreational Dive Planner will give shorter surface intervals and longer repetitive dive times for the same depth-time situations than the US Navy tables. Please do not let this confuse you. Keep in mind that each of these tables was based on a different mathematical model.

In order to compute repetitive dive times, we must consider the amount of nitrogen still retained by the body from previous dives and the surface interval between dives. Using this information, the diver will compute the maximum allowable no-decompression time for a repetitive dive.

A day of repetitive diving should be planned so that the deepest dive is performed first and successive dives are progressively shallower. The places less decompression stress on the diver and allows for longer no-decompression dives throughout the day.

**Make the Deepest Dive First
and Successive Dives
Progressively Shallower!**

Repetitive Group Designation: Based on depth and time of a dive, a letter is used to designate a theoretical level of nitrogen in the body immediately following the dive. This is a repetitive group or pressure group. For example, if a diver surfaces from a 40 minute dive to 60 feet, the US Navy repetitive group is "G". The higher the letter, the higher the level of nitrogen retained in the body.

Letters are used for most dive tables. These letters are not interchangeable. Do not mix tables and table values! Your companions pressure group "G" on the Recreational Dive Planner is a totally different value that your repetitive or letter group "G" on the US Navy dive tables.

Surface Interval: This is the time between repetitive dives. Officially, the surface interval begins as soon as the diver surfaces and ends when the diver begins the descent of the following or repetitive dive. From a practical standpoint most divers will simply compute repetitive dives based on an approximate and conservative surface interval. Let's assume that a group of divers return to their boat between 10:30 and 11 AM (the last diver is on board a few minutes before 11). Practically speaking, the surface interval can begin at 11 AM. The group leader informs the divers that they will be leaving the dock for the afternoon dive at 2 PM and be on site and ready to dive no later than 2:15 PM. In this situation, more conservative divers will simply use a three hour surface interval to compute the repetitive dive even though the surface interval may exceed 3 hours by 15 to 20 minutes. In most cases this would be considered as conservative diving!

Modern trends in dive planning appear to be toward more preciseness in timing and computation. For example, the Recreational Dive Planner has 26 pressure or repetitive groups compared to 14 of the US Navy tables. Consequently, the diver can use very precise surface interval, almost to the minute in some cases, to optimize repetitive dive time. Optimizing time also removes some of the safety buffer associated with more conservative use of tables. Squeezing every last minute out of a table is, in my opinion, eventually going to get some divers in trouble.

Some instructors and researchers have also expressed concern with regard to short surface intervals and the practice of bounce diving (i.e., repetitive deep, short duration dives with limited surface intervals). Since this is an area of concern that must still be explored by researchers, it is our recommendation that the minimum surface interval between dives be established at 1 hour until more information is available.

**Minimum Surface Interval:
1 Hour**

The PADI Recreational Dive Planner also has special rules for multiple dives. If you are planning three or more dives per day, beginning with your first dive, if the ending pressure group is W or X, the minimum surface interval between subsequent dives is 1 hour. If the ending pressure group is Y or Z, the minimum surface interval between all subsequent dives is 3 hours.

**PADI Recreational Dive Planner:
Observe Special Rules
for Multiple Dives!**

Surface Interval Credit and New Repetitive Group: During ascent and on the surface following a dive, you are *off-gassing*. In other words, your body continues to release excess nitrogen to the atmosphere with each breath until you return to pressure (dive again) or reach equilibrium with the atmosphere. Consequently, your repetitive group letter decreases as the length of surface interval increases. If your were a "G-diver" when you surfaced at 11 AM, you will be a "C-diver" for your 2 PM dive (NAUI/US Navy tables).

Residual Nitrogen: Practically speaking, this is the amount of nitrogen that remains in you body following a specific surface interval. This excess nitrogen must be accounted for when computing a repetitive dive. *Dive tables specify this residual or remaining nitrogen in terms of minutes of time that must be added to the repetitive dive in order to adjust for the nitrogen remaining from a prior dive(s).* The value, in minutes, will vary for the same repetitive group depending on the depth of the repetitive dive. For example, if our "C-diver" using the NAUI/US Navy tables plans to dive to a depth of 60 feet on the afternoon dive, the residual nitrogen time is 17 minutes. In other words, the diver begins the dive with an assumption that 17 minutes of bottom time have already elapsed, physiologically speaking. If the afternoon diver was limited to 40 feet, the residual nitrogen time would be 25 minutes.

Repetitive Dive No-Decompression Limit: The most frequent computation in scuba diving is determination of repetitive dive no-decompression time. This is quite simple. The no-decompression time for a specific depth is designated on the dive table. Keep in mind that this limit is for the initial dive only. *To determine the no-decompression limit for a repetitive dive, you must subtract the residual nitrogen time from the original no-decompression time for the planned depth of the repetitive dive.*

Let's assume that our "C-diver" (above) actually wishes to return to 60 feet on the afternoon dive. The revised no-decompression limit for 60 feet is 55 minutes. Subtract 17 minutes of residual nitrogen from 55 minutes and you have the maximum no-decompression dive time for the repetitive dive — 38 minutes. Several practice repetitive dive problems are included in the Appendices of this Section.

Drawing the Dive Profile. One of the best ways to prevent mistakes and avoid confusion in repetitive dive computation is to graphically represent the series of dives as a drawing — a dive profile. Enter all information on the dive profile. Ideally, both members of the buddy team should draw dive profiles and compare them when finalizing the dive plan. Dive profiles are included in the appendices of this section.

Depth Limits: Scuba diving depth limits have been discussed previously. For our purposes, any dive in excess of 60 feet shall be considered as a deep dive. This simply means that the diver shall take an extra degree of care in planning the dive and computing dive schedules.

Deep Dive:
Depth in Excess of 60 Feet

The absolute limit for recreational divers has been placed at a depth of 130 feet and an increasing number of instructors and organizations now endorse a 100 foot depth limit. For our purposes, recreational scuba diving shall be limited to depths of 100 feet or less. Even if the diver exceeds 100 feet on the initial dive of the day, many authorities now encourage divers to not exceed 100 feet on repetitive dives.

Recreational Dive Depth Limit:
100 Feet

Multilevel Dives: The scuba diver is a multilevel diver. A scuba diver seldom goes to one specific depth and remains there for the duration of the dive. Various mechanism *stepping-the-tables* (i.e., interpolating) have been used by commercial and recreational divers over the years. Many authorities discourage this procedure because, in some cases, dive times indicated safe by table-stepping are shown to exceed the safe times limits of the table model.

Currently, the *Wheel* version of the Recreational Dive Planner is used to compute planned recreational multilevel dives. In theory, the diver computes the various stages (levels or steps) of the dive and records this information on a slate prior to entering the water. The diver must now accurately monitor time and depth at each level to assure safety. In reality, divers do a poor job of monitoring depth and time even at just one level. The task of monitoring time and maintaining specific depth limits for two or three levels can become complicated and is subject to increased error.

Considering the complexity and potential for error, it is our opinion that multilevel dives be made only when using an electronic dive computer that continuously monitors the diver's theoretical nitrogen status.

Multilevel Dive Profiles:
Only with a Dive Computer

Exceeding No-Decompression Limits: Both recreational and scientific scuba divers are encouraged to remain within the no-decompression limits (no-stop limits) of dive tables. The PADI Recreational Dive Planner is strictly a no-decompression and exceeding a no-decompression limit is considered an emergency situation. For example, if you exceed the no-decompression limit by no more than 5 minutes, an 8-minute stop is mandatory at a depth of 15 feet and upon surfacing you must remain out of the water for at least 6 hours prior to making another dive. If you exceed the no-decompression limit by more than 5 minutes, a 15 foot decompression stop of no less than 15-minute (air permitting) is recommended and the diver must remain out of the water for 24 hours prior to making another dive.

In NAUI's adaptation of the US Navy Dive tables decompression time requirements are included for selected dive times that exceed the no-decompression time limits. The decompression depth is designated as 15 feet.

The U.S. Navy Standard Air Decompression Table gives stage decompression stops at 10 foot intervals for dive times that exceed the U.S. Navy's no-decompression limits. For example, this table requires a stop of 14 minutes at 10 feet for a dive to 120 feet for 30 minutes. These tables have been used for more than 30 years. The US Navy does acknowledge an increased incidence of decompression sickness associated with decompression dives and discourages decompression dives when using scuba.

The recreational and scientific diving community has also discouraged dives that require decompression. Furthermore, although various "experts" have dealt with no-decompression limits, rates of ascent, and safety stops, little information is available on air decompression diving. At present, we can only encourage scuba divers to avoid dives requiring decompression. In the event that decompression is unavoidable, a conservative approach is suggested. For example, some divers use a dive table depth that is 10 to 20 feet deeper than the actual dive depth to determine decompression. Furthermore, if at all possible, avoid making repetitive dives following a decompression dive.

Dives Requiring Decompression:
Not Recommended!

Multi-Day Diving: Most scientific and vacationing recreational divers tend to make one to two week long diving trips. Since most divers are paying a high price for their diving holiday, they wish to make as many dives as possible during this time period. Physiologist and diving authorities are now expressing increasing concern about divers who make several dives daily for several consecutive days. There is concern that slower level tissues will become progressively saturated and ultimately invalidate the decompression models. *Consequently, some authorities recommend that divers allow a 18 to 24 hour period of non-diving activity after every 3 consecutive days of repetitive diving.*

Reading Tables: The procedures for reading decompression tables are fairly straight forward and are included included in the appendices of the Section. In addition, they will be addressed in detail in lecture sessions.

HOW SAFE ARE DIVE TABLES?

Several publications and many recreational scuba diving instructors cite that a high incidence of decompression sickness can be expected even when the diver is using the U.S. Navy dive tables. A figure of 5% incidence is most frequently stated and figures as high as 10% are not uncommon. Such figures are without foundation. Some claimed that the US Navy accepted a 5% incidence of bends when initially developing and testing the tables. This is absolutely untrue. In fact, if decompression sickness did develop during testing, the schedule was adjusted and retested till the incidence was 0.00% [6, 7, 13].

Until 1970 there was simply a lack of reliable statistical data on bends incidence in air diving. The unfortunate combination of unfounded incidence percentages and lack of statistical data led to distrust, fear and in some cases disregard of the U.S. Navy tables. Arbitrary safety factors were promoted. Some individuals used this *uncertainty* to promote the use of dive computers and other tables.

In 1970 the U.S. Navy adopted a reporting system for both the number of decompression sickness cases and the number of dives. For the period of July 1, 1970 to June 30, 1971, the U.S. Navy documented 25 cases of decompression sickness out of 30,039 dives. Air dive exposures accounted for 26,035 dives and only 12 decompression accidents were noted in air diving, or an overall 0.046% incidence. The incidence for open-circuit scuba diving was slightly less. Expressed in terms of a risk factor, this is one case per 2,857 exposures for all dives [3].

In the 24-month period from January 1972 through December 1973, U.S. Navy divers recorded 127,103 dives or 97,242 person hours under pressure. Only 35 cases of decompression sickness were reported during this study period giving an incidence of about 0.03%. It is significant to note that only 12% of all dives were in the depth range of 100 to 200 fsw; however, dives in this depth range accounted for 57% of the cases of decompression sickness. Only about 7% of the annual dives involved decompression, but gave an incidence of 0.41% decompression sickness [4].

These early figures reflect an excellent record for the U.S. Navy divers and the U.S. Navy tables and are included for historical perspective. As data reporting and analysis of statistical data improved, the incidence of decompression sickness appears to be even lower for Navy divers. More recent reports indicate that decompression sickness does occur, even on apparently safe schedules. However, it should be noted that statistics for over 240,000 dives conducted by Navy divers indicated an average decompression risk of less than 0.01 percent [12, 28].

If the US Navy tables are apparently so safe, why is there such a concern today? Why have the no-decompression limits been modified? Why have so many new tables been developed? Why were the Navy tables so severely chastised? *First of all, many divers simply refuse to accept blame for their own mistakes. Divers are careless. Many simply fail to monitor depth and time correctly.* Some are under the impression that tables and rules do not apply to them. Others simply cannot read tables or compute repetitive dive schedules. For the experienced divers and instructors that I have offended with the above statements, I *do not* apologize! You know it is true as well as I do.

Furthermore, modern trends in diver education, in my opinion, preclude adequate training in the use of dive tables. In today's short courses, trainees simply do not have time to learn and *practice* use of dive tables. What many trainees learn may be soon forgotten. I feel that many Caribbean dive guides would support this statement. But of even greater concern, in many cases new divers are not being provided with sufficient information to understand and appreciate the gravity of the subject.

Second, our great American legal system is unable, in many cases, to accept the fact that ultimately individuals must take responsibility for their own actions. Even with the excellent safety record of the US Navy tables and the acknowledged certainty that it is impossible to develop a mathematical model of the human body that will enable development of an absolutely bend-free table, injured divers have still sued everyone in sight. Consequently, some, if not many, changes have been driven by "cover your hind end" factors rather than physiological factors.

Third, in 1976 Spencer published the fact that little bubbles are rushing around in the circulatory system following many asymptomatic dive exposures [22]. The Doppler technology was not available 20 years prior when the Navy tables were developed. This fostered an immediate response of concern in the diving community. Several individuals published reduced no-decompression limits and even new dive tables based on these findings [9]. Later research revealed that making a stop on the way to the surface, even if the table was pushed to the maximum no-decompression limit, indicated significant reduction in bubble formation [14].

Fourth, recreatinonal dives often push tables and dive computers to their absolute limits. On the other hand Navy divers by nature are more conservation. They either back off from the limit or "jump schedules" (i.e., use deeper depth and longer times that actually encountered during the dive to read tables). If enough people go to the edge enough times, some one is going to fall off. Divers who push the table limits run a higher risk of decompression sickness.

Fifth, recreational divers may increase their susceptibility to decompression sickness due to physical compromises. Basically, they invalidate the table models. Social habits alone compromise many divers. We live in an alcohol dominated society. Far too often divers are physiological compromised by the effects of alcohol and subsequent dehydration when they enter the water. This can significantly alter the nitrogen absorption-elimination mechanism(s) of the body.

Finally, one cannot escape the inter-agency politics and potential for economic gain associated with today's dive tables. There is both community status and economic advantage in producing and successfully marketing the "so-called" best dive table. We must also contend with the diving community's "one-ups personship" game and ego factors among it's leaders. New waterproof dive tables are marketed at $8 to $10 each. Special versions of the dive tables sell for $13 to $35. In theory, when a new dive table is issued hundreds of thousands of divers are encouraged to purchase new ones.

The fact remains that civilian divers have experienced decompression sickness while *apparently* following the tables exactly. The exact number and incidence percentage is not known since there is currently no effective data collecting system that identifies both the actual number of decompression sickness cases *and* the actual number of dives for civilian divers. I suspect that the number of cases is relatively small, but probably higher than that of the U.S. Navy. Currently, it appears that as many as 400 to 500 U.S. recreational divers experience decompression sickness annually. This includes those using all dive tables and computers, not just the U.S. Navy tables [29, 30].

There are a number of factors to consider. First, is it virtually impossible to develop a *practical*, totally bends-free table to fit every individual and situation. The times and limitations would be prohibitive. Nitrogen absorption and elimination in the human body are dependent upon a number of variables. Tables have been developed to best protect the normal, healthy adult diver. Physiological deviations associated with poor physical condition, aging, and obesity are sufficient to precipitate bends under the same diving conditions that would be safe for a normal, healthy young adult.

Second, the level of physical exertion and the thermal status of the diver alter nitrogen absorption-elimination. Persons who have worked hard and/or chilled significantly on a dive are more susceptible to decompression sickness.

Third, daily diver condition is important. A higher incidence of decompression can be expected in individuals who are suffering from minor illness (colds, diarrhea, etc.), lack of sleep, alcohol intoxication (and hangovers), alcohol or drug consumption prior to diving, and the like.

Fourth, some table schedules show a greater tendency to produce trouble than others. For example, the no-decompression limit of 100 minutes for 50 fsw is probably questionable. Other possibly questionable schedules, beyond the range of recreational divers, include 140 fsw/30 min; 140 fsw/40 min; 150 fsw/30 min; and 170 fsw/30 min [10].

Fifth, many factors exist in the civilian recreational diving community that are less likely to confront the Navy diver. For example, recreational divers are not bound by established rules and rigid supervision. Deep air diving that would not be permitted under Navy regulations, is common place in civilian diving. Furthermore, Navy divers are required to have a medical officer and hyperbaric chamber at the dive site for dives beyond a depth of 190 feet.

Many divers take a *haphazard* approach toward monitoring their depth gauge and dive timer. Consequently, it is not possible to select the appropriate dive schedule if you do not know the precise depth and time. Furthermore, depth gauges used in recreational diving may have an accuracy deviation of up to ± 5% of full scale depending upon the gauge model and manufacturer. This means that a new gauge (250 fsw model) could have a variation of 37.5 fsw to 62.5 fsw at an actual depth of 50 fsw and 117.5 fsw to 142.5 fsw at 130 fsw. In addition, mechanical damage from use and abuse can cause even greater variation. Until the recent development of better depth gauges and mechanical- or electronic-device that automatically recorded or marked maximum depth, many divers did not really know their exact maximum depth on any given dive.

Many recreational divers take exceptional liberties with personal modification of the U.S. Navy tables. Several modification schemes for multi-depth level scuba diving have been advanced in recent years. Although these *schemes* may appear logical and apparently work, they are generally not properly conceived or tested.

Conservatively used for no-decompression dives in depths of 100 fsw or less and with accurate depth-time determination, the U.S. Navy tables should provide the civilian diving population with a very low, if not negligible incidence of decompression sickness. Conservative recommendations have been given in the preceding discussion. *However, all divers must understand and accept the fact that no dive table or computer can guarantee bends-free diving.*

The same questions are now being asked regarding the safety of the PADI recreational Dive Planner. Preliminary testing in the laboratory and open water with modern ultrasonic Doppler equipment that was not available when the US Navy tables were developed suggest that the model and table maybe valid. However, the true test lies in extensive use by the general diving public. Insufficient data exists at this time to draw any final conclusions.

FLYING AFTER DIVING

When a diver surfaces following a dive, an elevated dissolved nitrogen tension exists in the body's tissues and fluids. The dive tables are calculated to keep the nitrogen tension below the theoretical critical level at which bubble formation would result when the diver returns to the surface pressure (sea level). If the diver then immediately ascends to a higher altitude in an aircraft or drives into the mountains, the reduction in ambient pressure can result in nitrogen tensions within the body that exceed the critical level for bubble formation. Consequently, the diver who was *safe* at sea level, can develop serious decompression sickness upon ascent to altitude.

Following an exposure to pressure the diver must remain at sea level for some specific period of time before ascending to altitude in order to allow the body to equilibrate. Exactly how long appears to be a subject of considerable controversy.

The U.S. Navy Diving Manual (1973 edition, p. 6-44) stated that the diver "definitely must not fly for at least 12 hours [25]." NOAA Diving Manual (published in 1979) stated, "Before flying in an aircraft in which the atmosphere will be less than 8,000 feet (usually the case in most flights), a diver who has completed any number of dives on air, and decompressed following the U.S. Navy Standard Air Decompression Tables, should wait at sea level breathing air for the computed surface interval that allows him to be classified as a Group D diver in the U.S. Navy Repetitive Dive Table [11]."

A more recent edition of the US Navy Diving Manual (1985 edition, p. 7-22) indicates, "Flying in aircraft with cabin pressures above 2300 feet altitude may be done after a 2-hour surface interval for no-decompression air dives and 12 hours for decompression dives. If aircraft cabin pressure is below 2300 feet altitude, then flying may be done immediately after an air dive [26]." Other dive manuals and research reports state times ranging from 2 to 24 hours [8].

The PADI Recreational Dive Planner designates that the diver must wait a *minimum of 4 hours* following a single no-decompression dive with less than 1 hour of bottom time. For a single no-decompression dive with a bottom time of more than one hour or after any repetitive dive, the diver must wait a *minimum of 12 hours.* Following any dive that required emergency decompression, the diver must wait a minimum of 24 hours before flying. The instructions further state that, whenever possible, a 24 hour wait is generally recommended in most cases [19].

The general lack of agreement among various authorities tends to leave the average diver with a degree of uncertainty. When in doubt, take the more conservative approach. If for some reason the cabin pressure were to be lost during a flight, the diver flying within a short period of time following any dive would be extremely susceptible to decompression sickness.

The following recommendations were made by a group of diving physiology and medicine authorities at the Undersea and Hyperbaric Medical Society's "Flying after Diving Workshop" (24 February 1989) for no-decompression diving [21]:

a. If you have *less that 2 hours* of accumulated dive time in the last 48 hours, wait 12 hours before flying.

b. For unlimited, multiday diving or if you have *greater than 2 hours bottom time* in the last 48 hours, wait 24 hours before flying.

If you made a decompression dive, wait at least 24 to 48 hours (48 hours if possible) before flying.

**Minimum Surface Interval
Before Flying
(No-Decompression Dive):
12 Hours**

Because of the complex nature of decompression sickness and because unverifiable assumptions are involved in decompression schedules, there can never be a flying-following-diving rule that is guaranteed to prevent bends completely!

DIVES AT HIGH ALTITUDE

U.S. Navy air dive tables were computed for diving with reference to sea level. The current US Navy tables (addressed in the 1985 edition of the US Navy Diving Manual, p. 7-22) may be used for diving in fresh water at altitudes up to 2300 feet provided that the actual measured depth, not depth gauge depth is used, to determine dive schedules and that if decompression is required, a decompression line measured from the surface is used and stop depths are increased by one foot [26].

**NAUI Recommends that the
US Navy Dive Tables be Limited
to Altitudes of Less than 1000 Feet
Above Sea Level!**

* * * * *

**The PADI Recreational Dive Planner
is not Designed for Use at Altitudes
Greater than 1000 Feet Above Sea Level!**

For diving at higher altitudes, two modifications must be made to correct for differences in atmospheric pressure when standard sea-level tables are used. The diver must compute, or refer to a table to obtain, the theoretical depth of the dive and the theoretical depth of decompression stops for a given altitude. Both the theoretical diving depth and decompression stop depths will vary with altitude. In addition, the diver's tissue nitrogen tensions change when traveling from sea level to altitude. An adaptation period or special dive table considerations are required. Also, conventional depth gauges may give erroneous readings when used at altitude and correction factors are required.

There are various procedures and tables for computing no-decompression limits and decompression schedules for high altitude diving. However, at the present time for diving at altitudes in excess of 2300 feet (700 meters) we recommend using the Buhlmann "Decompression Tables for Dives with Air at Various Altitudes" (Buhlmann, A., Decompression-Decompression Sickness (New York: Springer-Verlag, 1984) [5].

CONCLUSIONS

At present the risk of decompression sickness can be minimized, but not totally eliminated, through the *proper use* of dive tables and computers. Unfortunately, divers must select from among many dive tables and computers. This selection is difficult and debated even among the most knowledgeable experts in the field of diving. Dive tables and computers are aggressively advertised and marketed for prestige and profit, rather than simply the safety of the diver. I am certain that no one is advocating a table or device that is knowingly unsafe. However, the consumer is simply overwhelmed at this point in time. Fortunately, responsible individuals under the leadership of the Divers Alert Network, Duke University Medical School, and the Undersea and Hyperbaric Medical Society are attempting to sort out this entire issue.

Although this is only a superficial overview, you now know more about dive tables than most instructors. Most entry level divers are sheltered from the controversies that rage throughout our diving community. In many classes dive tables are *marketed*, not taught! Instructors and organizations tend to overlook the fact that it is your body and that you have a right to know something, actually a lot, about what you can expect to happen when you go under pressure.

Hopefully, the issues of decompression will soon be sorted out. Some of the information presented above may soon be obsolete. However, this is the picture as I see it now. All divers are cautioned to remain abreast of the latest developments through continuing education courses and seminars, attending lectures, and following diving literature.

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ACKNOWLEDGMENTS

I wish to express my deepest appreciation to Karl Huggins for his inspiration, many helpful suggestions, and critical review of this manuscript.

Manuscript completed: 30 December 1989
Manuscript revised: 17 April 1990
Manuscript revised: 18 June 1990

APPENDIX A

INTRODUCTION TO THE RECREATIONAL DIVE PLANNER
(TABLE VERSION)

INTRODUCTION

Terminology and basic procedures for using the Recreational Dive Planner were discussed throughout this Chapter 4-2. The following is a step-by-step progression through the various tables of the Recreational Dive Planner.

TABLE 1

Recreational Dive Planner Table 1 is used to determine maximum no-decompression and repetitive dive group. If you are planning only one dive in a six hour period, this is the only table that you will need to use. The best way to explain a dive table is through a example.

Let's assume that you intend to dive to a maximum depth of 55 feet. Depth is given in 10-foot increments (after the 35-foot column) at the top of table one. Since 55 feet is between 50 and 60 feet, *you must use the higher depth column for planning your dive*.

The maximum no-decompression time for that dive depth is displayed in the box at the bottom of the column. In this case the maximum no-decompression dive time for 55 feet (60 foot column) is 55 minutes.

Upon completion of your dive (Dive #1) to 55 feet your timer reads 35 minutes bottom time. If you enter the 60 foot column to 35 minutes, you can determine your Pressure Group at the end of that dive by reading the letter at the left side of Table 1. In this case you are in Pressure Group N. This information is only required if you intend to dive again within 6 hours.

TABLE 2

Two hours after completing your initial dive of the day your plan to make another dive. Since your body has been off-gassing nitrogen throughout this 2 hour period, you can receive credit for this time. Table 2 — Surface Interval Credit Table — is used to determine the amount of credit. Locate Pressure Group "N" from Dive #1 on the diagonal line of letters on the left side of Table 2. Enter the "N" row horizontally to the box containing the numbers 1:31/2:18. Your surface interval is between one hour, thirty-one minutes and two hours, 18 minutes. Now, follow that column to the bottom of the table to determine your new Pressure Group — "B".

TABLE 3

Table 3 — Repetitive Dive Time Table — provides you with residual nitrogen time and maximum no decompression time allowed for your repetitive dive time. Find the letter "B" along the top of Table 3. Now, let us assume that you plan to dive to a depth of 47 feet on Dive #2. Follow the "B" column down to the 50-foot depth row of figures (depths are on the left side of Table 3). You will find two numbers. The upper number is the residual nitrogen time (in minutes) remaining from Dive #1. The bottom number is the maximum allowable actual no-decompression dive time for Dive #2 — in this case 67 minutes. This figure — 67 minutes — is the maximum no-decompression dive time for 50 feet *less* the residual nitrogen time or (80 – 13 = 67).

Let us assume that your planned bottom time for Dive #2 is only 60 minutes. *In order to determine your Pressure Group at the end of Dive #2 you must add the actual bottom time and the residual nitrogen time.* In this case 60 minutes plus 13 minutes (RNT) equals 73 minutes. This is the Total Bottom Time or Equivalent Single Dive Time (ESDT). Returning to Table 1 you find that you are now in Pressure Group "W" (since 73 is not on the table you go to the next higher number). You only need to determine this figure if you plan to make another dive within 6 hours.

PLANNING A THIRD DIVE

Let us assume that you are planning to make a third dive and you wish to return to the water as soon as possible. Keep in mind that there are *"Special Rules for Multiple Dives"* stated below Table 3. If you are planning 3 or more dives in a day, beginning with your first dive if your pressure group after any dive is "W" or "X", the minimum surface interval between all subsequent dives is 1 hour. If your ending pressure group after any dive is "Y" or "Z", the minimum surface interval between all subsequent dives is 3 hours. In this case you were in Pressure Group "W" and according to the rule your minimum surface interval must be one hour.

To plan Dive #3, enter Table 2 on row "W" and move horizontally to the box 0:57/1:02. Now find your new Pressure Group at the bottom of this column — "I".

Dive #3 is planned for a maximum depth of 40 feet. Entering the "I" column at the top of Table 3, you proceed to the 40-foot row of numbers and find that your maximum allowable actual bottom time (ABT) is 100 minutes (bottom figure).

Most authorities recommend that you make no more than 3 dives per day. Sine you have made a series of repetitive dives you must wait at least 12 hours before flying in a commercial air craft. Ideally, observe a 24 hour surface interval before flying.

DIVE PROFILE

APPENDIX B

INTRODUCTION TO THE NAUI DIVE TABLES

The National Association of Underwater Instructors has modified and rearranged the US Navy dive tables and now market them under the NAUI trademark. Unfortunately, this arrangement and the various abbreviations used differ from those use with the Recreational Dive Planner (PADI), the Jeppesen Arrangement of the US Navy Tables (SSI), and the traditional US Navy Tables.

TABLE 1: END OF DIVE LETTER GROUP

NAUI Table 1 is used to determine maximum no-decompression dive time and repetitive group. In addition, the number of minutes of decompression required in the event that you exceed the no-decompression dive time is also included. The best way to explain a dive table is through an example.

Let's assume that you intend to dive to a maximum depth of 55 feet. Depth is given in 10 foot and 3 meter increments at the left side of the table. Since 55 feet is between 50 and 60 feet, *you must use the higher depth for planning your dive.*

The maximum no-decompression time (maximum dive time or MDT) for that depth is displayed as a circled number. In this case the maximum no-decompression dive time for 55 feet (60 foot row) is 55 minutes.

> *The value used for dive time or bottom time is defined by NAUI as the ACTUAL DIVE TIME — the total time spent underwater during a dive except for precautionary decompression stop time.*

The values to the right of this circled number — 60 over 5 and 80 over 7 — represent the amount of *mandatory decompression* that would be required at a depth of 15 feet in the event that you exceeded the no-decompression time limit. The top number is the dive time and the bottom number is the required decompression time. For example, if your actual dive time (ADT) was 62 minutes you would have to make a mandatory decompression stop at 15 feet for 7 minutes.

Upon completion of your dive (Dive #1) to 55 feet your timer reads 35 minutes actual dive time (exclusive of the precautionary decompression time; in reality automatic timers would continue to function throughout the 3 minute stop at 15 feet). If you enter the 60 foot row to 35 minutes (in this case 35 minutes is between 30 and 40; you must used the higher valve), you can determine your Letter Group designation at the end of the dive by following the column in which 40 appears down and reading the letter at the bottom of the table. In this case your Letter Group is "G". This information is required only if you intend to dive again within 24 hours.

> *Please take note that NAUI defines a repetitive dive as any dive within 24 hours of a previous dive.* The Recreational Dive Planner is based on a period of 6 hours and the US Navy tables use 12 hours.

TABLE 2: SURFACE INTERVAL TIME (SIT) TABLE

Two hours after completing your initial dive of the day you plan to make another dive. Since your body has been off-gassing nitrogen throughout this 2 hour period, you can receive credit for this time. Table 2 — Surface Interval Time Table — is used to determine the amount of credit. Locate Letter Group "G" from Dive #1 at the top of Table 2 (or bottom of Table 1). Enter column "G" downward to the box containing the numbers 2:58/2:00. Your surface interval is 2 hours. Now move horizontally to the left to determine your new Letter Group — "D".

TABLE 3: REPETITIVE DIVE TIME TABLE

Table 3 — Repetitive Dive Time Table — provides you with residual nitrogen time and the maximum no-decompression time allowed for your repetitive dive. Find the letter "D" in the column at the right side of Table 3. Now, let us assume that you plan to dive to a depth of 47 feet on Dive #2. Follow the "D" row to the left to the 50 foot column (depths are indicated at the top of Table 3). You will find two numbers in a box. The upper number (light face type) is the residual nitrogen time (in minutes) remaining from Dive #1. The bottom number (bold face type) is the Adjust Maximum Dive Time (AMDT) or maximum allowable no-decompression time for Dive #2 — in this case 51 minutes. This figure — 51 minutes — is the maximum no-decompression dive time for 50 feet *less* the residual nitrogen time or (80 – 29 = 51).

Let us assume that your planned actual dive time for Dive #2 is only 40 minutes. In order to determine your Letter Group at the end of Dive #2 you must add the actual dive time (ADT) and the residual nitrogen time (RNT) to determine the total nitrogen time (TNT) of Dive #2. In this case 40 minutes (ADT) plus 29 minutes (RNT) equals 69 minutes. This is the Total Nitrogen Time (TNT). Returning to Table 1 you find that you are now in Letter Group "I". You only need this figure if you plan to make another dive within 24 hours.

PLANNING A THIRD DIVE

Let us assume that you are planning a third dive and wish to return to the water as soon as possible. Although the tables provide for surface intervals as short as 10 minutes, *the policy of NAUI is that divers observe a minimum of one hour surface interval between dives.*

You were a Letter Group "I" diver upon completion of Dive #2. To plan Dive # 3 enter Table 2 in column "I" and move down to the box 1:29/1:00. Now you can find your new Letter Group by reading the letter to the left of Table 2 — "G".

Dive #3 is planned for a maximum depth of 40 feet. Entering the "G" row into Table 3, you proceed to the 40-foot column and find that your Adjusted Maximum Dive Time (AMDT) is 57 minutes (bottom figure).

Most authorities recommend that you make no more than 3 dives per day. Since you have made a series of no-required-stop repetitive dives NAUI recommends that you wait at least 24 hours before flying in a commercial air craft.

COMPUTING MINIMUM SURFACE INTERVAL

Many diver wish to complete two successive dives with know depth and dive time requirements and remain within the no-decompression limits for both dives. Let's assume that wish to make Dive #1 to 60 feet for 50 minutes and Dive #2 to 50 feet for 60 minutes. You must determine the minimum surface interval between the two dives.

Upon completion of Dive #1 you are a Letter Group "H" diver (Table 1). In order to determine your Letter Group at the beginning of Dive #2 you must enter the 50 foot column of Table 3
to the box which indicate an adjusted maximum dive time (bottom number, bold type) of 60 minutes or greater. Reading to the right you find that you are in Letter Group "B". Now continue to the right into Table 2 until you intersect the "H" column. The minimum value in this box is 4:50 or 4 hours 50 minutes.

SPECIAL RULES AND RECOMMENDATIONS

Rate of Ascent. The maximum rate of ascent is 60 feet per minute.

Dives Shallower Than 40 Feet. Dives shallower than 40 feet are to be considered as 40 foot dives for table use.

Dive Depth. Dive depth is the maximum depth attained during the dive. Use the exact or next greater value. For example, the 50 foot schedule would be used for a dive to 42 feet.

Dive Time. Dive time is the total time spent underwater exclusive of the precautionary decompression stop time. Use the exact or next greater value. For example, for a single dive of

31 minutes at 60 feet you would use the 40 minute column to determine your Letter Group. Precautionary decompression stop time is considered to be neutral time.

Precautionary Decompression. A precautionary decompression stop of *3 minutes at 15 feet* is recommended during ascent from each dive.

Mandatory Decompression Stop Dives. Dive requiring a mandatory stop are discouraged. Decompression times are included on Table 1 for use in the event that the recommended Maximum Dive Time (no-decompression time) is accidentally exceeded.

Omitted Decompression. In the event that you exceed the Maximum Dive Time *and* omit the decompression stop you should refrain from physical activity (rest), drink plenty of fluids, breath 100% oxygen, and watch for signs or symptoms of decompression sickness. If symptoms are evident immediately acquire medical attention and hyperbaric treatment. If no symptoms are evident, do not dive for at least 24 hours.

Flying After Diving. Wait at least 24 hours following no-decompression diving. Wait at least 48 hours following a dive that required decompression or following an omitted decompression.

Cold or Strenuous Dives: Use the *next greater bottom time* for cold or strenuous dives. For example, if you wished to remain within the no-decompression dive time limit for a depth of 60 feet and you are cold, limit the dive to 50 minutes or less. In order to determine the Letter Group at the end of the dive, use the next greater bottom time — for a 50 minute dive use 55 minutes or Letter Group "I".

Diving at Altitude: NAUI recommends that the use these tables be limited to altitudes of less than 1000 feet above sea level. Special tables are required for diving at higher elevations.

PRACTICE DIVE COMPUTATIONS USING THE NAUI DIVE TABLES

1. Maximum Actual Dive Time (no-decompression) for a dive to 66 feet.

2. You have been diving to a maximum depth of 72 feet and discover that your ADT is 45 minutes. What, if any, special procedure would you take in ascending to the surface?

3. Dive #1: 72 feet/30 minutes
   Dive #2: 58 feet

   Determine the Adjusted Maximum Dive Time (AMDT) for Dive #2 following a Surface Interval Time (SIT) of 1 hour 30 minutes.

4. Dive #1: 55 feet/40 minutes
   Dive #2: 35 feet

   Determine the Adjusted Maximum Dive Time (AMDT) for Dive #2 following a Surface Interval Time (SIT) of 1 hour 30 minutes.

5. Dive #1: 95 feet/20 minutes
   Dive #2: 50 feet/40 minutes

   Determine the minimum surface interval time (SIT) require in order to complete Dive #2 without making a mandatory decompression stop.

6. Dive #1: 80 feet/35 minutes
   Surface Interval: 1 hour
   Dive #2: 50 feet for Adjusted Maximum Dive Time (no-decompression)
   Surface Interval: 1 hour
   Dive #3: 40 feet

   Determine the Adjusted Maximum Dive Time (no-decompression) allowable for Dive #3.

ANSWERS: 1. *45 min;* 2. *mandatory stop at 15 feet for 10 min;* 3. *25 min;* 4. *81 min;* 5. *46 min;* 6. *43 min*

APPENDIX C

COMPUTING MINIMUM SURFACE INTERVAL

The following instructions will address the general procedure for determining minimum surface interval using *both* the Recreational Dive Planner (RDP) and US Navy Dive Tables: NAUI Arrangement (NAUI). *You will discover that the values will vary considerably depending on the Dive Table that you use.*

PROBLEM

Dive 1: 60 feet/50 minutes
Dive 2: 50 feet/60 minutes

Compute the minimum surface interval that enables you to complete Dive 2 within the "no-decompression limit" for 50 feet.

Step 1: Draw a dive profile and enter all known information (depth and time of both dives).

Step 2: Using the No-Decompression Limits and Group Designation Table (RDP Table 1) find the pressure group (repetitive group) at the completion of Dive 1 and enter letter on your dive profile.

Answer: RDP = "U"   NAUI = "H"

Step 3: Proceed to the Repetitive Dive Time Table (RDP Table 3) or Repetitive Dive Timetable (NAUI Table 3) and find 50 feet at the left side of the table (RPD) or top of the table (NAUI). Using the *RDP* follow the 50 foot row horizontally from left to right until you find the first adjusted no-decompression limit that is 60 minutes or greater (lower number in box) and follow that column up vertically to find the pressure group and enter it on your dive profile.

Answer: RDP Group "D"

Using the *NAUI Table* follow the 50 foot column down until you find the first adjusted no-decompression dive time that is 60 minutes or greater (lower number in box) and follow that role to the right margin to find the repetitive group and enter it on your dive profile.

Answer: NAUI Group "B"

Step 4: On the Surface Interval Credit Table (RDP Table 2) find pressure group "U" on the diagonal and pressure group "D" at the bottom and find the surface interval where they intersect. At this intersection you find 1:26 – 1:34.

Answer: RDP = "1 hour 26 minutes"

Using the NAUI Table follow repetitive group row "B" (Table 3) to the right to Table 2 (Surface Interval Time Table) and repetitive group "H" (bottom of Table 1) down to the box where they intersect. At this intersection you find 7:59 to 4:50.

Answer: NAUI = "4 hours 50 minutes"

CHAPTER 4-3

USES AND ABUSES OF DIVE COMPUTERS

Karl E. Huggins

INTRODUCTION

Since the introduction of dive computers (DCs) divers have been developing imaginative methods of use, not all of them very smart. This article will describe what a DC is, some of the misconceptions the general diving population have regarding them, and how they are being used. Examples of how dive are being used are presented along with recommendations adopted by the American Academy of Underwater Sciences (AAUS) for DC use in scientific diving programs.

Of major concern is the accuracy of the information passed on from instructors to students, salespersons to customers, and divers to other divers with regards to DCs. Too often in the diving community we see hearsay, biased, or inaccurate information presented on pieces of equipment as instead of factual information. DCs look as if they will be around for a while. They should not be condemned outright, nor should they be worshiped as a panacea for decompression sickness (DCS). They are only *tools*, and as such are no better or worse than the person using them.

WHAT IS A DIVE COMPUTER?

A DC is just that, a computer. It does not, as some people think, monitor the amount of nitrogen in a divers body. All it does is compute decompression status. This is done by sensing depth and time during the dive and then, by using a table or model, the decompression status is read or computed. This decompression status information is displayed to the diver, who can use it as an additional source of information in the execution of a dive.

The basic design of a DC is presented as a block diagram in Figure 1. The general components are the:

Pressure Transducer, which converts the ambient pressure surrounding the diver to a signal which is fed into the input of the A/D Converter.

A/D (Analog to Digital) Converter, which changes the pressure transducer signal to a digital "word" which can be "read" by the microprocessor.

Microprocessor, the "brain" which controls the signal flow and performs the mathematical and logical operations.

ROM (Read Only Memory), a non-volatile memory which contains the program steps which "tell" the microprocessor what to do. The ROM also contains the constants used in the program which determines the diver's decompression status.

RAM (Random Access Memory), contains the storage registers in which variable data and results are stored during computations.

Display, which presents the diver's decompression status.

Clock, which synchronizes the operational steps of the microprocessor and is used as the time input.

Power Supply, which runs the device.

Device Housing, which protects the components from the environment.

Many people believe DCs just read established dive tables. This is not true. Only one of the DCs available is table based (Suunto SME-USN). All the rest use a decompression model (algorithm) to compute the decompression status.

The algorithms used in DCs are mathematical and logical formulas with variables of depth and time, which makes them much more flexible than tables. A pure mathematical model affords an infinite number of depth/time solutions. Dive tables are finite listing of some of the solutions produced from a mathematical model.

The implementation of a decompression model in a DC is not "pure." As with tables the DC deals with depth and time increments, on a much smaller scale, based on the update interval of the computer (how often it recalculates the divers decompression status) and the resolution of the pressure transducer circuitry (the smallest change in depth it can detect). The U.S. Navy no-decompression table has only 135 depth/time combinations for depths between 0 and 140 feet of sea water (fsw). A model based computer that updates its status every 3 seconds and has a depth resolution of 0.5 fsw can distinguish 400 possible "square-wave" depth/time combinations in a one minute period over a 10 fsw depth range.

Tables also base decompression status on the assumption that the entire dive was spent at the maximum depth. Most recreational divers spend only a small fraction of their dive time at the deepest depth achieved during the dive. This means that during most of dive the diver is taking on less nitrogen than assumed by the tables. Model based DCs that update the divers status every few seconds will compensate for the changes in depth. This allows the diver to be presented with a decompression status based on the actual dive that was performed. The advantages of computing decompression status in this manner includes:

A. Profile Integration (no maximum depth – entire dive assumption).

B. Shallow portions of dive (safety stops) are taken into account.

C. Actual Depth used in Calculation (51 fsw not 60 fsw).

D. All compartments of the model are taken into account when calculating multi-level dive profiles (most table based techniques utilize the compartment representing their repetitive groups).

However, many of the advantages produce the disadvantages of DCs. If the device is pushed to its limit, the model is pushed to its limit. There are no safety factors programmed into the units except for the models which are more conservative than the U.S. Navy model. In using tables the maximum depth – entire dive rule adds a safety factor if the diver is at shallower depths during most of the dive. Another safety factor inherent in table use is the rounding up to a depth or time value greater than the actual depth and time of the dive. By using 60 fsw when the maximum depth is 51 fsw additional safety is added.

Other disadvantages present themselves. A diver needs to read the device, understand the information that is being presented, and act upon that information. There is also the possibility that the DC will become a crutch. Some divers might use it as an excuse to not teach, learn, or use tables (just like BC's are being used to circumvent the teaching of proper weighting). The major disadvantage, shared by tables and DCs alike, is the fact that all the DC or table knows about is depth and time.

DECOMPRESSION MODELS VS REALITY

Decompression models do not actually represent what is happening in the body. All the models do is attempt to produce depth/time combinations that are safe for most divers most of the time. Nearly all decompression models to date use these two variables, depth and time. These used to compute the decompression status displayed to the diver. Many other factors can change the divers susceptibility to DCS. These include ascent rate, physical exertion, water temperature, physical condition, hydration level, blood alcohol, age, gender, breathing mixture, etc.

If two divers perform the same depth/time dive profile, one being low exertion by a young, healthy diver in a warm Caribbean environment and the other, performed in cold water by an older, out of shape, hung over diver, who was working heavily then the same decompression status will be computed by a DC (if the same DC model is used). All the DC "knows" is depth and time. A DC also has no memory of how it has reached its present decompression status. It does not keep track of the dive profiles that have been previously performed to modify decompression status calculations on subsequent dives. All it "knows" is the gas loading the model has calculated up to that point.

A MATHEMATICAL EQUATION DOES NOT A BODY MAKE! Divers must be aware that they need to add safety factors based on their own physiological state, the diving environment, and their previous dive profiles, just as they have been taught to do when using tables.

GENERAL MISUSES OF DIVE COMPUTERS

There seems to be some general techniques that have been developed by "clever" divers to squeeze every second they can out of a DC. The reasoning behind these abuses ranges from stupidity to blissful ignorance. Some of these misuses follow:

Regularly pushing unit to limits: There are many divers who run their DCs down to zero no-decompression time, ascend to a shallower depth, and then run the time back down to zero. This pushes the decompression model in the unit to its limit.

Ignoring ascent rate warnings: Most of the DCs use ascent rates that are slower than the 60 fsw/min. U.S. Navy standard. Using a faster ascent rate than suggested may place them outside the limits of the model. Following the slower ascent rates has the added benefit of requiring the diver to have good buoyancy control.

Not reading or ignoring the information: Some divers will just ignore the information provided by the computer if they do not like the information that is displayed.

Turning off unit to clear residual nitrogen: Some divers who do not like the repetitive dive information being shown by the DC will actually turn it off to clear the residual nitrogen from the computer's registers and give them more time on the repetitive dive. Clearing the residual nitrogen memory from the DC does not clear it from the diver's body!

Using outside operating range: About half of the DCs on the market are designed to be used at sea level or the first few thousand feet of altitude. The DCs based on the Swiss model generally adjust to altitude. However, some divers use the sea level DCs "as is" at altitudes outside the model's operating realm. Another problem in this category is diving to depths that exceed the maximum depth range of the DC. Why have a DC if it is being used on dives where it can't calculate properly or is placed in ERROR mode?

Abusing safety features: Some of the DCs have safety features that allow a diver to get out of situations outside the model or electrical limitations of the DC. Case in point, the EDGE DC has a maximum depth resolution of approximately 165 fsw. At that point the depth register is storing the largest number it can. If the diver were to descend further the DC would not be able recognize the fact that the diver was at a deeper depth. However, a safety feature was added that assumes that the diver is at approximately 200 fsw any time the maximum depth has been exceeded. This assumption will only be "safe" (which is a questionable term for any dive to that depth) for a minute or so. After that time the compartment pressure registers will reach the maximum value they can store and they will not be able to distinguish any increase in compartment pressure, making the calculations and decompression information erroneous. There are divers who pervert this safety feature to make dives to 200 fsw with the EDGE and some who use it to depths deeper than 200 fsw. Why? In most cases another diver has told them they could do it. Most of the time the divers don't really understand how the DC works, even though some think they do and they will believe what they want to believe.

Hanging the Dive Computer: One of the most ludicrous techniques observed. Some divers who violate the DC's ascent rate or have surfaced while the DC still indicates required decompression will tie a rope to the DC and hang it over the side of boat to clear the warnings and prevent the DC from going into ERROR mode. What can one say? The computer understands depth and time. It has no idea if it is attached diver or a rope.

Use with gas mixtures other than air: At this time all the DC models are based on the use of air as the breathing gas. Use of nitrox (enriched air) mixtures with less nitrogen content than air will theoretically add conservatism to the decompression calculations. However, the computers do not know anything about the increased potential of oxygen toxicity while using these mixtures. Other gas mixtures can actually increase the risk of DCS if decompression status is determined with an air based DC.

Blind trust in numbers: Many divers think that because the DC is telling them something that it is "TRUE." The numbers produced by the DC are only a guide to a divers decompression status, based on a decompression model using depth and time variables. The diver must be aware of the other factors that may influence susceptibility to DCS and add their own safety factors. As pointed out at the AAUS Dive Computer workshop last year, "They are like a small television, and people believe what they see on television."

Turn thinking over to a machine: Some divers do not want to worry, or think about their decompression status so they let a little box made out of silicon, metal, and plastic take over their thinking requirements. As stated before, the DC information is only a guide, not the gospel! Divers need to be able to think for themselves and understand the risks they are taking.

HOW DIVE COMPUTERS ARE BEING USED

In 1987 a group ten sport divers were monitored during a 14 day dive trip. All the divers, except one, used a DC. Following 76 of the dives the divers were monitored using Doppler ultrasonic bubble detector to check for "silent bubbles." On 65 dives the actual dive profile was recorded (maximum depth every 3 minutes).

When compared to the U.S. Navy tables 52 of the dives indicated omitted decompression. The maximum omitted decompression for a single dive was 71 minutes. The average was 23.0 minutes. For an entire day the maximum omitted decompression was 145 minutes and the average was 46.2 minutes The maximum time extended past the U.S. Navy No-Decompression limits was 55 minutes on a single dive (average of 23.8 minutes).

The profile data indicated that 48.5% of the dive time was spent at depths which were 75-100% of the maximum depth of the dive. 26.2% of the dive time was spent in the 50-75% of maximum depth range. 16.3% of the time was in the 25-50% range and only 9.0% was spent in the shallowest quarter of the dive. This indicates that, for this group of divers, the DCs were not being used to make a short excursion to a deep depth followed by the remainder of the dive in shallower water. Also, the profiles did not follow the deep-to-shallow rule as can be seen in Figure 2.

The results of the Doppler monitoring indicated one definite and three possible cases of Grade I bubbles. No symptoms of DCS were observed in the divers.

Mike Emmerman reported dive profiles used on the Andrea Doria (1). What he observed was frightening. Divers would do a 210 fsw dive, wait 4 to 6 hours, and then do the same dive over again. Some did two dives a day and others did three! This was done three days in a row. Over 50% of the divers used DCs. Some used DCs that had maximum depth ranges that were shallower than the depths of the dives. Of the 16 divers on the trip six of them presented definite signs and symptoms of DCS! These six divers did express some concern for their condition, but none of them sought treatment!

Dr. Tom Neuman at the University of California – San Diego related a case of DCS where a diver and his buddy had been diving with DCs (2). The dive history obtained from the diver was first a dive to 254 fsw followed by a dive to 160 fsw 3-1/2 hours later. Dr. Neuman found this hard to believe until it was discovered that the computer the diver wore also recorded the dive profile. The profile was recalled and the dives were confirmed, except for showing a maximum depth on the first dive of 230 fsw. This was due to the fact that the maximum depth limit for the computer was 230 fsw. However, when the dive log information was retrieved from the buddy's DC (one that has a depth limit of 300 fsw) a maximum depth of 254 fsw was obtained.

Another case involves a 26 year old male diver on vacation in the Caribbean using a DC.

On the day the problem developed the first dive was a multi-level dive to 140 fsw for a total dive time of 56 minutes. Four hours later a second dive was performed to 160 fsw for 47 minutes. The diver noticed an onset of fatigue 2 hours following the second dive, however he decided to perform a third dive following a 3 hour surface interval. This third dive was a night dive to 47 fsw for 67 minutes. That night he had a restless sleep, cold sweats, and minor pain in the elbow. In the morning the fatigue and pain remained so he proceeded to perform another dive. The dive was to 65 fsw for 40 minutes and during the dive felt pain relief. It was at this point that he concluded that he probably was bent. The next morning the pain and fatigue remained along with a headache. That day he flew home to the states and sought treatment, four days after the dive series that produced the problem. After being treated with a Table 6 treatment table the diver had no apparent residual problems. At all time the diver was within the "no-decompression" realm of his DC, but was pushing those limits.

The final case involved a 53 year old experienced female diver in excellent physical condition. She performed three dives to depths of 70 – 80 fsw using a DC. At no time was there less than 5 minutes of no- decompression time remaining on the DC. However, on the second dive the sleeve to her dry suit ripped exposing her arm to very cold water. Following the dive she had pain in her arm, but attributed it to the exposure to cold water. The suit was fixed and she performed the third dive. Later that evening, the pain in her arm became intolerable and she sought treatment. Besides the cold water another extenuating factor was that she had not had any hydration during the day (when she finally passed urine it was dark brown). There was no way for the DC to know that the dry suit had ripped or that the diver was dehydrated.

THE DIVER'S RESPONSIBILITY

Divers must realize that they need to take responsibility for their actions and safety. They must acknowledge the fact that every time they dive there is risk involved. One of these risks is the possibility of developing DCS. A diver needs to make a risk/benefit assessment as part of the dive plan. The goal of such an assessment is to maximize the benefit while minimizing the risk.

The operation and limitations of the DCs being used need to be understood. The more the diver understands about the equipment being used, the more educated and safe the decisions will become.

Dive computers should not be pushed to their limits. Divers should add safety factors just they are added with table use. Remember, all a DC knows about is depth and time. DCs are not anti-DCS talismans. They will not ward off bubble formation or suck the nitrogen from the body. Most of all, a diver needs to employ common sense in all phases of diving.

CONCLUSIONS

It should be remembered that the advent of reliable DCs should not give the "train em fast and easy" people in diving an excuse not to teach tables and underlying decompression concepts, nor should they provide lazy divers an excuse not to learn and practice table use. I have talked to instructors who would have no qualms about having their students just strap on a little box that tells them their decompression status instead of teaching the use of dive tables. There are places where Basic students are showing up to the first pool sessions wearing DCs. What incentive do they have for learning the concepts and use of dive tables? The introduction of DCs means that along with table instruction there is now the need to teach students how to use and understand computers.

No dive table or computer 100% effective! Divers need to understand how and where the numbers are coming from, be it with tables or computers. They need to realize that all these devices understand are depth and time applied to a mathematical model. Common sense and understanding need to be part of the equation. Dive computers are good tools and as such can be used to enhance the diving experience, but they are only tools, not demigods to be worshiped and followed religiously. With hard work, training, and education we may be able to eliminate the event where a diver states, "I don't understand, my computer told me I could..."

AAUS RECOMMENDATIONS

In October 1988 the AAUS held a workshop on the use of DCs in scientific diving (3). The recommendations that were agreed upon that apply to recreational divers are listed below:

A. *Each* diver relying on a DC to plan dives and indicate or determine decompression status must have their own unit.

B. On any given dive, both divers in the buddy pair must follow the most conservative DC.

C. If the DC fails at any time during the dive, the dive must be terminated and appropriate surfacing procedures should be initiated immediately.

D. A diver should not dive for 18 hours before activating a DC to use it to control his/her diving

E. Once a DC is in use, it must *not* be switched off until it indicates complete outgassing has occurred or 18 hours have elapsed, whichever comes first.

F. When using a DC, non-emergent ascents are to be at the rate(s) specified for the make and model of DC being used.

G. Ascent rates shall not exceed 40 fsw/min. in the last 60 fsw.

H. Whenever practical, divers using a DC should make a stop between 10 – 30 fsw for 5 min. especially for dives below 60 fsw.

I. Repetitive and multi-level diving procedures should start the dive, or the series of dives, at the maximum planned depth, followed by subsequent dives of shallower exposures.

J. Multiple deep dives should be avoided.

REFERENCES

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2. Neuman, Tom, personal communications.

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SECTION 5

FUNDAMENTALS OF DIVER PROBLEM MANAGEMENT

CHAPTER 5-1

INTRODUCTION TO THE FUNDAMENTALS OF DIVER BEHAVIOR AND PROBLEM MANAGEMENT

Divers must understand the fundamentals of human behavior as it relates to stress and performance in diving. A competent diver should have basic ability in stress recognition, reduction, prevention, and management. The emphasis in diver training is placed on awareness and understanding. The diver must be aware of the potential causes or sources of stress. Through this awareness the diver can significantly reduce the likelihood of encountering a stressful situation. And, if a stressful situation is encountered the properly trained diver is more likely to be capable of dealing with it.

Divers must also be capable of dealing with certain problems that might be encountered in routine diving. Most divers problems are encountered on the surface rather than at depth. Analysis of diving fatalities suggest that many of the victims simple could not achieve flotation and solve problems on the surface. Overexertion and inability to deal with surface current are probably major factors in many diving accidents. Divers must be able to recognize problem in themselves and others and execute both self-rescue and second party assistance or rescue procedures.

A skill, knowledgeable diver will encounter very few problems underwater. If a diver is physically fit, comfortable in the water, and aware of personal limitations safe diving becomes somewhat routine. Combining these factors with the selection of a good diving companion, a properly executed dive plan, and monitoring of air supplies leads to pleasurable, uneventful diving. However, the diver must still be skilled in the management of underwater problems such as overexertion, air supply loss or depletion, regulator free flow, dislodgment of the regulator from the diver's mouth, mask flooding, loss of buoyancy, uncontrolled buoyant ascent, and entanglement. Procedures for dealing with these situations is discussed in detail in both lectures and skills training.

Divers must be prepared to administer proper first aid to an injured person. Standard first aid practices for lacerations, abrasions, neck/back injuries, cardiac arrest, drowning, fractures, burns, and other injuries and illnesses are learned in a Standard or Advanced American Red Cross First Aid Course. Consequently, standard first aid practices are not addressed in this manual. All divers are encouraged to complete an American Red Cross Standard First Aid Course including cardiopulmonary resuscitation.

Standard first aid courses do not address the management of injuries and illnesses related to pressure changes (barotrauma), inert gas absorption, breathing gas contamination, and marine life encounters. Consequently, these topics are addressed in detail in this manual. The diver is instructed in basic diagnosis and management of these conditions or injuries. More attention is directed toward dealing with diver injuries in remote locations.

NOTES:

CHAPTER 5-2

PSYCHOLOGICAL BEHAVIOR AND THE SCUBA DIVER

INTRODUCTION

In a medical journal paper, Lanphier made the following comment to physicians regarding the evaluation of diving applicants [10]:

> "Any organic neurological disorder, or a history of epileptic episodes or loss of consciousness from any cause, makes diving highly unadvisable. A more difficult problem for the physician to evaluate and handle adroit arises in the psychiatric area. The motivation and general attitude of some aspirants makes diving unlikely from the outset; and those who tend to panic in emergencies may well find occasion for doing so in diving. Recklessness or emotional instability in a diver is a serious liability for his companions as well as himself."

The nature of the human's reaction to conditions of physical and psychological stress has long been of major interest to researchers. The more obvious stressors associated with diving are physical exertion, cold, poor equipment performance, and nitrogen narcosis. Certain vocations and avocations present situations described as stressful because the individual's physical well-being and safety can be threatened by technological and environmental contingencies. Diving, whether practiced for recreation or employment, certainly presents situations that can be classified as stressful.

Keep in mind that it would be impossible to totally eliminate risk from any part of society, let alone scuba diving. Willingness, and even need, to take risks and challenge ourselves can be an important growth and life experience. The decision that a diver must make is, "What is an acceptable risk?" Furthermore, the amount of risk that is acceptable for one individual is not necessarily acceptable for another, as capabilities and desires differ. *Recognition of personal limitation is a sound basis for preventing injury or death.*

Civilian diving instructors, especially cave divers, began to recognize the significance of *stress* in scuba diving in the 1970s. Bachrach, Smith, and Mount were instrumental in focusing the attention of the recreational diving community on the basic fundamental aspects of diver stress [1, 13, 15]. Griffiths has more recently authored (or coauthored) several excellent publications on diver stress [7, 8, 9] and provided an in-depth scholarly discussion of recreational scuba diver stress in his textbook, *Sport Scuba Diving in Depth* [6]. Bachrach and Egstrom more recently published an excellent book on the subject, *Stress and Performance in Diving* [3]. An extensive bibliography of informative abstracts that include stress and human performance factors in cold water diving is published in *Cold and the Diver* [12].

Participation in certain activities involves *taking risk.* Risk is the possibility of loss or injury. It can be a statistic which implies the likelihood that injury or death will occur. Taking risk, in itself, is a source of stress. The amount or degree of stress varies with the individual. However, any activity such as scuba diving also provides *reward or benefit* to the individual. Benefit is something conducive to personal or social gain or well-being. Safety, on the other hand, is the condition of being free from harm or risk. *In scuba diving one must strive to maximize safety and benefit and minimize risk.* A particular diving situation may be assessed in terms of *risk/benefit* or, in other words, "What benefits will be derived from this dive in light of the risk involved?"

Individual risk/benefit analysis may be biased by peer pressure, social need, and economics. Often the individual will participate in a particular dive situation in order to simply prove that they can do it or to test themselves. For example, drift diving in a cold, fast moving river current under poor visibility conditions can be a challenging personal test. The need for novice divers *to prove themselves* personally and to others may result in a risk/benefit analysis that leads to participation in such a dive. On the other hand, the same situation analysis by a diver with "nothing to prove" may result in forgoing the particular diving experience.

Stress in diving should be treated as any other potentially life-threatening element or disease. A considerable amount of scuba diver training time is devoted to developing a basic knowledge in the cause, signs, symptoms, and prevention of the various physiological problems associated with underwater swimming. The trainee must understand that panic can be the diver's worst enemy. Water training exercises designed to prepare the diver to cope with emergencies are taught and practiced in order to lessen the diver's tendency toward panic in an emergency or stressful situation.

Modem equipment and diving techniques tend toward reduction in physical stress involved with routine diving. However, only through a comprehensive knowledge of diving and understanding of the sources and effects of psychological stress can a individual learn to deal with stress in a diving situation. Understanding stress is the key to preventing the development of stressful situations. Unfortunately, modern trends in diver training tend to minimize discussion of *negative aspects* of scuba diving. As course durations are shortened in an effort to market scuba diving travel and equipment fewer and fewer divers are being properly schooled in stress psychology.

In the following paragraphs I will discuss the sources, effects, and management of stress. This discussion, in part, has been developed from ideas and concepts presented nearly two decades ago by Smith [15]. It is intended to provide the diver with a *common sense* appreciation for the prevention, recognition, and management of stress factors in scuba diving.

SOURCES OF STRESS

Stress or emotional distress can be caused by both physical and psychological (mental) phenomenon. The complex interrelationship between physical and psychological stress is beyond the scope of this paper. However, certain causative factors and generalizations are important for divers to recognize. Most authorities agree that a physically fit diver is less likely to develop fatigue or exertion induced stress responses. Individuals who have physical deficiencies such as cardiovascular disease, respiratory ailments, or ear/sinus problems are probably more likely to experience stressful episodes.

Temporary physical deficiencies associated with colds, the effects of alcohol/drug use, or sea sickness can appreciably predispose a dive to stress. Most divers can relate to the obvious distress, physical and emotional, associated with the inability to equalize pressure in their ears during descent.

Sources of stress in everyday life can, in many respects, be related to diving. Most obvious are the phenomena related to time and task factors. Many recreational divers choose the sport in order to *escape the pressures* of their routine daily lives. In most cases this simply represents a substitution of one group of stressors for another.

Time is pressure is modem society, and a diving trip is no real escape from *time pressures*. Pre-dive packing, acquiring air fills, and travel must often involve the scheduling of a series of time events. Frequently, routine work schedules are escalated in order to get *time-off* for the diving trip. Weekend outings involving charter boat trips call for early moming departures. The diver must awaken early in order to get to the boat *on time*. Last minute tasks at home and packing for the weekend trip generally result in a late night before the scheduled diving day. Potentially, time has already compromised the diver's safety before boarding the dive boat.

Many aspects of the scuba dive involve time pressure. First, the *coordination* of donning diving equipment and water entry with a diving buddy and other divers imposes an element of time-related stress. Once underwater, dive time is limited by air supply duration and dive table allowances. Failure to continuously monitor time can lead to serious decompression complications. Basically, every element of the dive is time dependent. This is a subtle but very real form of psychological stress.

Another form of stress that eventually leads to a performance decrement is **task loading**. Task loading simply involves giving an individual more tasks than they can effectively perform in a given time period or assigning competitive tasks that require two or more manipulations at the same time. On a routine scuba dive, the diver must perform a number of separate and/or simultaneous tasks which include watching a buddy; holding a line attached to a surface float; controlling buoyancy; avoiding potentially hazardous marine life; constantly monitoring depth, time, and air supply; and, time permitting, performing some underwater task such as photography. Failure to *properly* perform any of these tasks, with the exception of the photography, could endanger the diver.

Often the diver's psychological status is further compromised by cold water. **Cold stress** imposes physical degradation such as loss of manual dexterity and coordination and reduced muscular strength. However, psychologically, cold stress can also lead to a significant reduction in attention span and reasoning ability as well as increased anxiety.

Another obvious physical stressor is **exertion**. Recently, diving educators have placed greater emphasis on reducing the amount of exertion involved with routine diving. Modern trends in marketing diving to the general public emphasize effortless underwater swimming. Greater emphasis is being placed on proper buoyancy control as a means of reducing exertion. Also, many divers are simply choosing to dive under less demanding conditions.

However, divers must also be taught to evaluate their own physical limitations and those imposed by the environment. Divers still expend tremendous amount of energy simply preparing for the dive, carrying air cylinders to the staging area, and dressing. Heart rates of 160 beats per minute are not uncommon among divers preparing to make surf beach entries on a warm day. This already *stressed diver* is now approaching what can be one of the most physically and psychologically stressful aspects of diving — an entry through surf.

Even though we live in a fitness-oriented society, the number of individuals of high-level physical fitness observed on dive boats and at dive resorts is surprisingly small. Far too often individuals will elect diving as a recreational activity for the social implications. They neither take the actual diving experience seriously or accept the commitment to maintaining physical condition that is necessary for safe diving.

Nearly everyone has experienced the *out-of-breath* feeling, from working too hard or running too fast. It is possible for a person to exceed his normal working capacity by a considerable margin before the respiratory response to overexertion is apparent. The end result is generally shortness of breath and fatigue. On land, this presents little problem.

Underwater (under increased ambient pressure), the problems of exertion are modified by several factors and are considerably more serious. Even the finest breathing apparatus offers some resistance to the flow of air. As the depth increases, so does the density of air, and consequently, it moves through the body's airways with greater resistance to flow. When shortness of breath and fatigue are brought on by overexertion, the diver may not be able to get enough air. The feeling of impending suffocation is far from pleasant, and it may lead the inexperienced diver to panic and a serious accident.

Overexertion can generally be prevented if the individual knows and observes his limitations, takes into consideration the working conditions, and plans the diving operation accordingly. For example, plan the dive so that you can move with the current and not against it. Divers should keep themselves in excellent physical condition. The equipment must always be maintained in excellent working condition. Be alert for signs of fatigue!

In some diving situations the **lack of visibility** is a source of stress for many divers, especially novices. Basically, we tend to fear what we cannot see. The threat of a shark lurking just out of the range of diver visibility, whether real or perceived, may impose a tremendous amount of psychological stress on the diver. This is especially true if the diver has been *scared* during instruction because of a distorted perception of shark danger or has recently viewed one of the popular shark movies.

This is only one example of perceived danger induced by limiting the diver's visual range.

Associated with lack of visibility is **orientation** or the directional requirement. One of the most stressful aspects of a non-diving survival situation is *being lost*. An individual must overcome this psychological stress to survive. Many persons have perished within a few miles of civilization simply because they have panicked.

Orientation anxiety in diving is a bit more subtle and often not recognized until complicated by additional stress factors. A scuba diver may swim aimlessly and unconcerned until the air supply is nearly depleted. Normally, when the air supply is depleted, the diver would simply surface. However, air supply depletion compounded by a sudden realization of being lost underwater can lead to panic reactions. The diver's respiration rate elevates as a result of anxiety, and the diver may momentarily swim aimlessly and rapidly around the bottom attempting to regain orientation or sight a familiar landmark. Air consumption may triple within a matter of seconds. Air supply depletion now becomes critical. In a last futile attempt to escape to the surface the diver may experience pulmonary barotrauma and/or drown.

In activities such as cave diving combining the directional requirement with lack of visibility, such as in a *silt-out*, can be one of the most stressful situations ever encountered by a diver. Emotional stability and proper training with specific environmental emphasis is necessary for such diving exposures. Some individuals must be eliminated, or eliminate themselves, during training.

In cave diving, ice diving, wreck diving, or professional diving endeavors which involve entry into underwater structures, one must consider the implications of confinement or restriction. **Claustrophobia**, fear of confinement in small spaces, is an obvious contraindication to most, if not all, aspects of diving. Most individuals are aware of their fear of confinement. These people should seriously consider activities other than diving.

Unfortunately, some individuals experience latent claustrophobia. These individuals may be unaware of their suppressed emotional problem. Under normal conditions, they may function satisfactorily in confinement. However, when faced with confinement in a restricted underwater situation, such as a tight cave passage, the claustrophobia may surface with catastrophic consequences. In confinement situations the phenomenon of direction also plays a role. For example, in normal diving the diver associates the surface with safety, and the normal, conditioned response is to *ascend directly up to the surface* in an emergency. However, this surface-oriented diver is now confined in an underwater cavern or shipwreck. The normal response is no longer valid as an emergency. The diver cannot *go up*, he/she must *go back*. This bizarre *perceived stress* can trouble a diver as he/she penetrates further into a tunnel or passageway, especially if it involves the negotiation of restrictions. Even if no emergency exists, the diver becomes increasingly concerned about exit — a stress response.

The human is a surface-oriented animal, unequipped to naturally move in three-dimensions. When placed in water, the normal body control responses are ineffective. The diver's movement patterns are sometimes *controlled* by water currents and buoyancy. In either case the diver may be moved in a direction he/she does not intend to go. *The realization of loss of body control, particularly when compounded by other stress factors, becomes a significant stressor.*

Equipment malfunction is seldom indicated as a causative factor in diving accidents. However, a diver who is experiencing any type of equipment-related difficulty will generally exhibit signs of stress or anxiety. Most equipment-induced stress results from such problems as air supply depletion, inadequate buoyancy control, and overweighting the diver. These are common problems resulting from inadequate/incomplete training, carelessness, and poor judgment.

During training and initial diving experiences an individual must be conditioned to perform certain fundamental procedures. For example, the diver must actually experience air supply depletion under controlled training conditions. This enables the diver to develop an appreciation for the seriousness of the situation, mentally and physically rehearse response plans or alternatives, and encourages future preventive practices. Subjectively, in my opinion an individual who has experienced a controlled air supply depletion during training is less likely to accidentally deplete their air supply during operational diving. The most common procedure for preventing air supply depletion is to *condition the diver* to monitor a pressure gauge.

Unfortunately, during training many instructors have students begin the class with a full scuba cylinder. Commonly, a student will complete a confined water session with about 25 percent of their air supply remaining. The student is likely to develop a *false sense of security* and lack appreciation for monitoring the pressure gauge.

Physical threat, whether real or imagined, is probably the most significant of stress factors. In diving an individual, especially a novice diver, is constantly aware of physical threat. The environment itself imposes such threats as physical injury during surf entry, shark attack, entanglement, and entrapment or becoming lost under ice or in a cave. The diver must always consider the possibility of an air embolism, bends, or drowning. *The diver's realization that error can lead to catastrophic consequences is in itself a significant element of psychological stress.*

An individual can be effectively destroyed emotionally by real or perceived damage to their pride, self-esteem, or ego. It is a well-documented fact that emotionally insecure individuals attempt to strengthen or develop their ego through participation in *heroic* technically complex and environmentally challenging activities such as sky diving, hang gliding, mountain climbing, and scuba diving. An emotionally mature person can walk away from potentially threatening situations with no damage to their ego. The truly emotionally mature and stable person can do so even when others in their peer group may extend themselves further into the situation either because of superior ability, greater physical strength, or foolishness. The challenge to one's ego can be quite stressful. The ability to say "NO!" is one of the diver's most important safety considerations. In the words of a famous individual, Dirty Harry, "A man has got to know his limitations!"

However, if this tolerance or ability to walk away doesn't exist, as in an emotionally immature individual, the situation can be quite serious. The immature individual, either challenged from within themselves or because of social pressure from peers, may overextend themselves and thereby endanger themselves and other divers. At this point, the individual has demonstrated an inability to withstand the stress of **ego threat** and is a prime candidate for a diving accident.

Divers themselves are an ultimate source of stress. By nature the human is a competitive being. Self-imposed ego threat is serious. Divers may stress themselves to compete with others even if, in reality, nothing can be gained. Other divers may impose stress on their companions by constantly bragging about depth of dives, number of dives, air consumption, breath-holding time, and so on. Beware of the individual who constantly boasts to companions regarding his or her fantastically low air consumption. Eventually someone, possibly an emotionally immature novice, will accept this as a *challenge*.

A diver may stress a companion into a potentially deadly situation by threatening their ego and by constantly challenging them to test their limits in order to save their pride. As a diver, do not submit to such challenges! Unnecessary competition against oneself, another diver, the clock, or the environment can pose an immediate and serious threat.

Social Drugs and Alcohol

Any form of stimulant or depressant should be avoided prior to and during diving operations. *Drugs and alcohol can be a major cause of stress.* Drugs affect the body's biochemical level. Those of most concern disturb the autonomic system or influence behavior. The autonomic system regulates body functions on the subconscious level and may interfere with the physiological capacity to adapt to changing conditions or stresses. On the other hand, if something distorts the diver's sensations, perceptions, thought processes, or muscular control, behavior patterns can be drastically altered. The modern term applied is *behavioral toxicity*. Brown discussed the influence of drugs on the diver, addressing everything from aspirin to LSD. The following is summarized from this work [4].

Downers, including sedatives like doreden, qualude, and barbiturates (reds and yellows), the minor tranquilizers like Librium, Valium, and meprobamate, and the opiates or narcotics such as cocaine, heroin, morphine, Demerol, Percodan, and Talwin, have paradoxical excitatory effects at low dosage; however, they also have sedative and anesthetic effects at higher levels. They cause mental confusion or impairment and numb fingers. Breathing is slowed and CO_2 buildup is imperative. Eventually, sleep is induced. Underwater this, of course, could lead to drowning.

Uppers, the amphetamine group (including speed) are powerful stimulants. They initially elevate *mood* with subsequent depression. They inhibit appetite, prevent sleep, and are capable of causing acute toxic psychosis (behavioral changes). Heavy users show marked reduction in mental function and emotional stability with possible delusions of persecution. Some divers have suggested that the use of amphetamine will counteract nitrogen narcosis. This is a misconception! At depth, amphetamine can actually increase the narcosis as well as predispose the diver to oxygen seizures.

Hallucinogens include LSD, psilocybin, mescaline, and stramonium, as well as common euphoriants, amphetamine, and marijuana. These drugs distort, or in a sense, create perceptions which do not reflect objective reality. While apparently expanding the mind, they may also cause long suppressed behavioral abnormalities to surface (the bad trip).

Although evidence of adverse long-term effects of smoking marijuana are considered inconclusive by some individuals, the smoking itself still produces some of the significant complications. In addition, this drug can produce significant temporary adverse effects on the diver's mental processes, motor coordination, physical stamina, and tolerance to cold. In warm water the diver may become ultra-relaxed, sleepy, unaware, lazy, and his work ability may be reduced significantly. Regardless of the effect, it is unlikely that the diver will be able to respond properly, if at all, in the face of panic or underwater emergency.

Consumption of alcoholic beverages prior to, during, and immediately after diving operations must also be avoided. The party atmosphere of holiday scuba diving is cultivating a social disregard for the potential adverse consequences of mixing drinking and diving [16]. The immediately apparent effects of mental disorientation, impaired physical coordination, vertigo, poor judgment, and general physical weakness all compromise the diver's safety.

The implications of physical and mental degradation imposed by alcohol are evident. Possibly less evident are the implications with respect to nitrogen absorption and elimination. Pre-dive alcohol consumption causes skin vasodilation and increases nitrogen uptake by the subcutaneous fat. It reduces surface tension in the blood, favoring the formation and growth of gas bubbles. It also increases plasma fat, which favors fat emboli and blood clotting, both important in the pathogenesis of decompression sickness and aseptic bone necrosis. Furthermore, alcohol can also produce a diuretic effect, thereby causing dehydration of the body which, in turn, affects the circulatory functions. The contraindications to alcohol consumption associated with diving are clear. Use of alcohol should be very limited or, more desirably, completely avoided for at least 24 hours prior to diving.

To date there has been relatively limited research in the area of drug abuse associated with scuba diving. Elevated ambient pressure may potentiate a drug, or reverse its action, or provoke totally unrelated effects. Alcohol apparently increases nitrogen narcosis where as other sedatives may oppose it. Many drugs do reduce oxygen tolerance. Some favor and others may retard decompression sickness. Side effects are unknown. Most drug interactions are not clearly understood. Do not mix drugs, not even prescription or *off the shelf* drugs. At best we must consider many drugs as *unpredictable* under pressure. *Street drugs and alcohol have no place in diving. Their use is a sign of fundamental ignorance. If you use social drugs, even occasionally, get out of diving!*

Smoking

Mounting medical evidence has not only proven that smoking can and does cause lung cancer but it is also a major factor relating to such conditions as hardening of the arteries, pulmonary emphysema, cholesterol buildup, and heart attacks. From a diver's viewpoint, smoking is probably the most common single cause of local intrapulmonary obstruction. Tobacco smoke irritants cause chronic inflammatory changes in the bronchial lining and increase the amount of bronchial mucous in the airways. These conditions could result in airflow obstructions which may induce lung barotrauma during ascent. Smoking heavily may impair one's ability to utilize oxygen by at least 15 percent, since carbon monoxide combines with hemoglobin, making it incapable of transporting oxygen. In general terms, the physiologically compromised diver is more likely to experience adverse responses to stressful situations than the physiologically sound diver.

Cumulative Effect

It is evident that many factors can impose stress upon a diver and that multiple problems are more stressful than a single problem. A simple problem can be compounded by the presence of other real or imagined problems. Essentially, there is a cumulative effect.

EFFECTS OF STRESS

It is evident that there are numerous potential sources of stress in diving. To further understand stress and develop a prevention mechanism, the diver must identify the effects of stress. One of the most notable effects of stress is mental narrowing. When mental narrowing occurs, there is a reduction in the diver's sensitivity to the ambient environment. The diver's ability to intelligently analyze his situation and his ability to recall learned skills and knowledge in order to cope with the situation may be significantly limited or reduced. The inability to analyze the situation may also be termed cognitive narrowing. Under stress the diver often fails to notice the more subtle aspects of his situation, and he perceives only the more obvious factors. This is perceptual narrowing.

The ability to properly respond to a situation underwater is directly related to learned knowledge and skills. Under stress the diver is most likely to recall and use skills that are *well-learned* and which have become essentially reflexive in nature. Poorly learned skills or behaviors are less likely to be recalled. Ideally, a diving student should *overlearn* certain emergency skills. Mask clearing, regulator purging, sharing air, and other non-routine diving skills should become, more or less, second nature. Unfortunately, modern trends in diver education are toward short duration training courses. Some training courses now only involve three lessons. In such limited training programs it is, in my opinion, impossible for an individual to master routine diving skills and overlearn skills that may be required for survival in a critical situation.

I can teach most individuals the fundamentals of swimming underwater, buoyancy control, purging a mask, recovering a regulator, sharing an air supply and so on in one or two lessons. However, to insure even a reasonable degree of long-term skill retention and the ability to perform that skill *under stress*, the individual needs 12 to 15 practice opportunities spread over a respectable period of time.

Unfortunately, some normal reflexive human behaviors are not always the best for dealing with certain situations. For example, prior to diving training a person learns to hold their breath when, for any reason, the air supply is terminated. When one submerges in water, even as an infant, the reflex response is to breath-hold and ascend to the surface. However, for the scuba diver, holding the breath and ascending upon termination of the air supply can be catastrophic and life-threatening. During training the student diver must break a lifelong reflex response and exhale during ascent. Under stress the poorly trained and/or emotionally unstable diver may revert to the more primitive behavior.

Another example is air-sharing. Under stress divers have been known to revert to conventional buddy-breathing techniques even though auxiliary breathing equipment is available. In earlier training sessions the buddy-breathing procedure may have been *overlearned* and may supersede the use of the more desirable auxiliary breathing equipment, often a less practiced skill because of its apparent simplicity, under stress. Keep in mind that even simple skills must be repeatedly practiced.

Panic is the ultimate form of mental narrowing. At this point the diver completely looses control of the situation, logic and reasoning disappear, and primitive instinct prevails. The onset of panic is not necessarily sudden or overwhelming. As indicated above, as stress increases the diver's ability to diagnose problems and properly respond decreases. It is predictable that more mistakes will be made and, consequently, stress increases. Mistakes compound the problem and increase physical threat. The diver's realization of their situation also poses an ego threat and, thus, increases the stress factor. Panic is the terminal response.

In any stressful situation, the individual must *break this escalating cycle as quickly as possible*. This is critical! The diver must learn to recognize symptoms of stress in his own behavior and signs in the behavior of others. Panic is the end result of a series of subtle but recognizable behaviors. The body has a physiological adaptation mechanism for dealing with stress. This adaptation system pumps adrenaline into the system. The body responds with an elevated heart rate and level of respiration. The *aware* diver will sense these changes. Increased respiration increases air consumption. A diver must always assume that this is happening under stress. In situations where air supply duration is critical, such as in cave diving, the diver must be capable of making deliberate and successful attempts to control this response.

All divers must be aware of **stress indicators** exhibited in the behavior of other divers. Often early detection of stress behavior and pending panic can avoid a serious situation. In scuba diving, watch for such things as the "wide-eyed look" and changes in breathing pattern, especially rapid, deep breathing or hyperventilation. Rapid, jerky, erratic, and inefficient movements are another obvious sign of diver stress. Anxiety often manifests itself in muscle tension response. The tight grip *white-knuckle syndrome* is an evident sign of stress. During initial open water dive training, instructors often ask students to take a hold of their arm or hand in the event that poor visibility conditions such as silting are encountered. As the visibility deteriorates and the novice realizes loss of orientation, the grip tightens. A diver may recognize subtle anxiety response in themselves by this phenomenon. Tightly gripping the handle of an underwater light is possibly a response to anxiety.

Hyperventilation initiated by anxiety and/or physical stress may result in unconsciousness or muscle spasms as possible consequences of excessive depletion of carbon dioxide with subsequent acid-base imbalance in the blood and body. The diver may not be aware of his pending problem. In water this can result in drowning. Some individuals are more susceptible to low CO_2 tension (hypocapnia) than others; however, loss of consciousness and muscle spasms could probably be induced in almost anyone with sufficiently prolonged hyperventilation.

Various problems in diving such as equipment malfunction, reaction to venomous animal wounds, cold stress, exhausting swims, etc., may cause a diver to panic. A frequent manifestation of panic is *rapid, shallow breathing* (hyperpnea), resulting in insufficient ventilation of the lungs. Subsequently, there is an accumulation of carbon dioxide in the lungs, blood, and body tissues (hypercabia). The diver's situation is further complicated by possible decrease in buoyancy due to inadequate inflation of the lungs.

The onset of the hyperpnea-exhaustion syndrome is indicated by rapid, shallow breathing; dilation of the pupils; inefficient swimming movements; and signs of exhaustion. The diver will experience anxiety and exhaustion. Collapse from exhaustion, unconsciousness, and subsequent drowning may follow. Divers exhibiting the signs or symptoms of this manifestation should immediately terminate the dive, surface, and inflate buoyancy compensator. Tenders and diving partners should watch for signs of distress. This condition may be responsible for some near-drownings and drownings in scuba divers who were swimming on the surface when they apparently lost consciousness.

Irritability or other extremes in mood are good indicators to the tender of a surface diver that the diver is experiencing stress response. In order to mask fear a diver may exhibit *extreme cockiness* before a dive, often making a joke of the entire experience. Others may *withdraw* from the group, remain quiet and, possibly, mentally dwell on the potentially negative aspects of the dive. Divers and support personnel may detect obvious behavior response in a diver suffering anxiety reaction relative to the pending dives before they enter the water. Knowing yourself and your companions is very useful in detecting subtle signs of stress.

Fixation or repetitive behavior is another subtle stress response. Preoccupation with another diver, a depth gauge, pressure gauge, watch, or buoyancy compensator is a common sign of stress in a diver. This may be a sign of either mental or perceptual narrowing. This should not, however, be confused with routine vigilance.

Probably one of the most significant effects of stress on the diver's performance is *making mistakes*. Under stress, performance of basic skills often deteriorates. A stressed diver will make errors in judgment and often becomes careless. Examples of common stress-related mistakes such as putting a regulator on the cylinder backwards, getting hair under the mask, forgetting to don certain items of equipment such as fins before entering the water are just a few of the many that can occur. A diver that continuously makes careless mistakes should seriously consider another avocation or vocation. This may well be a stress response to what would normally be considered routine diving.

PREVENTION OF STRESS

The diver has a capacity to develop a stress tolerance by learning and practicing specific techniques for dealing with stress. Some say that tolerance or lack of tolerance to stress is also an inherent trait. It is probably true that some individuals have a low stress tolerance and that diving is an ill-advised activity for such persons. However, by understanding the sources of stress, the effects of stress, and relating these factors to a diving situation, the diver can develop an ability to prevent or deal with stress.

Keep in mind that it would be impossible to totally eliminate risk from any part of society, let alone scuba diving. Willingness, and even need, to take risks and challenge ourselves can be an important growth and life experience. The decision that a diver must make is, "What is an acceptable risk?" Furthermore, the amount of risk that is acceptable for one individual is not necessarily acceptable for another, as capabilities and desires differ. *Recognition of personal limitation is a sound basis for preventing injury or death.*

One can alter these limitations by improving their capabilities through training, physical conditioning, and progressive acquisition of experience. It is equally important to recognize that capabilities can be reduced due to exhaustion, emotional stress, alcohol consumption, cold, equipment malfunction, and environmental adversities. Individuals can protect themselves by recognizing and admitting to reduced capabilities. Environmental hazards can be reduced by selecting another dive site or waiting for better conditions. Arriving at an acceptable level of risk involves maintaining an adequate margin of safety, and this requires the use of judgment.

Judgment is the process of forming an opinion by discerning and comparing. It means deciding if a particular diving situation is acceptable—safe or unsafe—for a given diver. It may mean postponing a dive. In general, a person who routinely takes risks that exceeds his or her abilities is probably best considered as an unsafe diver. *Exceeding ones abilities may actually be the number one cause of scuba diving injuries and fatalities.*

A diver will generally exhibit a greater tolerance to stress when it is of a type and intensity that can be anticipated. This means that it is very important for a diver to anticipate those aspects of the diving situation which may be stressful. The more familiar the diver is with an experience, the more capable he will be of dealing with it and exhibiting minimum stress. Diver training involves progressive repetitions of both routine and simulated emergency experiences. The more experience or exposure a trainee has, the less likely he is to be stressed by its *unexpected* occurrence. Training should involve numerous *practice experiences* for each skill. Many authorities suggest that a diver must practice such procedures as buddy breathing, octopus breathing, weight belt release, and so on, ten to twenty times in order to achieve a proper level of proficiency that will allow for proper recall and performance under stressful circumstances.

Progressive exposure to real open water diving situations, starting with simple dives under ideal environmental conditions and progressing to more complex and severe situations, is a vital part of training. First exposures to a new experience or environment should be in the company of an individual who is familiar with and competent with that situation.

In some cases, neither experience or simulation is feasible because the situation is too hazardous to practice or too difficult to simulate. Anticipation through *mental rehearsal* is in itself an effective way of combating stress and enhancing performance in a real emergency situation. Unfortunately, many entry level recreational diving trainees are sheltered from adversities that might be encountered in scuba diving. Being uninformed they are not in a position to understand or anticipate adverse conditions that they might encounter in future diving.

A diver should collect all available data about the diving environment he expects to enter. Data is gathered from other divers, personal notes or recollections of previous dives, guide books, and so on. This data is analyzed and committed to memory. *The idea is to avoid surprise.*

Dive planning is a group activity. The dive team moves as a single unit with each member anticipating both the environment and the actions of the other members of the team. The plan must be *sound yet flexible.* Each member of a good dive team will accept necessary modifications or alternatives without *getting uptight.* Individual dissension in a group dive situation can cause unnecessary anxiety and stress for every member of the team.

Following a *group* planning session, every diver should take time to think about the plan and their personal role in the dive. The divers may ask themselves such questions as:

* Does this dive involve new skills or situations?

* Does this dive involve skills that I have not practiced for a long time or conditions which I have not experienced for a long time?

* Am I properly equipped for this dive both in terms of diving equipment and the ability to use it?

* Am I physically and emotionally fit for this dive?

* Am I satisfied with my role in the dive plan?

Each diver and support person should formulate their own list of *self-evaluation* questions. ***Know your capabilities and your limitations and know when to say "NO!"***

Once in the water the diver should immediately establish and maintain orientation. If the route is to be retraced upon return to the boat or shore, observe features that will make the return easier. Always think ahead; anticipate what will happen next. This reduces time pressure. Anticipation through experience, simulation, and good dive planning can do much to minimize stress.

In training for activities that involve some form of stress, the principle of overlearning is an assurance of more effective performance in stress situations. Effective overlearning involves maturing a skill to the point where it can be performed correctly time after time and then practicing it more. Overlearning removes individual "doubt" relative to anticipation performance and stress. It reduces the probability of human error and builds confidence in one's ability to deal with complex situations.

Even overlearned skills are forgotten, often within a relatively short time period, if they are not used on a routine basis. Far too often divers learn emergency procedure skills in a basic course and never practice them for years thereafter. *Divers must develop a skill maintenance program.*

Divers must be familiar with every item of equipment that they are using on a dive. They must know where it is, how it works, and be skilled in its use. This also holds true for a buddy's equipment in scuba diving. Under the behavioral narrowing of stress, the diver does not have time to search for an item of equipment or to figure out how it works. The diver must know this equipment intimately. The divers must familiarize themselves with new equipment in a pool or shallow water.

MANAGEMENT OF STRESS

The diver must learn to recognize and control or, at least, minimize physiological responses under stress. Although the area of physiological control through thought processes is not fully understood, the stressed diver is well advised to take a minute and simply "get hold of themselves." Simply thinking about slowing down may be beneficial in reducing respiration level and heart rate if it appears that the body has physiologically overacted to psychological stress.

Scuba divers must be aware of the problems associated with *hyperventilation*. If the diver notices that he is involuntarily hyperventilating, he should take immediate steps to slow his breathing rate. A scuba diver should notify his buddy and, if the situation cannot be corrected, promptly ascend. When he reaches the surface, he should inflate his buoyancy system. Don't attempt to swim to the boat or shore unaided since unconsciousness may be imminent. A tender should continuously monitor the diver's breathing for signs of hyperventilation. If the diver starts to hyperventilate, he should be asked to stop work and rest. Holding his breath for short periods will aid in replenishing low CO_2 levels and possibly avert further complications. Drowning and the hyperventilation syndrome is discussed in detail by Prasser [16].

The diver must learn to think under stress. The first critical step in thinking under stress is observation and analysis. The diver must quickly assess the situation and decide on the appropriate solution. Unfortunately, an individual will attempt to instinctively or immediately respond. There is ample evidence to suggest that a person will take the wrong course of action under stress. Often the situation is not resolved until the third try. Underwater the person may have only one try. Taking the wrong action, no matter how fast, can be catastrophic.

In a real emergency the first step should be to observe what is happening and look for a solution. Start with the key to underwater survival — breathing. The diver should assure that he has a functional air supply or take immediate action to acquire it. Once the diver has air, the other problems are analyzed and resolved.

In order to think under stress an individual must have self-discipline. While this trait is inherent to various degrees in different individuals, one can instill some degree of self-control through training. The diver must concentrate on solving a problem, not worrying about it. Thinking about anything besides the solution to the immediate problem is very inefficient behavior. Concentration is the key to self-discipline. Underwater problem solving exercises, either while breathing from scuba or during breath-hold dives, is an excellent way to test and develop the ability to concentrate under stress. Unfortunately, modern trends in recreational scuba diver training precludes meaningful problem solving exercises.

In dealing with severe stress most humans have one basic inherent trait — the will to survive. The person who can get out of an apparently impossible situation is the person who believes in trying all the way. This philosophy is exemplified in the motto, *"When faced with dying or achieving the impossible, most will choose to live."*

SUMMARY

A good diver will develop an understanding of the causes and prevention of stress. Furthermore they will be able to recognize stress responses in themselves and companion divers. Good divers know their personal limitations. Social drugs and alcohol have no place in diving. Common sense and good judgment are major factors in safe, stress-free diving.

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Manuscript completed: 1 November 1989
Manuscript revised: 28 December 1989

CHAPTER 5-3

DIVER PROBLEMS AND SOLUTIONS

INTRODUCTION

Modern trends in diver education encourage de-emphasizing the potential problems associated with diving and emphasizing the pleasure derived from diving. In principle, this is a good approach. Instructors use to routinely use *scare-tactics* as a teaching method. Some students were on the edge of panic before they even entered the water. On the other hand, de-emphasis has been carried to such an extreme that beginning divers often fail to understand that a problem can develop, even on the best planned and executed dive.

Before, I begin the discussion of problems, a few words about prevention of problems. Diver problems need never be encountered if individuals simply understand diving and plan their dives. First and foremost, divers must know and observe their personal limitations. Divers must know when to say *"no!"* Good dive planning involves environmental analysis and developing a plan that is consistent with environmental parameters. For example, never struggle against a current when you can avoid it or use it to your advantage.

Equipment must be proper and in excellent working condition. If a BCD fails, it is generally the diver's failing for failure to maintain and test the unit, not the manufacturer's fault. Furthermore, divers must be capable swimmers *without the aid of their equipment.* An equipment dependent diver is asking for trouble. Use your equipment to gain every advantage, but do not let your life depend upon it. In my opinion, I should be able to take-away all of the diver's equipment at midnight at a distance of a mile and a half offshore and that diver should be looking for me on the beach the next morning to express an opinion about my parentage.

Finally, divers must select proper and safe diving companions. This topic is discussed in detail in *Selecting a Scuba Diving Buddy* [4]. Divers assume that their buddies will always be there to assist them. Although, scuba diving safety is based on the concept of mutual support, historically, the buddy system has not worked as well as beginning divers are lead to believe [1, 2, 3].

Most divers problems are encountered on the surface rather than at depth. Analysis of diving fatalities suggest that many of the victims simply could not achieve flotation and solve problems on the surface. Overexertion and inability to deal with surface current are probably major factors in many diving accidents. Divers must be able to recognize problems in themselves and others and execute both self-rescue and second party assistance or rescue procedures.

A skilled, knowledgeable diver will encounter very few problems underwater. If a diver is physically fit, comfortable in the water, and aware of personal limitations safe diving becomes somewhat routine. Combining these factors with the selection of a good diving companion, a properly executed dive plan, and monitoring of air supply leads to pleasurable, uneventful diving.

However, the diver must still be skilled in underwater problem management such as overexertion, air supply loss or depletion, regulator free flow, dislodgment of the regulator from the diver's mouth, mask flooding, loss of buoyancy, uncontrolled buoyant ascent, and entanglement. The diver who is prepared for the unexpected is a good diver. The procedures discussed in this paper emphasize divers' responses to problems. In addition, the individual diver's responsibility in sharing air with another diver is also discussed. Diver assistance and rescue responses will be discussed separately. Procedures for dealing with these situations will also be discussed in lectures and/or skills training.

OVEREXERTION AND EXHAUSTION

Nearly everyone has experienced the "out-of-breath" feeling from working too hard or running too fast. It is possible for divers to exceed their normal working capacity by a considerable margin before the respiratory response to overexertion is apparent. The end result is generally shortness of breath and fatigue. On land, this presents little problem.

In and under water, the problems of exertion are modified by several factors and are considerably more serious. Even the finest breathing apparatus offers some resistance to the flow of air. As the depth increases, so does the density of air, and consequently, it moves through the body's airways with greater resistance to flow. When shortness of breath and fatigue are brought on by overexertion, the diver may not be able to get enough air. The feeling of impending suffocation is far from pleasant, and it may lead the inexperienced diver to panic and cause a serious accident.

Furthermore, a diver's ability to do hard work underwater has definite limitations, even under the best of conditions. Many situations can lead to exceeding these limits and include:

* working against strong currents;
* prolonged heavy exertion;
* wasted effort;
* breathing resistance, especially with poorly designed and maintained breathing apparatus;
* carbon dioxide buildup
* insufficient breathing medium or contamination; and
* excessive cold or inadequate protection.

The diver will realize that he/she is overextended by recognizing such indicators as labored breathing, anxiety, and the tendency toward panic that accompanies the overexertion feeling.

If the diver feels the typical *air hunger* and labored breathing starting to appear, he/she should do the following:

* Stop, rest, and ventilate to get a maximum flow of air. Breathe deeply.
* Inform the buddy, if possible.
* If underwater, do not surface rapidly — terminate the dive with a slow, controlled ascent.
* Upon reaching the surface, the diver should inflate the BCD and return to the boat or shore, or if too exhausted, ask for buddy assistance or signal for immediate pickup by the safety boat.

Overexertion can be prevented if divers know and observe their personal limitations, take into consideration the working conditions, and plans the diving operation accordingly. For example, plan the dive so that you can move with the current and not against it. Divers should keep themselves in good physical condition and equipment must always be maintained in excellent working condition. Be alert for signs of fatigue!

Surprisingly, distressed divers sometimes forget the simplest form of self-rescue — inflating their own buoyancy unit. During training divers must condition themselves to inflate their BCD upon reaching the surface and not support themselves by holding onto the side of the pool or a lane marker. *The swimming pool must be imaged as an ocean.* A comfortable, properly weighted diver should never have to struggle or expend considerable energy to remain afloat. During times of exertion and environmental stress, the diver must be prepared to recognize personal performance degradation *on the surface* and take immediate action to assume a positive flotation mode.

CAUGHT IN A CURRENT

Occasionally a diver will encounter an unexpected current. However, such encounters should be rare if the diver uses common sense when planning a dive and analyzes the environmental conditions. More often divers carelessly find themselves adrift in a known current. Currents are routinely encountered at many dive sites and prudent divers plan their underwater swim accordingly.

Unfortunately, novice divers may become disoriented and frightened if they find themselves being carried away from a boat or staging area by a current. In their distress they often attempt to swim back to the boat against the current.

They may quickly fatigue and even panic in a futile attempt.

The exact procedure for dealing with a current is diver and situation dependent. The guidelines presented here are intended to establish a thought pattern that can be used to resolve problems in a variety of situations. First, the diver must use prudent diving procedures in order to avoid problems in the first place. When diving in a current from an anchored vessel, divers generally descend on the anchor line and swim into the current rather than drifting behind the vessel. Using bottom features and compass navigation, divers can then return to the anchor line for ascent. Most divers deploy a *trail or current line* (100 to 300 foot floating line) behind the vessel for use in the event that a diver drifts past the anchor or looses hold of the anchor line.

Second, prudent divers will never leave the vessel unattended. Larger diving vessels often carry small *chase boats* which may be deployed for diver pickup. Individual divers carry a signaling device such as a whistle or special air activated horn attached to their BCD inflation hose. The air horn can apparently be heard up to one mile away.

In addition, divers who routinely swim in high current environments carry some type of bright visual signal device. A large white, yellow, or orange plastic garbage bag may be inflated with air to provide a large visual signal that stands out on the blue water surface (white is least desirable if there are white capped waves). Others will carry a long yellow tube that may be inflated and held upright. Both of these items easy fit in a BCD pocket. I have encountered a few divers who have carried a small shiny stainless steel mirror in their BCD pocket. Bright flashes of light reflecting from the mirror may attract attention of observers on the boat or shore.

Military scuba divers and surface swimmers carry a combination Day-Night Flare that emits orange smoke from one end and a red flare from the other. Unfortunately, these items are generally not available to recreational and scientific divers. However, a small 30-second orange smoke signal is available at some backpacking stores. This smoke signal is about the size of a 35mm file canister. To activate the top is removed and a tab is pulled to ignite the flare. Once activated it may be set adrift on the water surface. *If you attempt to use this type of flare, be certain to read the instructions.* Also, they are not designed for submergence, divers must carry them in a small waterproof-pressure proof container. Be certain to deploy the signal down wind.

If adrift in a strong current, do not attempt to swim against the current. If operating from a shore base, you may wish to swim perpendicular to the current or even drift diagonally down current toward shore and walk back to your staging area. *Inflate your BCD and do not "fight" the current.*

In some cases when carelessly diving from an anchored vessel you might surface down current. If the current is not too strong, if you have sufficient air supply, and if the water is shallow, you may be able to return to the boat underwater. At the surface take a compass bearing on the boat, submerge, and establish orientation on the bottom. The current is often much less at the bottom (friction) and you may be able to use rocks to pull yourself along with your hands. Do not stay in mid-water where the current is stronger. Monitor you air closely so not to exhaust your air supply underwater and further complicate the situation. Ideally, it is still best to signal for a pickup boat if one is available.

LOSS OR FLOODING OF FACE MASK

The self-contained diver must learn to swim underwater without a face mask and how to purge water from the mask in the event of flooding. If the mask becomes dislodged and partially or completely fills with water, it should be repositioned on the face and purged of water by tilting your head backwards to place the lower edge of the mask at the lowest position. Then, press the upper portion of the mask firmly against your forehead and exhale into the mask through your nose. The exhaled air will displace the water and force it out under the lower edge of the mask.

If the mask is equipped with a purge valve, simply position the head so the purge valve is in the lowest position relative to the rest of the mask and exhale through the nose. Some divers prefer to press the top portion of the mask against the face while purging to limit the loss of air.

During training you will be expected to perform a number of no-mask and mask purging exercises. Unfortunately, some divers find swimming without their mask distasteful and attempt to avoid such exercises. I can not over emphasize the importance of mastering this skill, both physically and psychologically. I recall one diver who was apparently able to complete not only entry level training, but also received advanced and several specialty diver certifications. She was unable to endure mask removal underwater. During open water training for a specialty course she was required to remove the mask. She did so with great hesitation and almost immediately shot to the surface while holding her breath. Only the rapid response of the instructor probably saved her from severe pulmonary barotrauma.

PURGING WATER FROM THE BREATHING SYSTEM

There are various methods of purging water from flooded mouthpieces and hoses. Each method should be mastered. The simplest method is to place the mouthpiece in your mouth and exhale. This will generally purge the water from the assembly and restore free breathing. Inhale cautiously following the purging procedure to be sure that all water is out. When purging the single-hose regulator, position the exhaust valve so that all water will drain through it. This may require the diver to look straight ahead or tilt their head slightly backward.

If you do not have enough air in your lungs to expel the water, you will have to use the *free-flow method*. Raise the mouthpiece to your lips and initiate free flow by depressing the purge button. Insert the mouthpiece into your mouth while free flowing and resume breathing. An alternate method of purging a single-hose regulator is to place the tongue into the air inlet opening and depress the purge button. The water is forced out through the exhaust valve.

The diver should be alert for the cause of the flooding of the system. Some problems such as damaged to the diaphragm or exhaust valve may result in continued flooding and hamper successful clearing of the system.

RECOVERY OF LOST MOUTHPIECE

Single-hose regulators generally lead over the right shoulder. If the mouthpiece is dropped out of sight, you can reach back, feel the first stage of the regulator, and follow the hose to the second-stage mouthpiece.

An alternate method of mouthpiece recovery is to turn with your right side down and your right arm against your body. The regulator mouthpiece should then be hanging below you. Return to your normal swimming position and sweep the right arm in an arc. The regulator should be within grasp or in front of you at this point.

FREE-FLOWING REGULATOR

Modern regulators are very reliable and malfunctions resulting in loss or termination of air supply are very unlikely. Most regulator second stages are designed with downstream valves. In the event of malfunction, the regulator is more likely to free-flow. Regulator icing in extremely cold water can also result in free-flow. In addition, some regulators are very sensitive and will free-flow if only slightly out of adjustment.

You can still breathe from a free-flowing regulator. However, do not seal your mouth on the regulator mouthpiece; the continuous free-flow could cause lung over-pressure with subsequent barotrauma. Rather, press the regulators to the outside of your lips. You can breathe and let the excess escape around the edge of the mouthpiece.

Signal your buddy and begin ascent immediately. Your air supply will be depleted quite quickly through a free-flowing regulator. I recall one accident investigation which involved a regulator free-flow in cold water. A diver's regulator began to free-flow at a depth of about 100 feet. Apparently, the diver had been taught that if your regulator malfunctions, share your buddy's air. The diver dropped the regulator second-stage and signaled for buddy breathing. Neither diver had an alternate air source. The attempt at buddy breathing was unsuccessful and the diver attempting to supply the air apparently could not replace and purge his regulator. He made a rapid, non-breathing ascent to the surface and experience pulmonary barotrauma. The diver who was initially in distress remained on the bottom and drowned. The free-flowing regulator hung at his side.

When you reach the surface, turn off the air and do not use the regulator again until the cause of the free-flow has been corrected. Keep your regulator clear of sand and other debris and have it serviced on a regular basis and you should never have a problem. Regulator icing, emergency procedures, and de-icing procedures are covered in ice diver training.

LOSS OF BUOYANCY

Modern trends in diver education have de-emphasized watermanship and physical fitness while encouraging equipment dependency. Accident analysis have shown that some individuals, especially poor swimmers and people who are not comfortable in the water without equipment aides, have apparently been unable to cope with buoyancy unit failures. Unable to maintain buoyancy, the distressed diver panics, sinks below the surface (or to the bottom), and drowns. Unfortunately, emphasis on the ease of diving with modern BCDs has also fostered overweighting of divers, primarily through carelessness and lack of appreciation for proper diving techniques.

In the event of BCD failure, a diver may normally attain positive buoyancy by releasing of the weight belt. The weight belt must be considered *expendable*. Training exercise must include weight belt release as an emergency procedure. One word of caution! Some scuba cylinders are extremely negative buoyant even when the air supply is depleted. I have seen a few divers in full foamed neoprene wet suits who require BCD assistance to maintain neutral buoyancy at the surface. In such cases, the scuba may have to be discarded if the BCD fails.

The diver must also be trained in oral inflation of BCDs. In the event that the BCD inflation mechanism fails, buoyancy may still be achieved through oral inflation. In the past most BCDs were also fitted with an auxiliary CO_2 inflation unit. However, modern trends in BCD design and manufacturing have made this an optional accessory and, in some BCD models, precluded it as an option.

UNCONTROLLED BCD INFLATION

Modern scuba diver buoyancy control devices (BCDs) receive air supply from the scuba cylinder via the regulator. In some models of BCD inflators it is possible for a malfunction to result in continuous and uncontrolled inflation of the BCD underwater. The BCD may be filled to maximum capacity within a few seconds and the diver is propelled out-of-control to the surface by the increased buoyancy. Large volume BCDs can produce more than 50 pounds of positive lift. I recall one case where the diver experienced uncontrolled BCD inflation at a depth of 80 feet and was carried out-of-control to the surface in a few seconds resulting in a loss of more than 1200 pounds of air from his scuba cylinder before the inflation hose could be disconnected. The best prevention of uncontrolled BCD inflation is proper preventive maintenance of the BCD and inflator mechanism.

The diver can do very little except exhale in the event of instantaneous BCD inflation. *It causes a rapid positive buoyant ascent requiring continuous exhalation.* The diver should also attempt to disconnect the hose from the inflator mechanism. However, this procedure (rapid disconnect) is seldom if ever practiced in scuba diver training and is more difficult if the diver is wearing neoprene gloves.

LOSS OF AIR SUPPLY

Loss of air supply is probably one of the most feared and often overemphasized problems in diving. In reality, this is a rarely a problem. If a diver only uses a reasonable degree of care in dive planning and pressure gauge monitoring, the need for an emergency response can be avoided. Equipment malfunctions that result in loss of air supply are extremely rare. Unfortunately, some divers are careless and do not monitor their pressure gauges. These are divers at risk!

In the early years of diving, the diver faced with an air supply depletion or loss had two alternatives — buddy breathing or a controlled emergency swimming ascent. These skills were mastered during training. In reality, buddy breathing (single regulator method) really did not work that well for the general population. Successful buddy breathing depended on the response of *two* skilled, calm divers who had practiced and perfected the skill. This also meant that the divers had to review and practice the skill on a periodic basis. For competent divers, buddy breathing was an acceptable alternative. However, there are numerous accounts of buddy breathing failure and even double drownings that may have resulted from such failures.

On the other hand, the controlled emergency ascent (often called a free ascent in early days) was an independent emergency response. This procedure did not require coordination with another diver. It did not put another diver at risk. With a little practice, a calm, competent diver could easily ascent from normal scuba diving depths. However, this means of emergency ascent was considered a high risk activity to practice due to the fear of pulmonary barotrauma.

U.S. Navy diving authorities and many diving physicians felt that the risk was too high for civilian divers to practice the skill during training. They certainly endorsed the skill as an acceptable alternative in an emergency, but feared training exercises. They pointed out that Navy trainees practiced under controlled conditions, were supervised by a medical officer, and a hyperbaric chamber was immediately available.

The controversy raged for nearly two decades and some individuals are reluctant to perform the exercise even today. Numerous methods of lower risk simulations were devised by instructors. Incidents of pulmonary barotrauma did occur during training, however, they were very rare considering the number of practice ascents made by a growing recreational and scientific diving population. Today, controlled emergency ascent training is a mandatory skill in scuba diver training.

Keep in mind that if you act calmly and promptly when you experience an initial resistance to air flow, you may be able to complete a normal ascent with the small amount of air that remains in your scuba. In such cases, signal your diving companion that you are low on air and indicate immediate ascent (thumb up). Relax and breath slow and shallow. As you ascent more air will be available from your cylinder due to the increased pressure differential between the air inside your cylinder and ambient pressure.

Wouldn't it be better to share your companion's air supply? In most cases, yes! However, if your companion is also low on air, this places two divers at risk. The use of this procedure is a judgment call based on the experience of both divers, the environmental condition, and the situation. *Monitor you pressure gauge so you never have to make this decision!*

Alternate Air Sources. The alternate air source (AAS) has evolved into the preferred means of resolving an out-of-air supply emergency in today's scuba diving community. There are actually two categories of alternate air sources — the shared source and the independent source. The shared source, or octopus, is most commonly used today. Scuba regulators may be fitted with two second stage assemblies — a primary and an alternate. Alternate units may be either a separate second stage regulator or a combination second stage-BCD inflator. Many divers prefer the latter due to the requirement for one less hose on the scuba regulator.

The method of air sharing depends on the the type of air source. Divers using a completely separate regulator AAS will retain their primary second stage and provide the AAS second stage to the distressed diver. Once the distressed diver has established breathing control the divers will grasp each others right forearms in order to reduce the possibility of separation and dislodging of the mouthpiece and make a controlled ascent to the surface. Each diver is responsible for observing their respective view sector for obstructions as well as the other diver. Many divers will fit their AAS second stage with a longer hose (32- or 36-inches rather than the standard 28-inch hose).

For years there has been a controversy regarding which regulator the distressed diver is to receive — the donor's alternate or primary. Some authorities maintained that it was more psychologically assuring for distressed divers to receive a second stage that they know is operational — the primary. Furthermore, the primary second stage is most immediately available. On the other hand, a number of other authorities have suggested that the donor should not be placed at additional risk by removing the primary regulator from their mouth. This way both divers must deal with regulator purging and re-establishment of breathing control. *In recent years more and more authorities appear to agree on giving the alternate second stage to the distressed diver.*

Unfortunately, most combination second stage-BCD inflator AASs have too short of hose to allow for passage to a distressed diver. In this case, the donor must give the primary unit to the distress diver and re-establish breathing using the combination unit.

Unfortunately, AASs may be attached to the diver's equipment in a number of different ways or even placed in a BCD pocket. There is no standardization. Accident investigations have revealed that several serious accidents resulting from air supply loss or depletion involved situations where *the donor could not find the AAS second stage at the time of need.* In my opinion, the AAS must be secured with a quick-release device in the mid-chest area. If it is carried in a pocket, the pocket must be fitted with a special quick-opening mechanism and the diver must practice retrieving the AAS. Velcro-secured pockets can be quite difficult to open, especially underwater with neoprene mittens. Above all, do not let the AAS drag at your side where it can collect sand and mud.

Because of variations in second stage configurations be certain that you place the unit in your mouth in the proper position. If the regulator is upside down, you will have difficulty purging it and may inhale water.

Keep in mind that if one member of the dive team experiences an out-of-air situation, the companion diver may also be low on air. Now, with both divers sharing the same air supply, the demand for air is doubled. Furthermore, the natural stress and anxiety associated with such an incident is bound to increase respiratory demand in both divers. The remaining air supply in the donor's scuba may be depleted quite quickly. And, even before depletion as the air supply gets low the simultaneous respiratory demand of two divers may exceed the delivery capability of the regulator. As you can see, this standard type of emergency ascent is not without some potential complications.

Independent Scuba AAS. The independent AAS is available in several different configurations. The most common unit, popular among wreck divers, is a small auxiliary scuba containing 15 to 40 cubic feet of air. The auxiliary scuba is attached to the primary scuba in various ways. In this case, a diver may rely on their own emergency air supply or provide it to another diver in the same manner as described above. The auxiliary scuba is more cumbersome to handle, offers increased resistance when moving through the water, and cost more initially and for periodic maintenance.

An increasing number of serious cave and wreck divers are using two independent scubas of equal capacity. Two large capacity scuba cylinders are mounted in a double backpack. Each cylinder has an independent regulator and pressure gauge. The diver must use an air management scheme that requires switching back and forth from one cylinder to the other during the dive in order to assure that each retains a satisfactory reserve supply. Although this procedure is more complicated and requires strict discipline, most divers working in overhead environments feel that the merits outweigh the disadvantages.

One manufacturer markets a compact emergency scuba. This unit consist of a small aluminum cylinder with an combined regulator-valve assembly. The unit contains only a small volume of air and can be rapidly depleted, especially if the diver is in deep water and at high respiratory demand. Although the concept is excellent, limited air volume and high cost have probably been responsible for the limited acceptance of this AAS at this time. Divers using these units should receive special training and practice in order to completely understand the use, merits, and limitations of these units.

Controlled Emergency Swimming Ascent. Learning the technique of controlled emergency swimming ascent will be an important part of your training; however, this ascent procedure should only be used as a last resort to resolve an emergency situation. This ascent procedure is used when the air supply is completely exhausted or unavailable due to scuba malfunction and another diver is unavailable or unable to assist you. Sharing another diver's air supply is generally the procedure of choice. *An emergency swimming ascent can be hazardous and difficult to accomplish safely in situations of stress. Nevertheless, this procedure is probably the one that will save your life someday.*

Unless the breathing apparatus is hopelessly entangled, the diver should never abandon it even though it may be useless. The diver should not initially drop his/her weights unless negative buoyancy is obvious and precludes ascent. *The diver must begin exhalation prior to starting the ascent and continue to exhale throughout the ascent.* Some authorities recommend that the diver make a continuous *A-a-a-a-h-h-h* sound throughout the emergency ascent. The suggest that this method allows the diver to exhale enough air so that lung damage is avoided and prevents exhalation of too much air. The exhalation should not be so forceful as to completely empty the lungs to residual volume (point where no more air can be exhaled). This may result in small air way collapse and subsequent air trapping. Ideally, the lung volume is maintained at a level that is neither full nor empty. The head is extended back. This allows maximum opening of the airway and a good overhead view.

The diver should swim to the surface at a controlled rate, constantly being aware of possible entanglements or obstructions, and of the consequences of breath-holding. The diver looks upward throughout ascent and extends one hand overhead. In the past, divers have been trained not to exceed 60 feet per minute during emergency ascent. I truly doubt that you will be watching your instruments during an emergency ascent. The key is control versus out-of-control! The mouthpiece should be left in place. The weight belt should be dropped if the diver is having difficulty swimming to the surface. Inflate BCD and/or drop belt at the surface to facilitate staying afloat.

Training for controlled emergency swimming ascent is a serious and hazardous exercise. Students should make proper supervised ascents in a swimming pool first. The mouthpiece should be left in place. Long emergency ascents may be simulated by having the trainee swim the length of the pool while exhaling in a controlled emergency swimming ascent fashion. The same procedures should be followed if emergency ascent training is conducted in open water. The instructor and trainee should surface facing each other with the instructor holding and controlling the trainee through all phases of the ascent. The instructor may stop the ascent at any time in which case the trainee will simply take a breath from the regulator. An ascent line is used for stability, orientation, and control. Practice first in shallow water and progress to deeper water at the discretion of the instructor.

In desperate emergency situations where the diver feels that he/she may lose consciousness, etc., it may become necessary to make a positive buoyancy ascent with increased risk of entanglement, injury, and air embolism. This is accomplished by dropping the weight belt and/or inflating the BCD.

The ascent will be slow at first but will become more rapid as the wet suit and BCD expand, especially near the surface. A few kicks may be necessary to initiate the ascent. Positive-buoyancy ascents are to be used only in a life-or-death situation, and no other! Remember, in all emergency ascents, exhale continuously throughout; the possibility of air embolism is always present.

Modern divers have become extremely dependent of the buddy system to resolve loss of air supply emergencies. The sharing of air may or may not work in all cases. Recent diving accidents bear this out. In early years of scuba diving some authorities suggested that scuba divers should be limited to a depth from which they could make a successful controlled emergency swimming ascent. In fact, some scientific diving programs required demonstration of this capability in the ocean before a diver could advance in depth rating.

The controlled emergency swimming ascent is independent of other divers therefore does not require a coordinated skill effort nor places another diver at risk. It requires no additional or special equipment. There is no initial purchase or periodic maintenance cost. It is always available, except in cases of entanglement or when working in overhead environments. *However, it carries the highest risk of pulmonary barotrauma of any of the emergency ascent procedures.*

Single Regulator Buddy Breathing. In the event that an alternate air source is not available, it may be necessary for scuba divers to share a single air supply (buddy breathe) in the event of air supply exhaustion or equipment malfunctions. There are several methods of sharing air and the diver must use the one best adapted to the situation. Generally, air sharing is necessary only for direct ascents. The divers simply face each other and exchange the mouthpiece of the operative scuba while making a slow, controlled ascent.

When sharing air with a single-hose regulator, the diver providing the air should be slightly to the left (when facing the diver without air). Do not fill your lungs and then hold your breath while your buddy is taking a breath! Remember you are ascending and you must continue to exhale as you rise to prevent air embolism. The diver supplying the air should always retain control of the mouthpiece and grasp the harness/BCD of the distressed diver. The donor is generally in a better position to regulate breathing cycles and to control the ascent than the diver who has experienced air supply failure.

When working in caves or under ice, divers may find it necessary to move in a lateral direction before ascending to the surface. In this case the diver wearing scuba containing air swims with the right side down. The distressed diver remains in a normal prone swimming position with the donor to the right. Exchanges are made as above. This technique is often used in confined water practice sessions. Divers entering overhead areas are cautioned to always use approved AASs and never rely on sharing a single regulator.

Sharing air under emergency conditions is difficult even for the best trained and most experienced divers. Divers should practice the skill frequently. Furthermore, the use of auxiliary breathing systems or AASs is preferred.

SURFACE PROCEDURES FOLLOWING AN EMERGENCY OR UNCONTROLLED ASCENT

Upon reaching the surface after emergency ascent, or when in trouble at the surface following a normal ascent (rough water, exhausted, etc.), inflate your BCD and signal for pick up. When a long distance from assistance, it may be necessary to use the signal device or whistle to attract attention. The surface crew should be alert for divers in trouble at all times.

Do not descend (or allow another diver to descend) and continue diving following an emergency or uncontrolled ascent. With the BCD inflated, return to your surface craft or shore base. Observe for signs and symptoms of pulmonary barotrauma for at least 30 minutes. Also, if the ascent resulted equipment malfunction, be certain that the equipment is repaired or replaced before future diving.

If the breathing apparatus interferes with surface swimming, you may wish remove the equipment and tow it. Modern trends in equipment design have almost universally incorporated the buoyancy system and scuba as a single unit. Unfortunately, long distance swimming wearing scuba, especially under adverse conditions or when the diver is already exhausted, can be quite stressful and lead to further diver degradation. I would personally prefer to retain the buoyancy system on my body and safe myself rather than saving the scuba in an emergency. Under certain circumstances the diver might consider dropping the scuba cylinder and retaining the BCD, however, to my knowledge this procedure is not endorsed or taught in recreational diver training programs. Obviously, such actions require the diver to evaluate the situation and make survival decisions.

ACCIDENTAL RELEASE OF SCUBA CYLINDER FROM BACKPACK/BCD

Today there are numerous styles of cylinder retention devices on BCDs. Unfortunately, if some of these devices are not properly assembled, the scuba cylinder may release from the BCD without warning either on the surface or underwater. Divers should experience accidental scuba cylinder release underwater during training and learn to respond to such problems. If the cylinder does release underwater, simply remain calm and hold the regulator in your mouth with one hand if there is a strain on the regulator. Ideally, your buddy will respond and replace the cylinder.

If your buddy is unavailable or does not respond you will have to resolve the problem yourself. Unfortunately, there are so many different cylinder retainer designs it is difficult to formulate a universal procedure. A skilled diver on a firm bottom may elect to simply remove the BCD/scuba and reposition the cylinder underwater. However, the diver must be certain to discharge all air from the BCD prior to removal so that it doesn't float upward when removed. Always retain the mouth piece in your mouth. In other cases the diver may elect to hold the scuba in place by grasping the hoses and cylinder (if possible) and swimming to the surface for assistance or reassembly.

The major consideration is to remain calm, keep the regulator in your mouth, and monitor you air supply. In one fatal diving accident resulting from this type of mishap, a mother and her son apparently remained on the bottom attempting to reassemble the unit. The both depleted their air supplies and drowned. They would have both survived if they had simply remained calm and carried the scuba cylinder to the surface.

CRAMP RELEASE

At one time or another any diver will have to release a cramp. Cramps most commonly occur in the foot or calf muscles. The cramp is often preceded by a distinct twitch or unusual muscular contraction. Slowly stretch the affected muscle by grasping the sides of the fin with both hands and gently pulling the toe toward the knee. Massaging or kneading a cramped muscle may also help. Relax and very lightly exercise the affected leg after the cramp is released. Change to a different kick and/or stroke. Thigh cramps are more difficult to release in the water. On the surface the buoyancy unit should be inflated if the cramp is at all severe and remain inflated until the diver is ready to resume normal activity.

ENTANGLEMENT

Entanglements are rare in routine scuba diving. However, divers must be emotionally and physically prepared to deal with an entanglement, especially when swimming around piers and shipwrecks. The diver's knife is his/her best safeguard in an entanglement. The entanglement situation generally requires more thought than action. Do not struggle; this may only increase the degree of entanglement. This is where the buddy system is useful. The buddy can carefully cut the entangled diver loose. If a buddy is unavailable or unable to assist, systematically feel for and remove line or net from equipment and extremities. Cut with caution in order to avoid personal injury. Only as a last resort should the diver remove his/her breathing apparatus and attempt an emergency swimming ascent to the surface.

CONCLUSIONS

Problems and emergencies are actually rare in diving. However, every diver must be prepared to deal with the unusual and unexpected. Problem prevention is better than problem solution. Through the use of proper, well maintained equipment and training the average diver can avoid most problems. Furthermore, selection of good diving companions can reduce the possibility of problems introduced by the carelessness of other individuals.

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Manuscript completed: 2 January 1990; Revised: 5 February 1990, 7 February 1990

CHAPTER 5-4

COMMON SENSE DIVER RESCUE

INTRODUCTION

The emphasis placed on diver rescue training in entry-level scuba diving courses varies considerably throughout the diving instruction community. Most training agencies and instructor training agencies consider diver rescue to be an *advanced skill* and include little or no rescue training in the entry level course. Many instructors recommend that divers never attempt a *contact* assist or rescue unless they have completed special training in an advanced diver rescue course.

In theory, this is an excellent recommendation. However, in reality, most students never enroll in advanced or specialty diver training courses following entry level training. They simply go diving. Consequently, many, many scuba divers have little or no formal rescue training.

What would you do if your diving companion was in distress? Call for help? Panic? Watch? *Human nature will not generally enable a person to simply standby and allow another to die. Most divers, whether trained in rescue or not, will attempt to save a distressed companion.* I feel that every diver, regardless of training level, must understand the fundamental principles of diver rescue. Furthermore, I feel that it would be wise for diver training organizations to re-evaluate their position on elementary assistance and rescue training at the entry level.

The following information is intended to serve a number of purposes. First, it is a simplified progressive approach to diver rescue that any instructor can incorporate into a entry level scuba diver training program. It can be presented as a single *rescue session* or various skills can be intrgrated progressively throughout the complete course. Secondly, the individual diver can use this as a guide to evaluate their level of competence in diver rescue preparation. If they find that they did not receive training in the skills described, they should enroll in an advanced or specialty course. In my opinion, the skills presented are *minimum* requirements for safe diving.

Third, in the event that the diver cannot enroll in a formal course, a buddy team can use this presentation as a self-teaching guide. *Although this self-teaching approach should never be considered as a substitute for formal training, it is better than no knowledge or skill at all.* Self-taught divers are encouraged to seek professional training as soon as possible. ***Keep in mind that any time you attempt a contact assist or rescue you are risking your own life!***

Fourth, this presentation can be used as an information guide for non-diver watersafety or lifesaving instructors in order to better understand the rescue techniques that can be used when the rescurer and/or the victim is equipped with skin and scuba diving equipment.

PSYCHOLOGICAL PREPARATION

Rescue training is not just the acquisition of physical *skills*, it is the development of a philosophy. A fundmental principle of diving is *"to never place yourself in a situation where you will be either a rescurer or a victim!"* This doesn't mean giving up scuba diving. To the contrary, it means do more diving! The best way to become a good, safe diver is to *go diving*. Experience is a great teacher! Simply the repetition of preparing for a dive and going diving, whether in a pool, at a local quarry, or at a Carribbean resort makes you a better and safer diver. I encourage all divers to go diving as much as possible, even if that dive is only in a swimming pool.

Each time you go diving, analyze your personal performance, the condition of your equipment, things that made you uncomfortable, the performance of your diving companion(s), your personal emotional response to the situation, and so on. Be honest with yourself! But most important, correct anything that isn't just right. This means adjust your equipment straps to be comfortable and functionable, repair a regulator that is leaking air or water, help your diving buddy correct habits or mannerisms that make you uncomfortable, and the like.

Also, do not dive without the necessary equipment. For example, some divers still dive without an alternative breathing unit (or octopus). The excuse is that it is too expensive, it gets in the way, "A good diver will never have to use it!" or "I don't need it, I learned to buddy breath!" This type of attitude is not valid. Yes, ATTITUDE! *Attitude and emotional comfort are as fundamental to safe scuba diving as the regulator.* If you *KNOW* that you and your companion *BOTH* have the capability to supply air to the other in an emergency, the "quality of emotional diving experience" as well as your own personal safety is greatly enriched. You say, "my buddy won't buy an alternative breathing unit." Find a new buddy! This is only one of many factors that you learned in your diving course that you have to consider with regard to attitude.

Another fundamental principle of diver rescue preparation is the selection of that buddy. In an ocean environment, ***"Could you rescue your buddy?"*** First of all, that buddy must be properly trained, adequately equipped, sufficiently experienced, and physically/emotionally prepared to dive. You must determine this prior to each dive. If any of these factors are deficient, the possibility of a *rescue situation* occuring is greatly increased. Such things as inadequate or malfunctioning equipment could greatly compromise the rescue procedure.

Just as important, *"Could you physically handle that person in an emergency rescue situation?"* Let's assume that you are a 98 pound petite female wearing an 80 cubic foot scuba. Can you honestly say that you could execute a complete and satisfactory rescue of a 220 pound muscular male? This is not intended to be a sexist question at all. I am only interested in your personal safety and well-being. With training, proper equipment, and *practice*, you can develop unique rescue skills. However, you will never know until you try it. And, big buddy, "Don't be easy on this smaller person in the practice session!" Remember that both lives in the future may depend on honesty *NOW*.

Another consideration is, *"Could you get this unconscious, non-breathing diving buddy onto a beach through surf or into a boat and administer CPR if there was no one else to assist?"* Try it! Please understand that failure to perform such feats does not mean that you must stop diving with this person. What it does mean is that you may require special training and diving procedures. For example, do not dive as just a *two person* team. Visibility permitting, dive as a four person team or with a guided group! If you are on a guided tour and are unsure of your abilities, remaining in the vicinity of the dive guide is a reasonable consideration.

Rescue practice can be fun, "eye-opening", and fundamental to safe diving. And, all of this starts with an objective attitude toward diving and diving safety.

SUPPLEMENTAL PERSONAL SAFETY TRAINING

A diver will not learn basic lifesaving, first aid, and cardiopulmonary resuscitation (CPR) in most entry level or, even advanced level, scuba diving courses. I feel that all divers must be trained in first aid-CPR and should have at least some formal training in basic lifesaving and water safety procedures.

MENTAL ATTITUDE AND PHILOSOPHY

Keep in mind that the *"it won't happen to me"* attitude has lead to disaster for more than one diver. So, start your mental preparation now. The next step is to learn how to take care of youself in a stressful situation. *And, most essential to taking care of yourself is your ability to say such things as "NO!", "I CAN'T DO THIS!", "I WON'T DO THIS!", or "LET'S RETURN TO THE BOAT OR SURFACE!"*

When you take the necessary steps to remove yourself from the threatening or stressful stiuation, your are performing a form of rescue — self-rescue. The key is to not wait too long to make such a decision. The decision may be made at the time you observe the diving situation and note an increase in emotional stress as you observe other divers experiencing difficulties, high surf, fast current, and the like.

DRY PRACTICE

Most rescue skills are easier to learn if the divers *walk-through* the skill in the classroom, on the pool deck, or in shallow water before practicing the skill in deep water. The first rescue preparation skill is actually an activity that should be performed prior to each scuba dive – a safety check of your and your buddy's equipment. I am certain that you learned this in your scuba diving training sessions.

In preparing for a dive you should locate and test certain items of equipment. First, locate and operate your buoyancy control device (BCD) oral and power inflation components. If your BCD is fitted with a CO_2 inflation unit, you can simulate activation of the CO_2 inflation device in order to reduce the expense of CO_2 cylinder replacement. Locate, release, and drop your weight belt away from your body. For deck practice you can use a belt without lead weights. Repeat all of these procedures with your eyes closed.

Next, stand facing your buddy and locate his/her BCD oral, power, and CO_2 inflation devices. Now, operate each of these devices. Again, you can simulate activation of the CO_2 inflation unit. Repeat these exercises with your eyes closed. Next, locate and release your buddy's weight belt both with your eyes open and closed. Remember to pull it away from the body and drop it.

Next, as you approach your buddy, have them reach for you. First, block and grasp the outstretched arm at the wrist with your hand on top of the wrist. Grasp right arms with right hand or left arm with left hand. Now, pull the your buddy toward you and, at the same time, turn them so that they are facing away from you. Immediately grasp your buddy firmly in the arm pit and exert a sight upward force. At the same time move your initial contact hand upward to grasp your buddy's bicep.

This is a good place to start learning about self-protection and distressed diver control which will be discussed in more detail later. When inflating your buddy's BCD grasp him/her in the left arm pit with your right hand and operate the inflation mechanism with your left hand. Experiment with position relative to your buddy and ease in handling the equipment. The arm pit grasp should be *firm* enough to simulate support and control of the buddy in the water.

Instructors, keep in mind that dry land and shallow water exercises are extremely beneficial in that they allow you to more easily demonstrate the skill, observe and correct student mistakes, build student confidence, and save valuable pool time. If your pool time is limited, have the students bring their BCs and weight belts to the classroom where you can practice walk-throughs of most of these rescue procedures. The student can also be encouraged to practice at home with their classmates. Keep in mind that dry land or shallow water walk-through practice can and should precede deep water practice of most of the skills described below.

IN-WATER PRACTICE

Naturally, all skills must be practiced in the water. However, experience suggests that practicing with mask, fins, snorkel, and BCD is the most effective way to introduce the student to rescue skills. Most diving accidents requiring a rescue procedure occur at the surface. Since the rescue procedures used for a distressed scuba diver are basically the same as those used in skin diving, initial practice without the scuba simpler and more effective. Once the skills have been mastered in the skin diving mode, the students can practice all or selected skills while wearing scuba.

SELF-RESCUE

You have already been introduced to the mental aspects of self-rescue. Now, let's proceed to developing some skills. The skill training will follow a logical progression starting with self-rescue and proceeding to more complex second party rescue and defensive techniques. Hopefully, this progression will develop a *response pattern* that will enable the diver to initiate rescue procedures with the most simple response first and then progress to more demanding alternatives if the situation so dictates. Always remember, work from the simple to the more complex procedure!

I will often present the rescue procedure as if you were a "diver-in-distress" in order that you might create a mental image of real ocean situations. In this way you are not only developing a physical skill, you are also forming a thought pattern to assist you in dealing with real emergencies. Through *role playing* you can make your confined water learning experience much more effective.

The first important consideration in self-rescue is wearing a BCD. It should be noted that many divers *do not* currently wear BCDs while skin diving. I suggest that this is, in part, the result of modern trends in jacket-type BCD design. The larger and more cumbersome BCDs that are designed to be attached to the scuba cylinder are, for the most part, less comfortable for skin diving. The diver often leaves the BCD/backpack combination in their equipment bag rather than go to the trouble of removing the backpack or swimming with it attached. I cannot endorse skin diving without the safety of a BCD, therefore rescue procedures discussed throughout this presentation will often focus on the use of a BCD. If you intend to skin dive without the BCD, I suggest that both you and your buddy complete a personal life saving and water safety course.

The first thing you must learn to do is stop, rest, and breathe. Under periods of high physical and emotional stress, real or imagery, anexity increases and breathing patterns change. So take a few seconds to stop, relax, regain control of your breathing, and assess the situation. Things might not be as bad as they appear! Establish a more normal breathing pattern as soon as possible and be especially aware of hyperventilation or shallow, rapid breathing. With time both of theses patterns can lead to "unconsciousness without warning."

Keep your mask in place and breathe through your snorkel (or regulator) unless there is significant breathing resistance. Keep your head low in the water since raising it will place about 10 pounds of weight above water trying to force you down. Even though the distressed diver appears to be *handling* the situation in a self-rescue mode the buddy should be immediately available to assist if the need arises. A diver in a near-exhaustion state and breathing abnormally could lose consciousness at any time.

If you are not too *out-of-breath* orally inflate your BC and rest. A scuba diver would naturally use the power inflator. Now relax, look for your buddy, and further assess the situation. In most cases, *the worst of the situation* will be over and you and your buddy can coordinate the next step. It is important to remember, "Don't put yourself back into the situation that resulted in your initial distress!" Think about it! Was it an equipment problem? Were you overweighted? Were you struggling in a strong current? Were you getting too cold? Was your buddy's lead pace too much for you? Regardless of the cause, try to find a solution! This may mean terminating the dive and returning to the boat or beach.

If you are skin diving and find yourself too exhausted or distressed to orally inflate your BCD, immediately activate your CO_2 inflation device. Don't worry about cost! Unfortunately, this option is generally not available to modern scuba divers. Most scuba BCDs are no longer equipped for CO_2 inflation. If you plan to skin dive, buy a small collar-style BCD with CO_2 inflation capability.

Many divers and instructors consider CO_2 inflation devices to be inadequate and unacceptable. Some claim almost certain failure and even discourage their students from having one on their BCD. Manufactures provide BCDs both with and without CO_2 inflation devices; this is no longer an option on some BCDs. I personally feel that the CO_2 inflation device can be one of the most important rescue devices that you can have. However, remember that this device is only as good as the person maintaining it. It must be frequently inspected, cleaned, lubricated, and its operation verified. At this point, I also recommend that you actually expend a CO_2 cylinder as a self-rescue practice procedure. Most divers never practice CO_2 inflation or even know if the inflator will really function in an emergency. Such procedures cost too much! True, CO_2 cartridges are expensive. But, I feel the expense is worth it. You can use the smallest, least expensive cartridge for practice. However, be sure to replace it with a large capacity one before you go diving.

If you are unable to inflate your BCD, you can proceed to the next alternative or option – ***DISCARD YOUR WEIGHT BELT!*** In fact, with the decreased popularity of CO_2 inflation capability, this is becoming a more important procedure in modern day diving. The weight belt buckle should be released and the belt pulled away from the body and dropped. Simply releasing the buckle is inappropriate; belts tend to catch on other equipment.

Weight belt release is often ignored in diver training. First, many instructors do not appreciate the significance of the procedure, nor do they understand the importance of repetitious skill practice. Second, there is concern about damage to pool facilities. Third, this procedure is seldom practiced in open water for fear of weight belt loss.

Exercises involving physical stress (at the surface) followed by a command to release the weight belt is an excellent way to mentally and physically condition trainees in this self-rescue technique. Circuit training exercises involving weight belt releases are also excellent. Pool damage can be avoided by using pellet-type weight belts. For open water exercises a line attached to a float can be clipped to the weight belt. The discarded belt can then easily be retrieved from the surface. Be certain that lead weights are secured with *keepers* to prevent them from slipping off of the belt.

At some point in your self-rescue practice spend at least 5 minutes floating motionless. In the ocean, buddy teams often lock arms, right to right or left to left, to keep from drifting apart. Be sure to perform each procedure several times.

SELF-PROTECTION FOR RESCUERS

Double drowning! Dead hero! You do not have to place your life on the line to save the life of another! If you are properly trained and properly equipped, you can greatly reduce the risk in a rescue situation. And if you apply some common sense and good judgement, the risk can be further reduced.

Now, it is time to work on your *defensive rescue philosophy*. I will develop a few basic ideas here and inject more as I discuss rescue procedures. First, never swim directly into the grasp of your victim. Observe them, talk to them, determine your best approach, give yourself some positive buoyancy (by partially or completely inflating your BCD, depending on the model), and execute a well thought out procedure. The best rescue is where you never have to touch the victim. Words have rescued many distressed divers.

The key is *"protect yourself at all times."* If you are that 98 pound diver with the 220 pound companion, consider calling for assistance as the most appropiate rescue procedure. Do not let pride or stupidity also make you a victim. That goes for any potential rescurer, not just the small person.

Although, I will discuss defensive techniques later, keep in mind that the best defense strategy in rescue is avoidance, not aggression. Just one additional thought before I proceed. As long as the distressed diver is thrashing violently about on the surface, they keeping themselves afloat. Wait them out! Once they detect your presence they my calm down or they may lunge for you. Be alert and defensive. Several lunges and they might bring themselves back to the boat or shallow water. If they calm down you might be able to talk them into a self-rescue. If not, eventually, they will tire and you can move in for the rescue on your terms, not theirs!

ASSISTING A DISTRESSED DIVER

In a many situation, the diver on the surface is simply having difficulty staying afloat, but has not lost control. The distressed diver may appear fatigued, release the regulator or snorkel from their mouth, pull their mask off, attempt to hold their head high out of the water, and appear to gasp for air. *It is important for all divers to recognize signs of distress as early as possible in the sequence of events.* The sooner a diver can be assisted, the simpler the potential rescue.

At this point the distressed diver may still be capable rescuing themselves by jettisoning the weight belt, inflating the BCD, or regaining physical control of the situation. Individual problem solving has been discussed in detail above.

In this situation the buddy or rescuer can do several things. *First, encourage self-rescue by talking to the distressed diver.* Repeatedly call to the diver to inflate the BCD and/or drop the weight belt. If the diver is carrying objects in their hands, give a verbal command to drop those items. The assisting diver must remain calm; do not panic the distressed diver. If there is a float to push to the diver or other means of avoiding direct contact such as a line or pole, the rescuer should use it. Otherwise the rescuer must prepare to provide contact assistance.

The first principle of diver assistance and rescue is that the rescuer must protect himself/herself. Before approaching a distressed diver, even if the diver does not appear panicked, inflate your BCD and, ideally, place the regulator in your mouth. If you make a mistake and/or the victim grabs you, a good BCD should keep you both afloat. This procedure is especially true for beginning divers who have not had rescue training.

In approaching the victim, remain alert and be prepared to retreat if the diver lunges for you. The visual presence of an assisting diver may actually calm the distressed individual. As you approach, talk to the diver. Just before you make physical contact be sure to insert your regulator or snorkel mouthpiece.

The safest and simplest means of aid is to move to the side and behind the victim and reach around to inflate the BCD and/or release the weight belt. If the diver is not wearing a BCD or if this method is not feasible, the rescuer should support the diver from behind by gripping firmly under the arm and exerting a slight lifting force. If the diver is not wearing scuba you can support them by grasping under both arms and laying them back on your chest/BCD. If feasible, talk to the diver and allow them to rest and regain their breath. If the victim is wearing a weight belt, the rescuer should jettison it. The rescuer should continuously reassure the victim and keep calm. A calm reassurance can often prevent a panic situation.

Some authorities suggest that the rescuer remain in front of the diver, grasp the diver's wrist (left hand to left hand), and turn the diver with a pulling motion. As you approach the victim may reach for you. First, block and grasp the outstretched arm at the wrist with your hand on top of the wrist. Grasp right arm with right hand or left arm with left hand. Now, pull the victim toward you and, at the same time, turn them so that they are facing away from you. Immediately grasp your buddy firmly in the arm pit and exert a slight upward force. At the same time move your initial contact hand upward to grasp your buddy's bicep.

Dealing with a Panic Situation

Panic is a sudden unreasonable and overwhelming fear which attacks people in the face of real or fancied danger. Panic is the diver's most deadly hazard and is a contributory cause of practically all water accidents. *A panic situation is dangerous for both victim and rescuer. Rescuers must know what they are doing and apply all their skill and training to avoid personal danger. The natural desire to aid a distressed individual sometimes ends tragically for both victim and rescuer.*

The first impulse of a panic-stricken swimmer will be to "climb" the rescuer and get as high out of the water as possible. The rescuer must retain his common sense, good judgment and reasoning, and must avoid the victim's grasp. *Simply stay clear.* While the diver is violently thrashing in panic, these movements will probably keep them afloat. When the diver tires, the rescuer can move in and proceed with the rescue as previously discussed. The rescuer must be sure to remain in a position to avoid being grabbed by the struggling diver. By holding the diver firmly under the arm, the rescuer can both support and control the diver. Inflate the victim's BCD and/or jettison the weight belt as soon as possible.

Emergency BCD inflation is not as simple as it once was. When BCDs were equipped with CO_2 inflation capability, *and the system was properly maintained,* a rescuer could achieve immediate full inflation with the pull of a cord. Today, most BCDs are no longer equipped with a CO_2 inflation mechanism and it may take from 10 to 30 seconds to fully inflate the BC with air from the scuba (depending on the model and cylinder pressure). A complete discussion of CO_2 controversy is beyond the scope of this paper. However, the diving industry has elected to abandon this item of safety equipment for economic, materials, and perceived legal reasons. Interestingly, BCDs are not considered an item of life saving equipment by the industry, however, its role in diver rescue is presented as *essential* in diving literature.

Once the BCD has been inflated, the victim may or may not calm immediately. For the rescuer, the worst is probably over. In fact, once the BCD is inflated a rescuer can even move back and observe until the victim calms.

Approach

If it is necessary to approach the victim from the front, the rescuer must decide whether to approach on the surface or underwater. Each technique has advantages and disadvantages, however the underwater approach is probably safer for the rescuer. In either case the rescuer swims to within 6-10 feet of the struggling diver and submerges to approach the diver underwater. For years many divers followed the lead of conventional lifesaving specialist by grasping the victim at the knees and turning them around. From the moment of contact with the victim, the rescuer should maintain a firm hold and control the victim. The rescuer must be careful to not drag the victim underwater. As the rescuer moves up the victim's body the victim's weight belt can be released and the BCD inflated.

Many authorities suggest that the turning maneuver is unnecessary and possibly adds risk and complications. Since the rescuer is equipped with mask, fins, and snorkel or scuba, they suggest that it is more advantageous for the rescuer to simply maneuver behind the victim and into an immediate upper body control position *before contact*. When approaching from the rear, the rescuer should be in a position to move quickly out of the victim's reach in case he/she turns. Use the underarm grasp and control as required.

Transporting a Diver

Once the victim is under control, the rescuer may tow or push the diver to safety. In some cases the victim may recover sufficiently to return to the shore or boat under their own power. In this case the rescuer should monitor the diver continuously and assist as needed.

Regardless of the methd used in transporting a diver, the following factors must be considered:

1. Both the rescuer and transported diver must be positively buoyant (BCD inflated) and in a horizontal position.
2. The former victim's face must be out of the water.
3. The rescuer must have complete control.
4. The rescuer must protect the diver from further distress as much as possible.
5. The rescuer must be in a position of unrestricted swimming.
6. Ideally, the rescuer should maintain a position which allows for constant monitoring of the victims face and communication.

One of the simplest methods of moving an individual through the water is for the rescuer to place the diver on his/her back, grasp them under the arm (arm pit) with the hand nearest the diver's body, and push the diver. The diver's arm can be extended perpendicular to their body and grasped at the wrist with the other hand for added control and leverage. The rescuer breathes through their snorkel and easily observes the diver. This is sometimes called the *arm-push* method.

The *fin-push* is considered a far more acceptable procedure than the conventional tired swimmer's carry. With weight belt off and BCD inflated, simply have the victim rest on their back with legs straight. The victim's fins are placed on the rescuer's shoulders and the rescuer firmly grasps the diver's legs in the vicinity of the knees. This position facilitates observation and is reassuring to the victim.

Another simple method of towing the victim is for the rescuer to grasp the collar of the victim's inflated BCD or cylinder valve and swim on his/her side or back, towing the victim at arm's length. Care is taken not to kick the victim. This method does not allow for face to face observation.

The important thing is to keep the victim's head above water and maintain complete control at all times. If the diver in tow begins to struggle, the rescuer should stop moving and attempt to calm the victim. *Do not transport a struggling diver!*

Whenever possible call for assistance. Two rescuers can more comfortably and efficiently tow a victim on the surface. After the victim has been leveled on their back, weight belt removed, and BCD inflated, one rescuer is positioned on each side of the victim. The arm-push method works quite nicely for two rescuers. The rescuers swim in a snorkeling position.

When necessary and possible, the scuba should be removed. Placing the victim on his/her back with a fully inflated back buoyancy system provides significant flotation. If the rescuer has to render aid to the victim and the towing distance is great, the inflation hose may be disconnected from the BCD and the scuba cylinder released from the backpack and discarded. It is very difficult and inefficient to tow a scuba equipped victim. Unfortunately, distressed scuba divers sometimes place a higher value on their equipment than their lives. Tests have shown that in scuba diving rescue, the speed and efficiency of towing can be improved nearly threefold if the scuba of both the rescuer and victim are discarded.

Noncontact Assist

As previously stated, the fact that the buddy is generally in the water, near the victim, lessens the possibility of a reaching or throwing assist. However, it should be stated that if at all possible, direct contact should be avoided. If near a pier, boat, etc., the rescuer should reach for the victim with a towel, pole, or whatever may be available. If the distressed is too far away for a reaching assist, the rescuer should throw a rope, ring buoy, etc. In reaching for a diver, the rescuer should keep low and firmly placed in order to avoid being pulled into the water. The prone position is best.

Releases

If, for some reason, the victim gets a hold on the rescuer, the rescuer must know how to break it. Holds can sometimes be prevented by blocking the arm, grasping it, and turning the diver around; go directly to a control position and inflate the BCD. At other times it may be necessary to block the diver by ducking underwater, placing a hand on the victim's chest and pushing them away.

Aggressive counteraction may not always be necessary. For instance, if the victim grabs the rescuer's arm, the rescuer may simply straighten the arm, reach underwater with the other hand and inflate the victim's unit and/or release the weight belt. This is beneficial in preventing further distress or panic in the victim. Even if the victim does get a hold on the rescuer, the rescuer can inflate his own buoyancy unit to prevent himself from being pulled underwater. Larger capacity units will probably float both individuals until further action can be taken.

Should the victim actually gets a hold on the rescuer, the rescuer should not panic. If the rescuer's BCD is inflated, it should have sufficient buoyancy to support both divers. Simply locate the victim's BCD inflator and activate. Hopefully the victim will calm down, release the hold, and float. If the victim does not release the hold, the rescuer can simply grasp the victim's midsection and push them away. The more complex releases, turns and contact techniques common to conventional life saving need not be used since the victim is under flotation and there is little chance of them slipping away into the depths. Furthermore, some conventional lifesaving victim management procedures and releases may be complicated by the presence of mask, snorkel and/or scuba.

SUBMERGED AND UNCONSCIOUS SKIN DIVER

An unconscious, submerged skin diver (on scuba) must be brought to the surface as soon as possible and artificial respiration procedures started immediately. The rescuer should dive to the victim, release the weight belt, inflate the buoyancy unit (BCD) and pull the victim toward the surface by grasping an arm or the BCD. In shallow water the buoyancy of the BCD and wet suit (if worn) will generally lend considerable assistance to the surfacing procedure.

Assuming that the victim does not begin breathing upon surfacing, a decision must be made to begin resuscitation or tow the victim to shore (or the boat) where possible assistance and proper resuscitation procedures can be initiated. If the distance is short, the short time in getting the victim to assistance on a stable location may well be justified. If the distance is great, the rescuer has no choice but to begin mouth-to-mouth resuscitation immediately — in the *water*.

The most common method of administering in-water mouth-to-mouth resuscitation has been nicknamed the *"do-si-do"* method. This term was derived from the position similarity to the do-si-do in square dancing. The basic procedure is as follows:

1. Victim buoyancy is vital to the success of this procedure. Inflate the BCD immediately. Also, release the victim's weight belt. The success of this procedure also depends on maintaining the victim in a nearly horizontal position at the water surface. If the victim's lower body sinks to place them at a 15° or greater angle relative to the water surface, the water pressure on the chest may preclude inflation of the lungs and make resuscitation efforts ineffective.

2. Assuming that the victim is to the right of and facing the rescuer, the rescuer will reach between the victim's arm and body (as if twining elbows with the victim) with the right hand. The rescuer's right hand may then be moved in to a position to facilitate tilting the head back by grasping the collar of the buoyancy unit, or placed under the victim's back to provide support. Students should be encouraged to practice various hand positions and determine which they like best. Pulling the head back over the collar of the unit aids in opening the victim's air passage. If the victim is wearing a back-pack buoyancy unit, the rescuer can grasp the shoulder strap of the pack with one hand and use the other to seal the nose.

3. Using the left (free) hand, remove the victim's mask, grasp and seal the nose with two fingers, and press the palm of the hand on the victim's forehead to facilitate tilting the head back. Practice this while wearing the gloves or mittens normally used while diving. Please note that these hand positions are different than those recommended by the American Red Cross. The jaw lift method indicated by the ARC is the correct method on land however, it is difficult for a rescuer to use in the water. One arm/hand is need to stabilize and control the victim.

4. The victim may be easily rotated toward the rescuer who places his mouth over the victim's and begins routine mouth-to-mouth rescue breathing. Be sure to get a tight seal. Blow gently at first in the event that the victim is not totally unconscious. Rotate the victim's head *and* body together in order to avoid restricting the airway. This way the rescuer doesn't have to lift his head out of the water.

5. After two full lung inflation the rescuer may allow the victim to rotate back to the level position. If difficulties are encountered in getting air into the victim, the rescuer may have to pull the head back farther to clear matter from the mouth or airway. Listen for breathing sounds and watch for signs of breathing. Some of the procedures commonly associated with rescue breathing and CPR on land must be modified or even ignored in the water.

6. The rescuer should attempt to maintain a normal 12 breaths per minute rhythm for adults. The critical factor is, however, to get air into the victim as soon as possible and to continue ventilating the victim even if conditions dictate an irregular pattern.

7. Between inflations, the rescuer should call for additional assistance. Another swimmer can push the victim by grasping his fins or legs while the rescuer continues resuscitation. If no other assistance is available, the rescuer may start toward shore (or boat) with his victim under tow without changing positions. With practice the rescuer may quite successfully tow the victim and give resuscitation simultaneously. On the surface, the rescuer may cover the victim's mouth as the waves break over.

Practice *simulated* (without oral contact) rescue breathing procedure first in shallow water and then in deep water. Both the practice victim and the rescuer should wear all equipment that would normally be worn while diving. Also, practice in full equipment under various environmental conditions, especially in waves and cold water.

The use of mouth-to-snorkel rescue breathing has been taught for years and considered by many to be effective in rough water and when buoyancy is inadequate to keep the victim high in the water. This technique is a bit more difficult to master. Furthermore, most snorkels today are equipped with an exhaust valve making them unacceptable for this technique.

Pocket masks are special rescue breathing masks that have become extremely popular in recent years, especially considering the potential for disease transmission associated with convention methods. With practice they apparently can be used with some success in the water. However, very few divers carry them while in the water. I consider this mask a mandatory item of equipment at the dive site.

SUBMERGED SCUBA DIVER RESCUE

In the handling of submerged scuba divers we will consider both the possibility of a distressed conscious diver and the non- breathing victim lying on the bottom. In either case, the victim's diving buddy or another nearby scuba diver will probably be placed in the role of the rescuer. The time may come when you will actually have to rescue a distressed partner underwater. Diving buddies must learn to work together and should know and understand a standard set of signals. They should be in visible range at all time and observe each other.

Loss-of-Air Suppy

It may be necessary for scuba divers to share air (buddy breathe) in the event of air supply exhaustion or equipment malfunction. There are several methods of sharing air and the diver must use the one best adapted to the situation. Sharing air under emergency conditions is difficult even for the best trained and most experienced divers. Divers should practice the skill frequently. Many individuals feel that buddy breathing is a more hazardous emergency procedure for divers than the controlled emergency swimming ascent. A number of single and double drownings (and incidences of lung barotrauma) have been directly attributed to unsuccessful attempts at buddy breathing under stress situations. The use of diver carried auxiliary breathing units (octopus rig, pony bottle, etc.) is the preferred method of dealing with a loss of air supply situation. Equipment and procedures for independent or dependent emergency ascents have bee discussed previously. Proper training and diver discretion are key factors in handling loss of air supply emergency situations underwater.

Panicked Scuba Diver

What would you do if your buddy panics underwater and bolts toward the surface. The is no doubt on of the most feared situations a dive may encounter. There may be only seconds between the onset of stress and complete panic. Consequently, anytime you approach a potentially stressed diver underwater, be prepared for the worst! At the onset of panic the diver grab at the rescuer's mask and regulator or even attempt to climb onto the rescuer. Even worst, a panicked individual may revert to natural instinct and hold their breath while struggling toward the surface.

It is doubtful if a panicked diver can be stopped from ascending, nor should they! The best a companion can do is to slow the ascent sufficiently to hopefully assure exhalation. However, a word of caution — "It is important to determine whether the distressed diver is exhaling or breath-holding! The diver may be making an intentional emergency ascent; arresting the ascent could lead to more serious problems.

To slow an ascending diver, grasp one of the diver's legs to inhabit kicking. Be very careful to avoid being kicked yourself and losing your mask. If the victim appears to be breathing or exhaling allow them to proceed at a reduced rate of ascent. Do not become so involved as a rescuer that you forget to exhale or place your own well-being at risk.

Upon reaching the surface the distressed diver will no doubt still be panicked. Gain control as discussed previously, inflate the BCD, and stabilize the victim. Assist the victim to shore or the vessel and observe for symptoms of air embolism. Above all, do not allow the individual to submerge and continue the dive. Even if the victim appears to recover rapidly and ask to continue the dive, *DON'T!* The victim of a panicked ascent must, in my opinion, be observed for at least 30 minutes in order to detect signs of possible pulmonary barotrauma or neurological change that might indicate an air embolism. The cause of the initial panic must be determined and, when possible, corrections in diving procedures made. Also, if equipment malfunction played a role in the situation, the equipment must be repaired or replace before future dives.

Unconscious Scuba Diver

The potential rescuers of unconscious submerged divers encompass a much larger group of individuals. Any swimmer, skin diver or lifeguard operating in an area of scuba diving activity may find him or herself in a situation of recovering an unconscious scuba diver. This is especially true in recreational pools and beach areas where scuba diving is permitted. In shallow water, the victim may be retrieved by breath-hold diving. The rescuer should dive to the victim and proceed as follows:

1. As you approach the victim turn them to a position facing you. With your free hand, release the victim's weight belt and, if the victim cannot be pulled from the bottom, inflate his buoyancy unit. Do not attempt to remove the scuba unless it is entangled in rope, net, weeds, etc., and it is significantly inhibiting retrieval of the victim.

2. If the regulator is in the victim's mouth, leave it; if not, do not waste valuable time attempting to replace it.

3. The victim should now be positively buoyant and floating upward toward the surface. If not you may have to pull the victim to the surface by grasping an arm or piece of equipment. Stay with the victim, if possible. If you are nearing the limit of your breath-holding capability, ascend, take a breath, and dive back to the victim. Hopefully, the buoyant victim will have floated to the surface.

In years passed divers were taught to maintain the victim in the upright head held back position throughout ascent. It was felt that this was necessary for the prevention of lung barotrauma and air embolism. Some even advocated placing both arms around the victim's chest or abdominal area and squeezing to assure expelling of air. This practice is difficult when the victim is wearing scuba. Studies have now shown that the risk of pulmonary barotrauma is minimal in an unconscious diver so airway opening procedures are not stressed today.

Recovery of an unconscious diver is much simpler if the rescuer is using scuba. In recent years the British have conducted studies and introduced improved procedures for submerged diver recovery. Although each situation is somewhat unique, the following is a general procedure that may be used in most situations:

1. Approach the victim carefully and make mental notes regarding position on the bottom, regulator in or out of mouth, mask on or off, mask clear or flooded, evidence of injury, and so on. This information will be important to persons investigating the incident. *However, these observations should not delay the rescue.*

2. If the regulator is in the victim's mouth, leave it; if not, do not waste valuable time attempting to replace it.

3. Using your left hand, grasp the victim's BCD waist or chest strap and with your right hand locate the BCD air inflation valve.

4. Flow air into the victims BCD until the victim begins to rise. Maintain the left hand position and hold the BCD inflator in your right hand. Control ascent by discharging small burst of air through the exhaust valve. Additional air may be injected if necessary. The rescuer and victim are floated to the surface by the buoyancy of the victims BCD.

This technique is very easy to learn and nearly effortless for the diver. As previously stated, today the risk of pulmonary barotrauma in an unconscious victim is considered minimal. The buoyancy of the diver's hood may actually hold the head in an upward position. In the event that the diver is wearing a dry suit, the rescuer may have to vent air from the dry suit during ascent in order to maintain proper control. These procedures should be covered during advanced training in dry suit diving.

Investigations of diving accidents suggests that many divers found unconscious on the bottom still have sufficient air in their scuba to accomplish this procedure. If there is insufficient air to inflate the BCD, positive buoyancy may be achieved by discarding the victims weight belt.

In the event that the victim is still negative after the weight belt is released, the rescuer may establish positive buoyancy by inflating their own BCD. In this case it may be best to move behind the victim and grasp them by the chin, if the regulator is in place. In this way the rescuer can maintain the victim's head in an upright position and retain the regulator in the victim's mouth. Air will discharge from the victim's lungs through the regulator exhaust. If the regulator mouthpiece is not in place, be certain to adjust your grip position so as to not physically close the mouth or restrict air flow. You may grasp the top of the BCD or the cylinder valve or support them under the arm. The rate of ascent is controlled by the rescuer venting air from his/her BCD.

The rescuer must not endanger himself/herself during ascent. Attempt to maintain a normal ascent rate. If air is expanding in the victims suit and BCD and the rescuer cannot release it in order to control the ascent or slow by flaring, it may be necessary to release the victim and let them float to the surface. Ideally, stay with the victim and keep in mind the need for exhalation throughout the ascent.

Once the victim is on the surface, inflate the BCD and immediately start mouth-to-mouth resuscitation. Do not take time to remove equipment. If necessary, systematically remove the diver's scuba equipment without interrupting resuscitation procedures.

The presence of the scuba cylinder may complicate the rescue procedure. Once the belt has been dropped and BCD inflated, it is generally best to remove the cylinder if the victim must be towed significant distance. Cylinder removal may be complicated by the fact that on some units an inflation hose leads from scuba regulator to the buoyancy unit. This hose must be manually disconnected from the unit. If the unit inflation mechanism is functioning properly, air will not leak from the unit when the inflator is disconnected; if not, air will discharge and the inflator hose connection will have to be re-inserted to stop the discharge or loss of air.

Unfortunately, there is no standardization of inflation mechanisms for scuba diver buoyancy units. Each manufacturer seems to use a different type and location of the inflation mechanism. The rescuer may have to study the victim's equipment in order to properly inflate the unit. Persons who anticipate being placed in situations which may involve the rescue of scuba divers are encouraged to seek diver training themselves and routinely visit diving equipment suppliers to update themselves on the vast variety of buoyancy units and inflation mechanisms being used.

Most divers use a scuba system which incorporates the scuba and buoyancy device into a single unit. In this situation the BCD must be retained in order to retain the buoyancy. However, for long distance towing, the rescuer may elect to release and discard the scuba cylinder. It takes considerably more energy to move an unconscious person equipped with scuba through the water than one without the scuba.

Some BCDs have weights contained in the BCD itself. These weights may be dropped by pulling a release mechanism on the BCD. The rescuer should stabilize the situation, inflate the buoyancy unit to full capacity (orally or with air from the scuba), and use it as a float or raft for the distressed diver.

REMOVING AN UNCONSCIOUS DIVER FROM THE WATER

Unassisted removal of an unconscious victim from the water can be extremely difficult, if not impossible, for many individuals. Often the rescuer will have to continue ventilating a non-breathing victim until assistance arrives. Special lift and carry techniques are practiced in Rescue Diver training. Techniques are environmental specific and all divers are encourage to seek rescue training when they move to geographic locations where water and diving conditions are significantly different than in the area where they were trained.

For the beginning diver it is best to always dive with groups of experienced divers in order to assure that trained assistance is available in an emergency.

UNCONSCIOUS SCUBA DIVER ON THE SURFACE

The rescuer may encounter an unconscious scuba diver floating on the surface. In this case, the victim may have dropped his weight belt and even inflated his unit prior to losing consciousness. Unconsciousness may have been induced by factors such as cardiac arrest, decompression sickness, air embolism, contaminated breathing air, etc. Also, it is not inconceivable that the fatigued victim could have been unable to maintain his head above water sufficiently to breathe because of improper use of his equipment. In any case, the rescuer should immeditately take action to position the individual and, if necessary, start mouth-to-mouth resuscitation. Discarding the scuba may be necessary, but should not delay the initial resuscitation procedures. Handling the diver's equipment has been discussed previously. Tow the victim to shore or boat as instructed in the section on skin diving and take appropriate action to cope with the near-drowning and diving induced injuries.

TENDING TO THE VICTIM FOLLOWING RESCUE

Once the rescuer has towed the victim to safety, get him out of the water and, if not breathing, continue resuscitation efforts. Use cardiopulmonary resuscitation if necessary. Continue until professional help can be summoned and the victim is transported to a medical facility. Do not give up. Extensive periods of resuscitation have proven successful following victim submergence in excess of 30 minutes in cold water.

If the victim is resuscitated at the scene, treat for shock and transport to a medical facility for further treatment and observation. Do not let the victim leave the scene and do not leave the victim unattended. Secondary and delayed effects of a near drowning episode can be extremely serious and even fatal.

Following any rescue, regardless if the victim was unconscious or conscious, the rescuer must continue to assess the physical state of the victim and attempt to determine if the victim is suffering from conditions such as lung barotrauma, decompression sickness, carbon monoxide poisoning, etc. An unattended rescued scuba accident victim may pass into unconsciousness and even die within minutes or up to several hours after initial rescue as a result of physiological complications. The victim must be observed and, if any abnormality at all is present, a physician consulted. Above all, the rescuer must inform the first aid and medical personnel that the victim was participating in scuba diving at the time of the accident. Accompany the victim, if possible, to the hospital or at least attach an accident description to his clothing.

ESCAPE AND RESCUE FROM A SUBMERGED VEHICLE

Another type of underwater rescue is personal escape or the recovery of a live victim from a submerged vehicle. Tests conducted by the Michigan State Police in 1961 showed that a car will float from 3 to 10 minutes if they are not structurally damaged and if the doors are closed when they enter the water. Consequently, exit the car by rolling down a window while it is still on the surface. Doors can not be opened on the surface or underwater.

During the initial seconds of sinking and submergence the victim must remain calm and analyze the situation. Disengage the seat belt so that it will not hamper movement.
to the rear and roll down a side window or break the rear glass to escape. The rear window is made of tempered glass and will shatter easily if struck with a hard sharp object. Unfortunately, some vehicles that are equipped with electrically operated windows and, if the electrical system fails, the windows may or may not operate. However, doors can generally be mechanically unlocked, even on vehicles with electrically operated locks. Unlock door immediately.

Contrary to popular belief there is generally little or no air air remaining in the passenger compartment once the vehicle sinks. However, if the occupant survives submergence he/she may still escape through a window or a door. The technique for opening the doors or windows will vary with vehicles. Basically, water pressure will initially prevent the opening of the door. Once the car is nearly filled with water and the remaining air is trapped and compressed, the inside and outside pressure will equalize the victim may be able to open a door. As the victim leaves the vehicle and begins ascent, they must remember to exhale during ascent. Pulmonary barotrauma can occur — compressed air has been breathed under pressure.

When a vehicle starts down the front portion will generally sink first because of the weight of the engine. As the vehicle fills with water air will rush to the back of the vehicle and substantial amounts may discharge. As the vehicle come to rest underwater, there is generally not be significant air inside. Furthermore, the air contained in the vehicle may be in a thin layer in the top of the vehicle. The occupant may or may not be able to breath from this air; many experts suggest not.

Is one side of the vehicle higher than the other? Once on the bottom, the door on the higher side should be opened since it is less likely to be blocked by debris on the bottom.

In water depths of more than 15 feet the car may turn over during sinking and settle on its top. This makes escape improbable for an occupant.

Entry *into* a submerged vehicle can be quite difficult, especially at night or in very poor visibility water. Initially, a person may simply breath-hold dive to the vehicle. Quite often water depths adjacent to roadways may be shallow. The vehicle may be visible from the surface or its position determined by escaping air, oil, or gas. Tire track, damaged flora, and so on may indicate the point of entry. Upon initial contact look or feel for open windows and doors. Attempt to open the door. In this case be immediately prepared to deal with a victim. Once you have found an unlocked door or open window be certain that you have enough breath-hold time left to deal with the situation. You may wish to return to the surface, breathe, and dive again to open the door. Be very careful about entering the vehicle while breath-holding; take it one step at a time!

If the windows are closed and doors locked on a submerged vehicle, there is very little that a breath-hold diver can do to gain entry. Even a scuba diver may need special equipment to break a window or open a door. Keep in mind that the rear window made of tempered glass will shatter easily if struck with a hard sharp object. Keep in mind that potential survival time can be 30 minutes or more for a victim submerged in cold water. Call for assistance and, if possible, mark the position of the vehicle with any kind of float and line that you can find. This will be of great assistance to professional rescuers when they arrive. Breath-hold diving rescuers should take care not to overextend themselves, especially in cold water. The best one can hope for is to do their best, not give their life.

After a breathing victim has escaped or been rescued from a submerged vehicle, in addition to other required first aid, this person must also be handled as a scuba diving accident victim would be handled until the possibility of pulmonary barotrauma and subsequent air embolism has been ruled out.

CONCLUSION

A prudent diver will take great care in selecting diving companions as well as dive sites that are consistent with level of training and diving experience. The most important factor in common sense rescue is to avoid situations where rescue may be necessary. In the event that you are faced with an assistance or rescue situation the most important considerations is to protect yourself. Analyze the situation and plan your response. At this point in your diving career, you lack both the skill and practice required to respond instinctively.

Manuscript completed: 7 February 1990
Manuscript revised: 11 February 1990
Manuscript revised: 20 June 1990

CHAPTER 5-5

FIRST AID FOR DIVING-RELATED INJURIES

INTRODUCTION

During the 1980s the number of recreational scuba divers trained and actively participating in the sport has increased significantly. Presently, there are more than 2.5 million Americans trained in scuba diving, and this number is increasing by thousands each year. Diving equipment and diver education have evolved to keep pace with modern technology, marketing, and the requirements of a more sophisticated diving population.

This document has been prepared to assist entry-level divers, divemasters, and instructors in developing a better understanding of the requirements for field management of an injured diver. It is intended for use as a support document to illustrated lectures and workshops. ***This document by itself does not constitute adequate training in first aid for diving-related injuries.***

The reader is also reminded that first aid procedures change as the diving and medical communities develop new insights into pressure related injuries and hyperbaric physiology. Athough many of the procedures presented in this document have remained unchanged for many years, others have changed significantly over the past decade. In some injuries, the appropriate first aid procedure is still a subject of debate.

Some diving manuals, even of recent publication, may not necessarily reflect modern views on injury management. Furthermore, the information presented here may be soon outdated. All divers must maintain current knowledge through reading and attending seminars.

Diving accident management is a vital part of a diver's training. Unfortunately, modern trends in diver training reflect decreases in both course content and duration for entry level scuba diving instruction. The instructional community relies instead on a strong continuing education program. Essentially, the course content of earlier basic and advanced diver training programs is now spread out over 6 to 9 courses. In theory the concept of strong continuing education is excellent. Unfortunately, far too many divers do not participate in continuing education programs and are insufficiently prepared to deal with diver injuries.

Fortunately, the Divers Alert Network (DAN) based at the Duke University Medical Center, is available 24 hours a day to provide diving accident management information and assistance to divers, instructors, emergency medical personnel, and physicians [36]. The availability of this service has both simplified and complemented the training of divers, physicians, and other support personnel.

Diving Accidents in the United States

The University of Rhode Island's Underwater Accident Data Center has reported an average of 147 fatal scuba diving accidents in the United States annually since 1970 [41]. The number of fatal diving accidents dropped to 116 in 1986 and 108 in 1987 [42]. In spite of the increase in the number of active divers, the number of annual diving fatalities appears to be on the decline. However, the number of non-fatal diving accidents appears to be increasing. During 1981-82, 117 non-fatal sport diver accidents involving *neurologic injury* were reported to the National Diving Accident Network (DAN) [23, 24, 43]. The number of nonfatal recreational scuba diving accidents reported to the Divers Alert Network for 1983-1987 was [56]:

1983	177 cases
1984	196 cases
1985	462 cases
1986	537 cases
1987	409 cases
1988*	553 cases

* Unpublished verbal report.

The actual number of diving injuries treated annually during these years still remains unclear. For example, a survey of hyperbaric chamber facilities in the United States and Canada for the years 1979 to 1983 indicated an average *annual* treatment of 399 cases of decompression sickness and 99 cases of air embolism. This survey did not address treatments conducted in Caribbean-based hyperbaric chambers which were estimated at 121 cases per year [56]. Based on these figures it appears that there was an average total of 619 cases annuallly during the five year period. However, this figure may include some multiple treatments of the same diver.

Furthermore, these reports may include deaths, injuries to military or professional divers, and other medical conditions. Of the 409 cases reported to DAN in 1987 only 270 were addressed in the statistical analysis of recreational scuba diving accidents. The assessment of diver risk is further complicated by the fact that there is not an accurate data base reflecting the actual number of active divers or number of dives made per year. Estimates vary considerably. For example, in the early 1980s Skin Diver Magazine and the Diving Equipment Manufacturers Association surveys and estimates by the National Underwater Accident Data Center varied by a factor of three. Since there is no accurate reporting system in the United States estimates can be inflated and deflated to best serve special interest groups. It is advantageous for the diving industry to demonstrate that the incidence of diver injury is small.

The fact is that the incidence of injury in diving is probably quite small in comparison to other recreational activities such as skiing, hang gliding, and rock climbing. Unfortunately, accurate data is probably not available on these activities either and that which is available is also subject to manipulation by special interest groups. *However, diving injuries do occur and every diver must be prepared to respond.*

Causes and Prevention

The University of Rhode Island National Underwater Accident Data Center publishes annual reports on fatal scuba diving accidents in the United States [41, 42], and the Michigan Sea Grant College Program has sponsored a review of scuba diving accidents in the state of Michigan [31]. As previously stated, the currently available scuba diving accident data base in the United States only addresses fatalities, not incidents which involve non-fatal injury.

The term *accident* is perhaps misleading. Most scuba diving injuries and fatalities *are not accidents* in the sense of being random and totally unpredictable. Most often the causes of the injury or fatality are readily apparent when the environmental conditions, the equipment, training, and capabilities of the diver, and diving procedures are analyzed. *The prevention of an injury or fatality involves assuring that there is a reasonable match between the performance capability of the diver and the demands of the environment.* For example, a novice scuba diver with no training in river diving procedures and only limited experience in calm water diving is at significantly higher risk when entering a fast moving river than an experienced diver specifically trained in river techniques. Prevention of potential injury or fatality, therefore, involves altering an immediate potential cause of a mishap (by not diving in the strong current) and acquiring proper training/experience before attempting such a dive in the future.

The following are examples of contributing causes of diving incidents that may result in diver injury or fatality:

Performance/judgment errors

- Exceeding abilities;
- Lack of or insufficient training for a particular diving activity;
- Diving alone or improper buddy diving;
- Loss of control in current, surf, or waves;
- Failure to adhere to dive plan;
- Failure to recognize risk factors;
- Failure to exercise proper safety precautions;
- Failure to acknowledge personal health factors;
- Failure to use decompression tables/devices properly; and
- Failure to provide a *margin of safety.*

Bad judgment in using equipment

- No alternate air source;
- Improperly maintained equipment;
- Use of malfunctioning equipment;
- No or inadequate pre-dive equipment inspection;
- Inaccurate depth gauge;
- Failure to monitor scuba pressure gauge;
- Overweighting;
- Failure to use a watch or depth gauge;
- Inadequate or insufficient equipment for a given diving situation;
- Improper use of dive computers;
- Improper use of any item of diving equipment; and
- Inadequate training in the use of equipment in both routine and emergency diving situations.

Environmental conditions

- Lack of training for specific environmental conditions such as ice, caves, surf, kelp, cold, current, and so on;
- Failure to analyze environmental conditions prior to committing to a dive; and
- Strong current, heavy surf, and adverse weather.

Risk is the possibility of loss or injury. It can be a statistic which implies the likelihood that injury or death will occur. Benefit is something conducive to personal or social well-being. Safety is the condition of relative freedom from harm or risk. In diving one must strive to maximize safety and benefit and minimize risk. A particular diving situation may be assessed in terms of *risk-benefit* or, in other words, what benefits will be derived from the dive in light of the risk involved.

Keep in mind that it would be impossible to totally eliminate risk from any part of society, let alone scuba diving. Willingness, and even need, to take risks and challenge ourselves can result in important growth experiences. The decision that a diver must make is, "What is an acceptable risk?" Furthermore, the amount of risk that is acceptable for one individual is not necessarily acceptable for another, as capabilities and desires may differ considerably. Recognition of personal limitation is a fundamental basis for safe diving and the prevention of accidents.

Divers can alter these limitations by improving their capabilities through training, physical conditioning, and experience. It is equally important to recognize that capabilities can be reduced due to exhaustion, emotional stress, alcohol consumption, cold, equipment malfunction, and environmental adversities. Individuals can protect themselves by recognizing and admitting to reduced capabilities. Environmental hazards can be reduced by selecting another dive site or waiting for better conditions. Arriving at an acceptable level of risk involves maintaining an adequate margin of safety, and this requires the use of good judgment.

Judgment is the process of forming an opinion by discerning and comparing. It means deciding if a particular diving situation is acceptable—safe or unsafe—for a given diver. It may mean postponing a dive. *In general, a person who routinely takes risks that greatly exceed the realm of accepted diving practices is to be considered an unsafe and unacceptable diving companion.* Exceeding one's abilities may actually be the primary cause of scuba diving injuries and fatalities.

In summary, being aware of the causes of accidents will help you to prevent them. Both your enjoyment and your safety are best assured through understanding your personal capabilities and limitations and those of your companions and equipment. Participation in a given dive should be a conscious decision, based on sound judgment.

The Accident Management Network

An accident management network consists of a number of responders. Seven basic responder groups are usually involved in the management of a serious diving accident, such as decompression sickness or an air embolism. The role of the first responder is obvious — rescue, first aid, and acquisition of medical services. Immediate and proper first aid can make the difference between life or death and ultimately, the successful management/treatment of the injury. *Consequently, the most important role in diving accident management is that of the first person(s) on the scene — the buddy, divemaster, instructor, or boat operator.*

The second response group includes the professional emergency medical technicians and paramedics who will manage the injured diver during transport to a local medical facility. At a local hospital or clinic the third response group includes the emergency room physicians and support personnel. This group will evaluate the nature of the injury, stabilize the patient, and arrange for prompt transport to a hyperbaric medical facility. Improper medical management and unnecessary delay at this point can significantly compromise the patient's recovery potential.

At this time, a fourth response group may be required for medical consultation and information on the availability of hyperbaric treatment facilities — this is DAN. Unfortunately, many physicians are not schooled in the management of pressure-related or diving injuries. DAN provides a vital service to both the diving and medical communities. *It is the responsibility of all divers to provide attending medical personnel with information about DAN and the emergency telephone number (919/684-8111).*

The fifth response group is the medical/technical team that will transport the patient to a hyperbaric medical facility. Depending on the condition of the patient and the distance, either ground or air transport may be used. Generally, the most rapid means of transport is desirable. Most hospitals with hyperbaric chambers have helicopter landing facilities, and the increasing popularity and availability of medical helicopter services increases the likelihood of the use of air transport. For long distance transport, some small jet air ambulances and military transport aircraft can pressurize to sea level pressure during high altitude flight.

Upon arrival at the hyperbaric facility a special medical team trained in the treatment of diving injuries will take charge of the patient — the sixth response group. This team will manage the patient through one or more hyperbaric treatments and subsequent recovery. In serious cases, a final or seventh response group including both physical and mental therapists may be required as a part of the rehabilitation program for the victim.

The care provided by the first responder is the vital link in the chain of events that will ultimately determine the victim's future. *All divers, instructors, divemasters, and boat operators are encouraged to assess their personal level of training and competence in rescue, first aid, and accident management.*

THE FIRST RESPONDER: A PERSONAL PROFILE

The ability of the first responder to rescue a distressed diver and properly manage a pressure-related injury will, of course, depend on the level of training that the individual has received. Depending on the type of course and the instructor, the training in accident management provided to entry level diving students ranges from essentially none to reasonably comprehensive. Some instructors are reluctant to address the serious nature of diving-related injuries in fear of the possibility of heightening the anxiety level of the student. The scared student may drop-out of diving; thus a loss of potential revenue to the entire diving industry. Unfortunately, only a relatively limited number of individuals actually continue up the education ladder.

Unfortunately, very few entry level diving students are trained and competent in life saving, first aid, and cardiopulmonary resuscitation (CPR). The first step in developing a good first responder is the acquisition of American Red Cross (ARC) or equivalent training in Standard and/or Advanced First Aid (including CPR) and Advanced Lifesaving [1, 2, 3, 4, 5]. Many divers and instructors may challenge this statement on the basis that such a requirement is too time consuming and expensive for the average individual. They may fear that if people get the impression that they must go to such extremes to be good divers, they might reject diving in favor of another sport. However, training and certification in these three areas can be accomplished in about 40 hours, depending on the type of course, at minimal cost to the student. ARC chapters throughout the country offer thousands of courses each year. *And I suggest that every citizen, not just scuba divers, should have at least some level of competence in CPR, first aid, and lifesaving.*

Ideally, the above-mentioned training should be a pre-requisite to entry level scuba diver training. It is very difficult for a diving instructor to teach in-water rescue and resuscitation techniques unless the student has a basic understanding of lifesaving and CPR fundamentals. First aid for pressure-related accidents is somewhat unique to the sport and not addressed in ARC first aid training. However, first aid fundamentals such as the management of shock, thermal problems, and injury assessment procedures are addressed in ARC courses, and these fundamentals are basic to proper diving accident management.

Unfortunately, it is unlikely that the day will ever come when a prospective diving student will be required to provide evidence of such training prior to entering a diving course. In fact, we must consider ourselves fortunate if some entry level divers can swim 200 yards and stay afloat for 10 minutes without the use of mask, fins, or snorkel. A few individuals suggest that even this swimming requirement is too rigid and demanding of prospective students.

Fortunately, all of the diving instruction agencies have developed and promoted diver rescue and accident management speciality courses [14, 15, 25, 35, 47, 49, 59]. *All entry level divers are encouraged to seek continuing education through advanced and specialty diving course offerings such as Medic First Aid and Rescue Diver.* These courses should be completed as soon as possible following entry level training. These speciality courses include 20 to 50 hours of instruction depending on the instructor and the sanctioning agency's requirements. However, divers must keep in mind that some of these courses may not provide comprehensive coverage in the fundamentals of standard first aid, CPR, and lifesaving. Additional ARC or equivalent training may be required.

ESSENTIALS OF ACCIDENT MANAGEMENT

Mental Preparation. To deal with an injury in a diving situation, you must first acknowledge that a diving accident can occur. Many divers, especially entry level divers, are protected from the realities of diving. There is great concern that some individuals will not enter (or continue) diving if diving injuries are openly discussed. Thus, many individuals truly lack any knowledge of diver and pressure-related injuries and the serious nature of scuba diving.

Furthermore, modern trends in diving instruction suggest that entry level course duration and content may be even further reduced. Complete pool and theory training is now offered in a weekend program or three class periods. This barely leaves time for the most basic fundamentals.

In my opinion, every diver must have a working knowledge of accident management and first aid. You must be able to organize a response and apply it to the situation at hand. Adequate planning includes preparing a simple, yet effective, emergency plan for the particular dive site so that you may provide proper care and evacuation for the injured party.

A prudent group leader will visualize the *worst accident scenario* for a given location and diving activity and mentally rehearse the management of that hypothetical accident. Some leaders/divers will actually sketch an accident management flow diagram. Others will systematically develop specific procedures for each dive site and record them on note cards or in a notebook that can be placed in their first aid kit or briefcase. Once the accident has occurred it is often too late to identify the most satisfactory course of action.

The accident management plan may include, but not necessarily be limited to, the following:

* Communications (location of nearest telephone, ship-to-shore radio, etc.);
* Transportation (boat, aircraft, emergency vehicle);
* Emergency medical/paramedical and advanced life-support (location and contact procedures);
* Location of nearest hospital or medical facility;
* Diver Alert Network number for consultation; and
* Name, address, and telephone number(s) of a relative or guardian for each diver in party (in the event that permission for treatment, consultation, or unusual medical procedures is required).

Physical Preparation. Physical preparation involves the ability to actually perform rescue and first aid. Reading a book on giving CPR is a good place to start; however, this provides incomplete knowledge until the physical experience of actually performing CPR has been repeated often enough to master the skill. Some dive clubs and advanced diving classes actually stage *practice accidents* so that members can rehearse.

Group Preparation. Although all members of a dive group should have a working knowledge of first aid and accident management, a few individuals will generally have more advanced knowledge and experience. These individuals must be identified by the leader and known to all members of the group. Ideally, a dive leader will have advanced first aid training and/or will specifically include a person with such capability in the dive group. All members of the group must consider what they would do if someone was injured or lost. Too often *NO ONE* ever thinks about the unfortunate possibility of an accident occurring.

Material Preparation. Material preparation for management of a potential accident includes acquiring, testing, organizing, and packaging appropriate equipment and supplies needed for the diving activity. In addition to all personal diving equipment, this includes personal and group first aid items. Naturally, divers traveling to the Caribbean will not be able to include a backboard and oxygen delivery system in their first aid kit. However, both individual divers and dive groups must make every effort to include (or assure availability of) such items for both local and expedition or vacation outings.

THE DIVER'S FIRST AID KIT

All divers or dive groups should carry a first aid kit. Individual diver kits should be small and compact, yet contain the necessary items to deal with cuts, abrasions, sprains, pain, burns, and so on, in accord with routine first aid requirements [1, 5, 29, 32, 39]. Additional items may be required for specific geographic locations (i.e., a kit for tropical ocean diving will generally include items not generally considered necessary for northern quarry diving). The diver's first aid kit should include, but not necessarily be limited to, the following:

* Assorted dressings and bandages (adhesive bandages, sterile gauze pads, roller gauze, athletic tape, triangular bandage, and elastic bandage);
* Antiseptic and cleansing solutions (alcohol pads, povidone iodine solution/swabs, etc.)
* Pain relief (aspirin or equivalent);
* Decongestant;
* Motion sickness preventive (boat diving);
* Sunscreen and sunburn medication;
* Snake bite kit (for some geographic areas);
* Vinegar (for tropical diving);
* Heat producing packet (or materials for heating water; for tropical diving);
* Tweezers and/or needle;
* Pocket mask; and
* Oxygen delivery system.

Consult my publications on hazardous marine life and adventure travel for more information on special first aid kit requirements [51, 52].

The most important item of equipment for dealing with a true diving emergency is an **oxygen delivery system**. The ability to immediately administer 100% oxygen to a victim of air embolism, decompression sickness, carbon monoxide poisoning or near-drowning cannot be overemphasized. Although the administration of oxygen by first aiders is not included in American Red Cross Standard First Aid Training, all divers are encouraged to learn how to operate a simple oxygen delivery system and adminster oxygen to diving accident victims. The equipment is relatively simple and similar in principle to scuba. Administering oxygen to a conscious, spontaneously breathing person with this equipment is not difficult and is usually safe [43]. Special courses are available from community colleges (EMT courses) and some diving organizations to assist divers in learning to use oxygen delivery equipment and understanding airway management [17, 18, 38].

Proper management of a victim of an air embolism includes keeping the victim in a prone left-side position. Ideally, a special stretcher or backboard is a desirable addition to the first aid kit. However, because of travel and space restrictions the first aider may be required to improvise in many situations.

Many people draw a false sense of security from the physical presence a first aid kit. Without the knowledge of what to use or when to use it, the items in a kit are useless. The competent first aider should be able to accomplish a number of first aid procedures with no more than two bare hands and the materials normally found in a diver's equipment bag and the surroundings.

RESPONDING TO AN ACCIDENT

When a diving accident occurs, many things must be done. Some must be done immediately, while others may be delayed until the situation is better understood and the victim is safe from further injury. The following steps have been adapted from mountaineering first aid practices [39] and, in order of priority, can be followed with any diving accident.

Take Charge of the Situation. The designated leader or first aid (medical) person must take charge of the situation immediately in order to maximize group response in minimum time. Available personnel must be organized and specific tasks assigned. If no leader has previously been designated, then someone must become the self-appointed leader and assume these responsibilities. Other members of the party must become good followers.

Rescue the Victim. If the victim is still in the water, rescue efforts will generally be initiated by the nearest diver or buddy. If the divers are a long way from the beach or boat, the divemaster may elect to dispatch other swimmers or a pickup boat to provide assistance. In-water resuscitation may be necessary during return to base if the distance is great. However, avoid unnecessary delays in moving the victim to a safe, stable platform.

Management of an unconscious victim in the water or removing that victim from the water into a boat or on to a beach can be a difficult task requiring considerable strength and/or special equipment/techniques. A team of only two divers can find themselves in a difficult, if not impossible, situation if one of the divers is rendered unconscious. Furthermore, a very small diver might have great difficulty in handling a larger diver. Use discretion in selecting diving partners and always have beach/boat support personnel. Rescue techniques and in-water resusitation is discussed in various diver rescue manuals [14, 15, 44, 47, 49].

Occasionally, a diver will surface and report separation from and loss of a buddy underwater. If the lost diver has not surfaced in accord with prescribed procedures, an underwater search must be immediately organized. Before commiting to an underwater search, the water's surface must be thoroughly searched by visual scanning and with the pick-up boat. Concurrently, an underwater search team is selected, equipped, briefed, and, if the surface search is unsuccessful, deployed. Systematic underwater search is discussed in several diving textbooks and search and rescue manuals [30, 35, 44]. Generally, the simple circle search pattern is most effective for an untrained search team to organize and execute. Ideally, the search should begin at the last known position of the lost diver. A circle search line can be attached to a heavy anchor or submerged object. All dive leaders and, ideally, all divers, should include a simple reel or line bag with at least 100 feet of line in their personal dive kit.

DO NOT EXPOSE UNQUALIFIED PERSONS TO UNNECESSARY RISK DURING SEARCH AND RESCUE OPERATIONS!

Select the underwater search team carefully. Assign novice divers to perform selected surface tasks. Ideally, a prudent dive leader will have selected one or more potential underwater search teams in advance as part of the emergency planning procedure.

Frequently, the victim of a diving-related illness or injury will be on the boat or beach before symptoms appear. Keep in mind that symptoms of decompression sickness will generally appear within one hour following the dive; however, delays up to 36 hours have been documented. Air embolism is generally evident within minutes of the barotrauma.

Perform Urgent First Aid Procedures. The first responsibility of the *first responder* or first aider is to treat conditions that can cause loss of life. In the water this often means provisions for immediate flotation in order to prevent possible drowning. Keep in mind that a conscious victim can lose consciousness without warning.

Evaluate the victim at once, at a minimum, to determine if breathing has stopped, if there is no pulse, or if bleeding is severe. Treat these conditions immediately!

Protect the Victim. Now that immediate life-threatening factors such as drowning, breathing, circulation, and bleeding have been addressed, measures must be taken to protect the victim from further physical and *emotional* harm. Whatever the extent of the injury, the victim will require protection from the environment, either hot or cold. Talk to the victim, explaining what you are doing and what you intend to do. Do not allow a crowd to surround the victim! Do not discuss the critical nature of the victim's condition with other persons where he can overhear the discussion! Do not add to the victim's emotional distress by expressions of regret about his condition!

Provide the victim with gentle and encouraging expressions of reassurance! Keep in mind that certain marine life injuries, such as the bite of the blue-ringed octopus involves the injection of a neurotoxin and a neuromuscular blocker, resulting in a painless skeletal paralysis. The victim's conscious state is initially normal in such cases, even though he may not be able to open his eyes or respond to his environment. Even when administering CPR in such cases, reassure the victim, who may hear you but cannot communicate to you. Let him know that everthing will be all right and that you understand his condition.

NEVER LEAVE THE VICTIM UNATTENDED!

Even a conscious and apparently stable victim of air embolism, decompression sickness, gas supply contamination, or some marine life injuries can cease breathing without warning.

Prevent/Manage Shock. Observe the victim for general reactions and shock. Shock can be life-threating! It is advisable to lay the victim down and keep him as quiet as possible. The symptoms of *shock* include glassy eyes with dilated pupils; wet and clammy skin; weak and rapid pulse; pale or ashen skin tone; increased breathing rate (shallow or deep and irregular); and sensations of coldness [1]. First aid measures for prevention and management of shock [1] include keeping the victim lying down and covered only enough to prevent loss of body heat. No attempt should be made to add heat since raising the surface temperature of the body can be harmful. Elevate the feet or end of stretcher 8 to 12 inches.

Giving fluids by mouth has value in shock; however, fluids should only be given when medical assistance is not available within a reasonable amount of time (delay of more than one hour). Fluids should not be given when the victim is unconscious, vomiting/likely to vomit, or experiencing seizures, since such states may result in aspiration of fluids into the lungs. Water that is neither hot nor cold (preferably a salt-soda solution, 1 level teaspoon of salt and 1/2 level teaspoon of baking soda per quart of water) is given at about 4 ounces every 15 minutes. Do not give the victim sea water. Discontinue fluids if the victim becomes nauseated or vomits. Obtain medical assistance as soon as possible. *Keep in mind that physiologically or emotionally induced shock may be associated with any diving injury.*

Check for Other Injuries. Once the life-threatening emergencies have been identified and controlled, the victim should be examined in detail to determine if there are any other problems, either major or minor.

Plan a Course of Action. Once urgently needed first aid has been given, protection from the environment provided, and other injuries/problems identified/corrected, time must be spent planning further tasks. Basically, the situation needs an objective analysis and the development/execution of a comprehensive plan of action.

Execute the Plan. After a complete examination of the entire accident situation and development of a course of action, execute the plan. Generally, this involves acquisition of emergency medical services, transportation to a medical facility, stabilization of the patient at that facility, and, in the case of decompression sickness and air embolism, transport to a hyperbaric treatment facility.

The responsibilities of the first aider will generally be completed when the victim's care is transferred to the emergency medical team. *However,* the leader/first responder should follow the victim's care through the system to insure that proper measures are taken to deal with the diving-related illness or injury. In the event that emergency medical personnel or hospital/clinic personnel are not knowledgeable in the proper management procedures for pressure-related accident victims, the first responder may have to provide further assistance in seeking appropriate consultation and care.

Ideally, the first responder (or a designated member of the dive team) should accompany the victim to the final treatment facility if at all possible. Not only can this person assure that proper care is given, he may be able to provide valuable information about the accident situation and victim to the treatment team. All divers should include a copy of the DAN manual [43] in their kits. The manual can be very valuable to emergency and medical personnel who are unfamiliar with diving-related accidents and their management.

LIFE-THREATENING EMERGENCIES

Absence of breathing or a pulse may result in death after only a few minutes. Since the diving accident victim is often in or under water when the incident occurs, many serious diving-related accidents must ultimately be managed as near-drownings regardless of the initial cause. Near-drowning is no doubt the most common life-threatening situation encountered in diving. If the victim is not breathing, the first responder must begin mouth-to-mouth artificial respiration as soon as possible. When there is no pulse evident, cardiopulmonary resuscitation (CPR) is necessary.

When you approach an apparently unconscious victim, you must immediately check for absence of breathing and pulse [1, 12, 39]:

* *Check for unresponsiveness!* Speak loudy to the victim and gently touch or shake; if no response, open airway.

* *Position the victim!* Roll onto back if necessary.

* *Open airway!* If there is no reason to suspect a neck or back injury, place one hand on the victim's forehead. Place the tips of two fingers of the other hand under the bony part of the victim's chin. Tilt head and lift the jaw up and forward. Avoid closing the victim's mouth or pushing on the soft part under the chin.

  If there is reason to expect a neck or back injury, use the jaw thrust method. Place your hand on each side of the victim's head, and push the base of the jaw up and forward. Do not tilt the head back.

* *Check for breathing!* With your head turned so that you can observe the victim's chest and abdomen, place your ear and cheek next to the victim's nose and mouth. *Look* for movement of chest and abdomen. *Listen* for breath sounds. *Feel* for air movement against the side of your cheek.

  If you see chest or abdomen movement without hearing or feeling air movement, suspect airway obstruction. Recheck head/jaw position to assure that airway is open.

* *If the victim is not breathing!* Give *two full* breaths and proceed with resuscitation effort as required. Pinch the victim's nose shut. Open your mouth wide and take a deep breath. Now, make a tight seal around the outside of the victim's mouth. Give two full breaths pausing between each breath so you can breathe. Observe the chest for movement (rise and fall) and listen/feel for escaping air.

* *Check for circulation!* Place your index and middle fingers on the victim's voice box and then slide your fingers down the side of the victim's neck to the space between the voice box and neck muscle. Feel for a pulse for 5 to 10 seconds. If a pulse is present, continue with mouth-to-mouth artificial respiration. If not, give CPR.

Keep in mind that victims of *cold-water submersion* (water below 68° F.) may be successfully resuscitated even though they have remained submerged without breathing for more than 30 minutes [45]. Consequently, a near-drowned diver should receive complete resuscitation efforts even though the period of submergence may be relatively long.

The procedures for safe and effective mouth-to-mouth artificial respiration and cardiopulmonary resuscitation are beyond the scope of this presentation. Learning to administer CPR requires special training and practice on mannequins in accord with American Red Cross or equivalent training/certification procedures [1, 2, 3, 5].

Major wounds can cause severe, life-threatening bleeding. Although not as common in diving accidents as absence of breathing and pulse, severe bleeding can also be fatal in minutes. Quick, decisive action is mandatory. Severe bleeding injuries in diving are more likely to be associated with such incidences as shark attack or being struck by a boat propeller.

Severe bleeding may be controlled by applying direct pressure to the bleeding area. If the wound is on a limb, elevate the bleeding extremity. If these measures do not control bleeding, application of pressure to an artery, at a pressure point, can reduce the flow of blood through the artery. If these measures fail, and the wound is on an extermity, a tourniquet may be required. ***The decision to apply a tourniquet is in reality a decision to risk sacrifice of a limb in order to save a life!*** Specific first aid procedures for the management of severe bleeding are addressed in American Red Cross first aid courses and manuals [1, 4].

BASIC FIRST AID

This booklet has been prepared to address the management of specific diving and pressure related illnesses and injuries. However, divers must also be capable of administering proper first aid for other types of injuries. For example, more divers are probably injured in motorbike accidents on Bahamian and Caribbean islands in a single year than in diving-related incidences over a 10 year period.

One of my former students reported an incident involving a diver entering the water using the backward roll method from a boat. Another diver, already in the water, was rendered unconscious when the entering diver's scuba cylinder struck her on the head. Fortunately, the injured diver only sustained a mild concussion. However, skull fracture and cervical (neck) injury could have resulted in life-threatening or crippling consequences. Ironically, the divemaster never even considered the possibility of such serious injuries, *dragged* the unconscious/dazed victim into the boat without precaution, and allowed the individual to continue diving upon regaining consciousness.

Any diving expedition leader will routinely deal with a variety of minor injuries including cuts, abrasions, insect bites, blisters, sprains, and sunburn. On the other hand, the leader must be prepared to provide first aid for neck, head, and back injuries; temperature-related problems such as hypothermia and heat stroke; drug abuse; fracture; and burns. Basic injury management procedures are included in numerous manuals and textbooks [1, 5, 9, 12, 29, 32, 44, 59]. As previously stated, all divers, and especially divemasters and instructors, are encouraged to complete the ARC first aid training program or its equivalent. Furthermore, dive expedition leaders are encouraged to carry a complete first aid kit, especially when diving in remote locations. For general first aid information I recommend that the diver acquire and read, at a minimum, the following manuals (most current editions):

* *American Red Cross Standard First Aid Workbook* [1]

* *Mountaineering First Aid* [39]

EXAMINING AN INJURED DIVER

Once the first responder has rescued the distressed diver, dealt with immediate and life-threatening injuries, and taken measures to protect the diver from further harm, *a complete assessment* of the diver's condition must be completed. You must identify if the diver has any other conditions or injuries which pose potential risk to the individual's well-being. In addition, you must be in a position to provide complete information to emergency and medical personnel. Finally, you must have a *baseline* by which to recognize subsequent changes in the victim's condition.

Assuming that the victim is conscious, introduce yourself to the victim and give some indication of your first aid capability (if not already known and recognized by the victim). *Ask the victim if you may help her.* The victim has the right to refuse your assistance. Additional explanation may help the victim to accept aid. Keep in mind that the victim may not be aware of the seriousness of her injury/illness.

Even if the victim appears to be unconscious, not breathing, and unable to communicate, she may be able to hear everything you say and be aware of what is happening. You must reassure the victim that she will be all right and that you understand her condition.

Do not discuss the serious nature of a badly injured victim's condition directly in the presence of the victim! The resulting emotional trauma can add considerable complication to the subsequent management of the injury or illness. You can actually *create psychosomatic symptoms*, especially in victims of suspected decompression sickness. Ask the victim the following:

* What happened?

* How did it happen?

* When did it happen?

* What hurts?

* Do you have any other problems? Medical conditions? Allergies?

* Are you exhausted? Cold? Hot?

Information gained from a conscious victim is important in identifying first aid needs. In the event that the victim later loses consciousness, this information may be very important to the emergency medical personnel and attending physician. Ask similar questions of others who might have witnessed the accident or who know the victim. Record all information.

In examining a victim the following basic principles should serve as a guide [33]:

* Do no further harm to the injured person.

* Be complete and systematic.

* Use direct observation.

* Compare left and right body parts.

* Have one person do the examination.

* Record all of your findings (or have an assistant record information).

* Record both signs (observable indications) and symptoms (sensations reported by the victim).

Since this booklet deals primarily with diving and pressure-related injuries or illnesses, the details of examining a trauma victim such as someone involved in a mountaineering accident, motor vehicle accident, or similar incident will not be addressed. Readers are referred to *Mountaineering First Aid* for an excellent discussion of performing a ***head-to-toe examination*** of a trauma victim [39].

Vital Signs

Observing and recording vital signs is an essential part of any examination. These signs include pulse, breathing, skin color and temperature, pupillary reaction, state of consciousness, sensation of pain, and ability to move. Vital signs must be recorded initially and periodically thereafter. If the victim's injury is apparently minor, frequent taking of vital signs is not necessary. However, in a seriously injured or apparently unstable victim, vital signs should be taken every ten to fifteen minutes. These vital signs are very important in determining if the victim's condition is stabilizing or deteriorating.

A complete record of the examination and the vital signs must be documented in writing. Record information in a notebook or on a special examination form.

Pulse. Pulse can be felt at the wrist or on the neck. Count the number of beats in fifteen seconds and multiply by four. Also note the strength and regularity/irregularity of the pulse. An adult's pulse rate is normally 60 to 80 per minute; 80 to 100 per minute in children. Fear and exercise may increase heart rate.

Breathing. An adult normally takes 12 to 15 breaths per minute (20 to 30 for young children). Determine if breathing is deep or shallow and easy or labored (difficult). Is there the presence of gurgling sounds or sputum/froth coming from the mouth or nose? Such conditions as labored breathing and/or froth could be a sign of pulmonary barotrauma.

Skin. Normal skin coloration has an underlying reddish tone. Absence of this tone is seen as ashen or pale color in light-skinned persons or dull ashen gray in dark-skinned persons. Bluish tones may indicate oxygen deficiency or carbon dioxide retention due to inadequate ventilation or circulatory deficiencies. A mottled appearance may indicate decompression sickness. Note the presence of sweat (or lack of perspiration on an exceptionally hot day) and if the skin is unusually warm or cool.

Pupils of the Eye. Abnormal pupil response can be an indication of central nervous system dysfunction or head injury. This observation is very important in assessing diving accident victims and will be discussed in more detail later. Size variations, movement, and reaction to light should be documented.

State of Consciousness. The victim's state of consciousness is another indication of central nervous system function. Note departures from normal alertness, combativeness, confusion, speech (clear or slurred), or personality changes evident to persons who know the victim.

Pain and Movement. Specific complaints of pain in lower back, legs, and joints may be symptoms of decompression sickness. Lack of reaction to pain-producing stimuli may denote damage to the central nervous system. Even an unconscious person will move away from pain stimuli if there is no paralysis of appropriate muscles. When you touch an injured victim ask if he can feel the touch. Movement should be accomplished easily upon command. Such tests should begin with small movements such as asking the victim to wiggle toes or fingers. Then progress to the use of large muscle groups. Strength tests, to be discussed later, are commonly used to determine neurological deficits. Note any specific pain reactions or deficiencies and movement capabilities.

The Neurologic Examination

The first responder will seldom have to perform a neurologic examination. However, in the event that an accident occurs in a remote location where neither emergency medical services or physician services are available, the first responder may have to provide a detailed assessment of the victim's condition to physicians by radio or telephone. In suspected cases of air embolism and decompression sickness, obvious neurological symptoms or lack of such symptoms may be very important in determining the seriousness of the illness and a proper course of action.

By following a simple guide, any diver should be able to perform a neurologic examination. Contrary to popular belief, doing a simple neurologic examination in the field does not require as much training or understanding of the nervous system as one might think. It only requires the ability to recognize and report *obvious abnormalities.* Most neurological symptoms are obvious, even to untrained people, but their significance is missed. What is often lacking is the discipline to thoroughly evaluate a distressed diver and look for the less obvious symptoms. The examination procedures given here have been modified from those given by Daugherty for use by diver-medics in commercial offshore diving [20].

A neurologic examination performed by a first aider is not intended to serve as a major diagnostic factor. Most often diagnosis is made by competent physicians at a medical facility. The examination does not test every single nervous function. However, it can be complete enough to detect and monitor important problems. The initial examination serves as a baseline for repeated evaluations. The examination can be directed by a physician by radio/telephone or later discussed with a physician in determining an appropriate course of action. The examining first aider should systematically follow the guidelines given below and record the findings (including the time of the initial and subsequent examinations).

Mental Alertness. Ask the diver who he is, where he is, and the approximate time of day. Test memory by asking simple questions about his dive buddy, the dive location, what he ate at his last meal, his mother's maiden name, etc. Have him perform simple arithmetic problems in his head. Do not use trick questions! All that is expected is the ordinary mental function that everyone is assumed to have.

Ordinary conversation is often the best mental examination procedure. The first aider can observe the diver's response to questions and instructions, then ask specific questions if he/she becomes suspicious. Mood and personality changes are often a subtle sign of brain dysfunction, and may only be obvious to someone who knows the diver well. If you, the first aider, do not know the diver, have someone who does with you during the evaluation.

An excellent example of *personality change* was demonstrated when a resident in an emergency room interpreted the rather dull, unintelligent responses of a sheriff's department diver as "normal for a person in that profession." He was preparing to discharge the patient when a diving physician arrived on the scene. The line-tended scuba diver had been rapidly and unsuspectingly pulled to the surface as a result of signal misinterpretation by a tender. The circumstances of the incident prompted the diving physician to perform a more thorough examination. Slight neurologic dysfunction was detected and the diver was recompressed. The diver immediately responded to treatment and exhibited pleasant, outgoing, and intelligent personality characteristics after the treatment. In this case a victim of air embolism was almost discharged without treatment.

Cranial Nerves. The examiner does not have to know the names and Roman numbers of the cranial nerves; such knowledge is unnecessary and soon forgotten. The first aider should learn to recognize functional abnormalities and report them in simple terms (i.e., "the right side of the face sags" or "the left eye cannot look outward").

Eyes. While following a moving finger, both eyes should track the movement together, up and down and side to side. Both pupils should be round and approximately the same size. When a light is shined into one eye, both pupils should react; test both eyes. Pupils should constrict when gaze is shifted from far away to 4 or 6 inches in front of the nose.

Face. Both sides should move equally when the diver is asked to raise her eyebrows, frown, close her eyes tightly, smile, or show her teeth.

Mouth. The soft palate (soft fleshy back part of mouth) and uvula (small, fleshy process hanging down from the middle of the soft palate above the back of the tongue) should rise when the diver says "AH". When the tongue is stuck out it should not deviate to either side and the diver should be able to wiggle it from side to side.

Hearing. Ask the diver if she notices anything unusual about her hearing such as roaring, humming, or ringing in the ears. With the diver's eyes closed, test her ability to hear whispers or the rubbing of fingers together. See how far from her ears the diver can hear the sound. Compare with your own hearing.

Neck Muscles. Have the diver turn her chin sideways against the palm of your hand. Feel the force and observe the neck muscle contraction on each side. Pull down on the wrist and have the diver shrug each shoulder upward against this resistance. Both sides should have approximately equal strength and movement.

Strength. The strength of major muscle groups can be assessed by feeling the force exerted by the victim against a resistance applied by the examiner. The right and left sides of the body are compared.

Upper Extremities. To test grip strength have the victim grip the examiner's index and middle finger and tell him to squeeze as hard as possible. Grip the diver's hand and have him pull and push against the resistance. Keep in mind that the dominant hand and arm may be stronger; note significant differences. Have the victim hold his hands straight out in front and have him attempt to bring his hands together and apart against a resistance. Have the victim hold his elbows out to the side and resist pressure applied to force them downward.

Trunk. Weakness in the trunk is more obvious since the victim will have difficulty sitting, standing, walking, or remaining upright. Test include observing sit-ups and straight leg lifts.

Lower Extremities. Have the diver do deep-knee bends and toe-ups on one foot at a time. Hold the victim's ankle and ask him to straighten and bend the knee against resistance. Have the victim raise his big toe and hold it strongly against resistance.

Sensation. Numerous tests are possible, but only a few are significant to the first responder. Sensations often obvious to the victim are pain, numbness, tingling, hot-cold, or a wooly, heavy feeling in extremities. The examiner should keep in mind that an injured victim will generally have some sensation or feeling. Therefore, ask the victim, "Does this feel normal?", not "Can you feel this?"

Light Touch. Drag fingers lightly over the front and back of the victim's arms, trunk, and legs with particular attention to the fingers, toes, palms and soles of feet. Touch the hairs on the arms and legs lightly. Compare the right and left sides.

Sharpness and Dullness. Using the point and head of a safety pin or the point and eraser of a sharp pencil, press on the skin and ask the victim to identify sharp versus dull sensation. Compare the right and left sides and keep in mind that some areas will normally be more sensitive than others. Gently drag the point of the pin across the body surface (vertically on the body and around the extremities) looking for strips of dullness or different feeling. Take care to not scratch the skin.

Position. With eyes closed, have the victim determine the direction in which the examiner is moving various joints (up or down).

Balance and Coordination. The examiner should try these tests himself in order to have some idea of their difficulty.

Gait. This may be the best all-purpose test. Ordinary walking is a deceptively simple act which we do without thought. However, it is impossible to do normally without an intact nervous system. Slight abnormalities in a person's walk are surprisingly easy to detect, even by an untrained observer. The test can be made more difficult by having the diver walk heel to toe (forward and backward) in tightrope fashion. If on a vessel, be certain to consider response to natural vessel motion. Also, in examining a stranger be certain to determine by inquiry whether the individual has any normal gait variations (i.e., a limp).

Rhomberg Test. Have the victim stand with feet together, arms outstretched, and then close his eyes. Most people will weave a little, but the victim should be able to stand in this manner without falling over or leaning severely in one direction.

Alternating Movements. The diver should be able to jog in place, tap toes, and clap hands smoothly without clumsiness.

Orientation in Space. Without looking, have the diver touch his index fingers over his head, separate, and touch again. Have the victim alternately touch his right and left index finger tips to his nose with eyes closed. While sitting and with the eyes closed, have the diver put the heel of one foot on the opposite knee, then slide the heel down the shin bone to the big toe. Repeat with other foot. With eyes open, have the diver place his index finger into the center of the examiner's palm, which is held in different locations, alternating right and left sides.

Unconscious Victim. The most important factor to consider in this case is the fact that the diver is unconscious. Unless it is immediately evident without doubt that the unconscious state resulted from some other problem such as physical trauma, drug usage, etc., the diver must be considered to be a victim of air embolism or decompression sickness. Even in cases such as trauma and drugs this possibility cannot be totally dismissed. I recall one suspected air embolism victim that I treated who had reportedly consumed quantities of a hallucinogen and alcoholic beverage prior to diving. The diver apparently surfaced rapidly as if in panic and lost consciousness. Since an objective neurologic exam could not be performed, even when the victim regained consciousness, recompression was absolutely necessary. The victim responded to treatment and was subsequently discharged without residual effects.

The first aider can do little but monitor the victim, assure breathing and circulation, and give appropriate first aid for suspected air embolism. In the event that the consulting physician wants to gain some insight into the neurologic state of the victim, he may direct the first aider to test sensation to pain by pinching muscles, fingertips, or toes, or jabbing with a pin. The normal response is withdrawal of the limb or other protective response. Failure to respond usually means that there is no feeling in that area.

Another pain response test is to use the knuckle of the index or middle finger to press hard into the sternum (breast bone) with a rotating or grinding motion. This can cause great pain, but do no harm (unless unreasonable pressure is applied). The victim may respond in a variety of ways depending upon the state of coma. Note if all extremities react to this stimulus. Compare upper to lower, right to left. If the victim clearly responds to pain but fails to move a limb, this suggests paralysis or severe weakness.

Hold both eyes open to observe reaction to light and if the pupils are approximately equal. Note if the eyes will track or if one moves and not the other.

As previously stated, the first responder will seldom, if ever, have to perform a neurologic examination. In the rare situation of isolation from immediately available medical services, the first aider might have to examine a victim and report the findings to a physician by radio or telephone. However, there are situations in which a dive buddy or leader may use some of the above procedures (primarily those requiring observation only) to determine if a diver has been adversely affected during an emergency ascent or other type of incident.

For example, if a diver experiences an uncontrolled ascent, that diver should not be allowed to immediately submerge again. Rather, the diver should return to base (boat or shore) under positive flotation, relax, and be observed for at least 30 minutes. The observer must take great care to not alarm or emotionally distress the diver with probing questions. Simply observe for obvious indications of normal body function or dysfunction. If dysfunction is noted, appropriate measures must be initiated to further evaluate the diver and administer proper first aid.

The Incident

A complete understanding and documentation of the circumstances or conditions of the accident can be very important in determining the appropriate first aid measures and, ultimately, the medical management of the victim. For example, ***a diver experiencing neurological deficiencies following an emergency ascent must be considered as an air embolism victim!*** Neurological deficiencies or joint pain following a day of extensive diving close to or beyond the no-decompression limits suggest a high probability of decompression sickness. On the other hand, a person who complains of discomfort in a knee joint following a single dive to 30 feet is probably *not* suffering from decompression sickness.

The first responder should, if possible, obtain a complete pre-incident history of the victim and activities including, but not necessarily limited to, the following:

* Signs/symptoms of respiratory infection (common cold, coughing, etc.) prior to the dive;
* Depth and duration of all dives within the past 24 hours (include previous days if diving is conducted every day);
* Recalculation of dive schedules and repetitive dives in order to determine if there were any mistakes in the original calculations;
* Does the diver recall any incidence of physical injury such as twisting a knee, back strain, etc., associated with the dive in question or other activities prior to or following the dive;
* Amount of sleep, alcohol consumption, food intake, and exercise/strenuous activity in past 24 hours;
* Prior incidences of decompression sickness, pulmonary barotrauma, and other diving (pressure) related illinesses; and
* Exertion level and thermal condition during dive(s) in question.

QUESTIONABLE SITUATIONS

Sometimes a diver will experience fatigue, a variety of minor pains, and, simply, feel *poorly* following a dive. There are countless factors that could account for such symptoms or feelings. A generation of more mature divers now bring numerous aches and pains of aging muscles and skeletons to the dive site with them. Some days I feel "bent" after taking a shower. Athletically inclined divers may experience residual pain from tennis or jogging. Hours in an airplane seat on the way home can produce discomforts that may mimic mild symptoms of decompression sickness.

Quite often the diver must ask herself, "What are the chances of my having decompression sickness?" *Ironically, fatigue is a definite symptom of decompression sickness.* Fatigue is also a symptom of thermal stress. If every diver who complained of fatigue following a dive or at the end of a diving day were to submit herself for treatment of decompression sickness, large hyperbaric chambers would be required at or near all dive sites. The diver and the dive leader must be prepared to *sort out* the possibility of real decompression sickness versus simple fatigue and general physical discomforts associated with exercise and environment.

There are no simple rules for such determinations except judgment, common sense, and objectivity. Emotional distress and fear of decompression sickness can produce a host of psychosomatic symptoms, especially if other persons begin to support the premise of serious illness. ***If a diver complains of discomfort or illness following a dive, the possibility of decompression sickness or pulmonary barotrauma must always be considered.*** However, immediate and hasty diagnosis of a minor discomfort or illness as a serious diving-related injury or illness can lead to difficult and expensive consequences.

Ideally, it would be desirable for any individual who is suspected to be a victim of air embolism or decompression sickness to be transported to a hyperbaric facility and examined by a diving physician as a precautionary measure. Unfortunately, in scientific and recreational diving such precautionary procedures and hasty actions could most often be an expensive and complicated procedure. For example, let's assume that the incident occurs on a Caribbean island. In haste, a decision might be made to immediately transport a questionable victim back to Miami for evaluation or treatment. The *panicked* leader orders a jet air ambulance from the states to pick up the victim and deliver him to Miami.

Most private air ambulances will not take off unless payment is appropriately guaranteed or the bill is paid in advance. The cost of this service from the locations in the Caribbean to the states may run as high as $7,000 to $10,000. Upon arrival in Miami, the victim may be found to be asymptomatic and hyperbaric treatment not necessary. A more prudent decision would have been to monitor the victim for a short time to determine if the symptoms subsided or intensified. In addition, a telephone call to DAN at Duke University would have provided the leader with consultation and assistance in developing a proper and reasonable course of action.

In cases of minor, and probably non-diving related, discomforts the diver and dive leader should objectively analyze the dive schedules and activities for the day (and prior days of consecutive diving) to determine if there have been any mistakes or violations of proper diving schedules. The diver should simply *relax* and not submit to further emotional or physical stress. The diver should maintain an awareness of increased severity of symptoms.

For example, if a diver with minor pain or discomfort in the knee has only injured the knee by twisting or physical contact, the discomfort should not worsen significantly if the individual relaxes and does not place weight on the leg. Also, the pain should intensify if the painful area or joint is physically touched or pressed against. However, if the discomfort is a result of decompression sickness, it will probably intensify and spread within a few hours, even if the diver is resting. In addition, discomfort should not intensify with touching. Furthermore, other areas of the body may develop symptoms indicative of decompression sickness. In cases of intensifying or spreading pain and development of neurological abnormalities, serious injury must be suspected and appropriate management measures begun.

Some authorities recommend that a person experiencing minor, questionable discomforts following a dive (or series of dives) be placed on ***precautionary oxygen breathing*** and consume plenty of fluids for a period of one to two hours. One dive tour leader reported an incident involving a diver who had made multiple dives each day for several days. The dives were probably within the no-decompression limits;

however, since the diver was using an underwater propulsion vehicle for multi-level dives, exact depth-time relationships could not be established. Following a repetitive dive the diver complained of severe headache, neck pain, and extreme fatigue. The diver was directed to rest and breathe oxygen for an hour or so and the discomforts disappeared. Wisely, the tour leader recommended that this individual forgo diving for the remainder of the trip.

Was this diver suffering from decompression sickness? Possibly? Probably? Questionable? Would the diver have experienced more serious symptoms if oxygen breathing had not been initiated? We will never know. One can only speculate at this point. ***The use of precautionary oxygen breathing at atmospheric pressure may be of considerable value.*** Possibly, it may prevent the development of further complications. However, more research and medical information will be necessary in order to determine if this is to be designated as a standard practice in scientific and recreational diving situations. ***Keep in mind that this practice should not be considered as a substitute for proper hyperbaric treatment of decompression sickness.***

Like sharks, decompression sickness can be predictability unpredictable. Unfortunately, the *unlikely* may occur in diving. A young, healthy female completed a single dive to 60 feet for 30 minutes. Following the dive she developed symptoms of decompression sickness. Subsequent hyperbaric treatment relieved all symptoms. According to accepted diving tables the no-decompression limit for a dive to 60 feet is 50 to 60 minutes (depending on the table selected).

In another incident a young, healthy male diver completed a single dive to 40 feet for about 40 minutes. Four to five hours following the dive he flew in a commerical airliner and developed joint pain. His condition was subsequently diagnosed as decompression sickness and several hyperbaric treatments were administered. Even so residual joint discomfort remains two years following the incident. According to several publications and recently developed recreational dive tables, this diver was considered *safe* for flying.

In still another case a diving instructor reported to a hyperbaric chamber facility with pain in both arms approximately 36 hours after a properly executed dive. Symptoms appeared in association with the passage of a low pressure weather front. Hyperbaric treatment on a standard table relieved the discomfort and he was later released from the hospital symptom free. It is interesting to note that this diver's buddy had actually experienced decompression sickness on the dive and had been treated the previous day. Dive leaders should keep in mind that, "If one member of the dive team bends, observe the other diver closely for development of symptoms!" I can recall several cases where the buddy experienced delayed symptoms.

In 1976 Spencer reported on the evaluation of divers using ultrasonic detection to determine the presence or absence of venous gas emboli (VGE) following exposure to pressure [53]. In this study he found that, "There are bends-prone and bubble-prone individuals who, if they dive, should do so only in very shallow water, i.e., less than 30 feet in depth." His findings demonstrated that there is a strong individual propensity to form VGE, which correlates with susceptibility to decompression sickness.

Unfortunately, the recreational diver does not have the luxury enjoyed by some military and commercial divers where hyperbaric chambers are more readily available and a commom diagnostic technique is *a test of pressure*. If the suspect diver is placed under pressure (recompressed in a hyperbaric chamber) and the discomfort is relieved, the standard procedure is to treat for decompression sickness. In the event that the symptoms are not relieved, further and complete medical evaluation is necessary to determine if the diver is actually a victim of decompression sickness or otherwise. However, even this procedure is not foolproof. In one incident wrist pain in a military diver was not relieved and re-occurred following several hyperbaric treatments. A subsequent X-ray revealed a wrist bone fracture. It is unlikely that the individual ever had decompression sickness.

Caution! Divers should not attempt a test of pressure by placing the suspect diver back in the water. This could only lead to the absorption of additional nitrogen and potentially other complications!

ADMINISTERING OXYGEN

The administration of oxygen by first aiders has been questioned by some *non-diving* authorities. Oxygen is considered to be a drug, and there are laws in some states which regulate the use of oxygen. Rescuers and divers should be aware of such laws, especially if they specifically forbid the use of oxygen in a first aid situation.

Supplemental oxygen is a valuable adjunct in the first aid management of air embolism and decompression sickness. *In fact, many authorities consider it to be an absolute necessity!* Breathing oxygen will eliminate some nitrogen from the body by producing a pressure gradient between the problem bubble(s) and the surrounding tissues. This favors resolution of the bubble since this pressure gradient, or driving force, causes nitrogen in the bubble to dissolve in the bloodstream and be eliminated through the lungs. Any increase in oxygen being supplied to the injured area will also be physiologically beneficial, especially if brain tissue is involved [43].

Administering oxygen to a conscious, spontaneously breathing individual is not difficult and is usually safe with the proper equipment. The concentration of inhaled oxygen should be as near 100% as possible in order to achieve maximum benefit. A demand-type oxygen breathing unit with a tight-fitting, double seal mask and an adequate oxygen flow rate is necessary to deliver the required concentration. Constant flow devices (inhalators) using nasal cannula, simple elongated face masks, partial rebreather masks, etc., will only deliver low, ineffective concentrations (25% to 60%) depending on the metered flow rate. In the event that only a constant flow device is available, deliver oxygen at a flow rate of 10 liters per minute [19].

If the victim is unconscious or not breathing spontaneously, oxygen administration becomes more complicated. In this situation the first aider must have a thorough understanding of airway management and the use of adjunctive equipment. As in the case of CPR, such techniques and equipment are beyond the scope of this publication. The diver and dive leader can only be encouraged to acquire additional special training. Many community colleges offer Emergency Medical Technician courses which include this training [16] and the National Association of Underwater Instructors (NAUI) sponsors workshop programs on emergency oxygen administration [17, 18].

The use of oxygen in the early stages of managing a diving accident victim may reduce or totally relieve the symptoms within a short time. If this does happen, do not be deceived into thinking that the problem has been completely resolved. Oxygen breathing should be continued, the victim transported to the nearest medical facility, and a diving physician consulted. Oxygen breathing at atmospheric pressure must not be considered as a substitute for hyperbaric treatment in cases of decompression sickness and air embolism [43].

High oxygen concentrations should not be delivered to hyperventilating victims or victims with chronic obstructive pulmonary disease (emphysema).

IN-WATER RECOMPRESSION

The equipment and techniques for in-water recompression have been discussed by Edmonds for application in managing diving accidents in extremely remote tropical areas [26]. However, the standard of care in the American diving and diving medicine community does not advocate such procedures and, in fact, discourages any attempts at in-water recompression. It has been found that the victim is usually further compromised by incomplete treatment, additional nitrogen uptake, and cold. If oxygen is used the high risk of oxygen toxicity must also be considered. If the initial symptoms are serious, the results are usually disastrous. ***In-water recompression should never be attempted!*** [43]

SERIOUS DIVER INJURY: AIR EMBOLISM AND DECOMPRESSION SICKNESS

The two most potentionally disabling and life-threatening conditions that can result from exposure of an individual to elevated ambient pressure situations such as scuba diving are air embolism and decompression sickness. Air embolism, resulting from the entry of air bubbles into circulation as a result of pulmonary barotrauma, can occur in water depth as shallow as 4 feet. It is most common among trainees, inexperienced divers, and infrequent divers. Decompression sickness involves nitrogen being released from solution in the form of bubbles in body tissues as a result of inadequate decompression procedures. This condition is more common among experienced and frequent divers who dive beyond depths of 30 feet.

Pulmonary Barotrauma

In a diminishing pressure situation, e.g., a scuba diver ascending from depth, the air in the lungs is expanded because of decreasing external pressure. If the normal exhalation route of the expanding air is interrupted either voluntarily, by breath holding, or involuntarily, from local respiratory tract obstruction, the intrapulmonary pressure progressively distends the alveoli (air sacs) and rupture of lung tissue may ensue. A pressure differential of about 100 mm Hg (2 psi or 4 feet of seawater equivalent) may be sufficient to rupture lung tissue. From the point of rupture, the air may disperse along the bronchi and enter the mediastinum (tissues surrounding the heart) to create *mediastinal emphysema*. A diver with a mediastinal emphysema may exhibit such manifestations as substernal pain (especially during exercise), breathing difficulties (including shortness of breath), change in voice, and even collapse (fainting) due to direct pressure on the heart and great vessels. Cyanosis (blueness of skin, lips, and fingernails) may be evident.

From the mediastinum, the air frequently migrates into the subcutaneous tissues *(subcutaneous emphysema)*, most often in the neck and supraclavicular region (over the collar bone). This will be evident by enlargement and feeling of fullness around the neck, voice changes, breathing difficulties, and crepitation (cracking sensation or sound when skin is touched in enlarged areas).

If there is a weakened area on the surface of the lung, air may rupture directly into the pleural space (chest cavity) causing the lung to collapse. This is a *pneumothrox* and may involve partial or complete collapse of a lung. As the diver continues to ascend, the air trapped in the pleural space expands at the expense of the collapsing lung and may eventually cause displacement of the heart and great vessels. This is a very serious complication because both respiration and circulation may be impaired. Manifestations include chest pressure and sharp pain, breathing difficulties (shortness of breath and rapid, shallow breathing), and cyanosis.

These conditions in themselves generally do not require hyperbaric treatment. However, the victim must be continuously monitored and immediately placed under the care of a physician. If signs or symptoms of any of these conditions are evident, the first responder must suspect that the injured diver has also experienced an air embolism until proven otherwise by a physician. Keep in mind that more serious and life-threatening manifestations may appear at any time.

Air Embolism

The most serious consequence of alveolar rupture is the release of air bubbles into pulmonary circulation, and via the pulmonary vein, left heart, aorta, and carotids, into cerebral circulation. The cerebral area is most frequently affected since the diver is usually in an erect or head-up position during ascent, and the bubbles tend to rise. Any bubble too large to pass through an artery will lodge and obstruct circulation to adjacent areas or organs. This is an *air embolism.*

The wide spectrum of symptoms and signs associated with cerebral air embolism include severe headache, vertigo (dizziness), visual disturbances (blurred or lost vision), nausea, paralysis (hemiplegia or involvement of one side of body), seizures, stupor, limb numbness, weakness, cessation of breathing, and loss of consciousness [57]. Death may result from coronary and/or cerebral occlusions with cardiac arrhythmias, respiratory failure, circulatory collapse, and irreversible shock [34]. The diver may or may not experience discomfort or pain in the chest prior to or during tissue rupture. The tearing of lung tissue may result in the discharge of a bloody froth from the victim's mouth; however, the absence of bloody froth does not preclude the possibility of air embloism [54].

The onset of symptoms is generally dramatic and sudden, usually occurring within seconds of surfacing, or even prior to surfacing. In a review of 39 cases of air embolism, Dick and Massey found that 69% of air embolism victims had symptoms upon surfacing and 91% had symptoms within 10 minutes of surfacing. Rarely, symptoms began as long as 12 hours following the dive. Forty-one percent of the victims in this study became unconscious within minutes of surfacing [23, 24].

Decompression Sickness

Decompression sickness is a pressure-related illness which results from a reduction in ambient pressure sufficient to cause the formation of bubbles from gases dissolved in body fluids and tissues. During exposure to elevated ambient pressure, inert gas in the breathing medium dissolves into the diver's body. During ascent or decompression, some quantity of this inert gas in the tissues must diffuse into the blood, travel to the lungs, and be released from the body in expired air. If decompression exceeds some critical rate, the tissues will not release the gas rapidly enough and will become saturated. When this happens, some of the inert gas comes out of solution in the form of bubbles, and if enough bubbles develop, manifestations of decompression sickness result.

The signs and symptoms of decompression sickness are variable in nature and intensity depending on location and magnitude of the bubbles. Localized pain has always been considered the most predominant symptom of decompression sickness, occurring in about 89% of all cases, according to early studies and the U. S. Navy [22, 54, 55]. The recent Dick and Massey report on 70 cases of sport diver decompression sickness indicates that the progressive onset of limb numbness and paresthesias (sensation of pricking, tingling, and creeping on the skin) are the most common symptoms, evident in 56% and 34% of the cases, respectively [23].

Limb weakness was more common than paralysis. Limb paralysis was noted in 8 of the 70 cases. Other signs and symptoms included dizziness, nausea, mild headache, and loss of coordination. Twelve (about 17%) of the cases of decompression sickness exhibited symptoms within 10 minutes of surfacing and 44% of the cases were evident within one hour of surfacing. Twenty-four percent of the victims became symptomatic more than 6 hours following a dive and 2 divers developed decompression sickness more than 24 hours following a dive.

Skin itching and mottling are considered to be a sign of mild decompression sickness and may precede the development of more severe symptoms. The onset of pain is often gradual with progression in severity and extent. A localized pain may extend centrifugally to involve a progressively larger area. Generally, the pain is neither aggravated nor alleviated by local motion or palpation (touch). Joint and tendinous structures are the most common locations of pain symptoms.

Transient blurring of vision and other visual disturbances occasionally accompany more serious manifestations of decompression sickness. Respiratory distress is a rare symptom of delayed development of substernal "burning" sensation that may intensify and spread. The victim can become cyanotic (blue) and the condition may advance into clinical shock with subsequent loss of consciousness.

Marked fatigue, often disproportional to the physical exertion expended, may be experienced following deep dives or a series of repetitive dives. The onset of fatigue may occur 2 to 5 hours after the diver surfaces and is characterized by an overwhelming desire to sleep.

Most central nervous system (CNS) lesions occur in the spinal cord, particularly in the lower segment; cerebral damage is relatively rare. Quadriplegia, paraplegia, and paralysis of a single or several extremities in every combination have been reported. Early vasomotor collapse and severe clinical shock are associated with more serious manifestations. Various body functions may be affected. Initial and permanent residual damage may result in loss of bladder, bowel, and sexual function.

First Aid For Suspected Air Embolism or Decompression Sickness

The first responder(s) must provide immediate and proper care for possible victims of air embolism or decompression sickness at the scene of the accident. Furthermore, arrangements must be made to enter the victim into the hyperbaric trauma system as soon as possible. ***Avoid delay!*** "One of the biggest factors related to ultimate therapeutic success is minimizing the time between the onset of symptoms and therapeutic recompression. It is suggested that part of the initial process of taking care of the patient include immediate contact with the appropriate EMS system in order to expedite transport. *A transport plan should be made prior to every dive trip* so that a diving casualty may be moved to a sophisticated hospital facility with minimum delay, and then to the nearest appropriate recompression facility." (Recommendations from Workshop on Diving Accident Management reported in *Pressure*, Vol. 19, No. 2, March/April 1990.)

All symptoms of air embolism and decompression sickness are generally considered together in the early management of a diving accident. It is more important to use proper early first aid than to attempt to distinguish between the two conditions because the initial management of both conditions is essentially the same until hyperbaric therapy is started. The first aid procedures recommended below are in accord with those published by the Divers Alert Network (DAN) and the Undersea Medical Society (UMS) [21, 43].

The most important initial factor in managing a diving accident is to recognize that a diver has sustained injury. In most situations this is obvious; however, occasionally mild symptoms may be dismissed or not recognized. As previously discussed, both symptoms/signs and circumstances are important in diagnosis. The following are obvious indicators of serious complications, and air embolism and/or decompression sickness must be suspected until proven otherwise by a physician:

* Diver loses consciousness underwater or shortly after surfacing (cause unknown);

* Diver exhibits symptoms of neurological abnormality following ascent from a shallow dive (pulmonary barotrauma/air embolism can occur when ascending from a depth as shallow as four feet);

* Diver exhibits symptoms of pain or neurological abnormality following ascent from no-decompression dives deeper than 30 feet or even shallower depths for repetitive dives (decompression sickness); and

* Diver exhibits symptoms of pain or neurological abnormality following ascent from deep dives and dives near or beyond no-decompression limits.

An injured diver may fail to recognize mild symptoms. Severe fatigue or unusual tiredness and itching are considered mild symptoms and may respond to oxygen breathing. If a diver experiences mild symptoms upon surfacing, have the diver lie down and breathe 100% oxygen. The oxygen may relieve the symptoms or prevent them from getting worse. If the symptoms are relieved after an interval of oxygen breathing, do not discontinue oxygen breathing immediately as the symptoms may recur. Continue oxygen breathing for at least 30 minutes. If symptoms are relieved, consult a physician for further instructions and monitor the diver for recurring or new symptoms. If symptoms are not relieved, proceed with first aid protocol given below [43].

Unfortunately, many divers who experience decompression sickness go through a period of *denial*. The simply will not accept the fact that they may be "bent!" I have interviewed deep shipwreck divers who have experienced significant neurological deficits following deep dives — lower extremities numbness, weakness, and pins/needles sensations and fatigue, general overall "feeling poorly", and severe back pain. Most of these divers have not submitted to hyperbaric treatment or even seen a physician. They stay home from work, take pain-relief pills, and deny that they are ill or injured.

The first aid procedures for management of a suspected air embolism or decompression sickness are given and discussed below:

Perform Life-Saving Procedures. Administer CPR if required and protect the diver from further injury.

Victim Position. A recent review of diving accident management procedures indicated, "It seems prudent to keep the patient in a supine position rather than head up position, but current knowledge does not support the use of the head down position." (Recommendations from Workshop on Diving Accident Management reported in Pressure, Vol. 19, No. 2, March/April 1990.)

Previously, divers were instructed to position a victim with impaired consciousness (right- or left-side down) to minimize the possibility of aspiration of vomitus. The first aider must still be very cautious and prevent aspiration of vomitus.

Historically, for nearly two decades, the standard first aid practice for suspected air embolism was to place the victim on left side in a head down, modified Trendelenburg position, with the entire body maintained at an angle up to about 30 degrees [36]. It was felt that this position would encourage a bubble in the brain to dislodge itself and migrate to a less damaging area. This phenomenon has been demonstrated in the laboratory on animals but not on human subjects. In practice this position can cause a certain amount of physical stress and discomfort for the victim. It also increases the likelihood of vomiting and aspiration of vomitus as well as complicating breathing and airway management in some individuals. Furthermore, it was difficult to maintain a patient in this position during transport without special equipment.

In about 1988 many authorities suggested that in cases of suspected *air embolism only*, the victim should be placed in a head down position for up to 20 minutes as tolerated and only in cases where the victim is breathing adequately. Today, this aggressive and acute angle position has been challenged by some individuals. Consequently, DAN suggests that this modified Trendelenburg position should not be viewed as absolutely necessary [36].

Thus, the best information currently available (June 1990) supports placing a diver with suspected air embolism in a supine (lying on back with face upward) position. However, do not allow the victim to stand or sit upright.

Airway Management. It is important to insure that the airway is open and to prevent aspiration of vomitus. Continously monitor the victim and make adjustments as necessary in order to prevent/manage these conditions. If trained emergency medical personnel and/or a physician is available, the placement of an endotracheal tube can be used to correct these problems.

Administer Oxygen. Administer as high a concentration of oxygen as possible by tight-fitting mask (100%). Continuous 100% oxygen administration and maintenance of intravascular volume is considered the most important feature of immediate management, and should be continued until the victim reaches the hyperbaric chamber [21, 43]. Do not remove the oxygen except to clear the airway, administer fluids (when applicable), or if the victim shows signs of convulsions [43].

Diving accident victims who receive oxygen immediately after their injury have a better recovery rate than if no oxygen is used. The crucial value of early oxygen breathing must always be emphasized, particularly for sport diving injuries not occurring near hyperbaric chambers [43]. The use of oxygen and oxygen breathing equipment has been previously discussed.

Management of a Convulsion. If convulsions occur, do not use forceful restraint. Turn the victim on side (supporting head and neck), maintain airway, and remove vomitus. Hold the victim loosely to prevent self-injury and do not force airway or tongue blade. Resume oxygen breathing when convulsions subside.

Protect Victim. Protect the injured diver from excessive heat, cold, wetness, or noxious fumes.

Fluids. For a conscious and stable victim who is more than one hour from medical assistance, give oral non-alcoholic liquids such as fruit juice or balanced electrolyte beverage (such as half-strength Gatorade) at a rate of 4 ounces ever 15 minutes [17, 18]. Davis, in an earlier publication [21], recommended one liter in the first hour. If the delay in hyperbaric treatment is to be extensive, continue sufficient fluid intake to maintain a urine output of 1 or 2 ml/kg/hr (kg means kilograms body weight) or approximately 1/3 to 2/3 fluid ounces per 22 pounds of body weight per hour [21]. *If possible, consult with a physician by radio/telephone when long delay is anticipated and adjust fluid intake per physician instructions. Fluid level maintenance is considered very important in the management of decompression sickness.*

The most recent recommendation is, "In an awake patient who is not nauseated or vomiting and whose airway reflexes are intact, oral administration of fluids is recommended until such time as intravenous access can be obtained." (Recommendations from Workshop on Diving Accident Management reported in *Pressure*, Vol. 19, No. 2, March/April 1990.)

The Divers Alert Network has stated, "Encourage a conscious and stable patient to drink non-alcoholic, non-acidic fluids. Record amount and type of fluid given. Record urinary output and check for bladder distension. Fluids are given only if the patient is conscious, stable, and is *not* suffering from stomach pain, urinary retention or paralysis unless a urinary catheter is used. If the bladder becomes distended give no more fluid until a urinary catheter is inserted." (*The DAN Emergency Handbook*, 1989 edition.)

Anticoagulants: "There is no scientific evidence at present to support the use of any anitcoagulants, *including aspirin*, in the treatment of diving injuries." In some forms of decompression sickness administration of anticoagulants might worsen conditions. (Recommendations from Workshop on Diving Accident Management reported in *Pressure*, Vol. 19, No. 2, March/April 1990.)

This is contrary to previous recommendations approving of the use of 2 aspirin (5 grains each) as an anti-platelet agent where many authorities concluded that aspirin can do little harm and might do some good.

Local Medical Care. Evaluate and stabilize the patient at the nearest hospital emergency room prior to transfer to a hyperbaric chamber facility (if needed) [43]. Several factors must be considered. First, serious and potentially life-threatening conditions such as heart failure, kidney failure, severe shock, etc., require immediate attention. Failure to properly stabilize the patient could result in serious complications or even death enroute to the hyperbaric chamber. In serious cases, an aggressive intravenous fluid replacement procedure may be started, a urinary catheter inserted, and drugs administered. Secondly, through proper medical evaluation and consultation with DAN it may be determined that the patient has not experienced air embolism or decompression sickness and that hyperbaric therapy is not required.

Consultation. Physicians not familiar with the management and treatment of diving related injuries must be encouraged to consult with a diving physician and/or DAN. The National Divers Alert Network located at the Duke University Medical Center provides 24 hour telephone consultation at

(919) 684-8111.

This number may be called collect in an emergency. For medical problems, the caller is connected with a physician experienced in diving medicine. The DAN physicians can assist with diagnosis and initial treatment of an injured diver and supervise referral to appropriate hyperbaric chamber facilities while working with regional coordinators throughout the nation [43].

Hyperbaric Chamber Facility Contact. It is necessary to contact the hyperbaric chamber facility to which the patient is to be transported *prior to initiating transport procedures* in order to assure that the chamber is available and that a treatment team is assembled and prepared to receive the patient. Hyperbaric chambers may be occupied, out of service for maintenance, or closed.

Transporting the Patient. A major determinant of the successful outcome of a treatment is the expedience with which the patient can receive proper hyperbaric therapy. If the distance is too great for suface transportation, air evacuation must be used. It is critically important that the patient not be exposed to significantly decreased barometric pressure at altitude. Flight crews must maintain cabin pressure at sea level or fly at the lowest safe altitude in unpressurized aircraft. If a patient is moved by helicopter, the pilots must be instructed to keep the flight as low as possible but not greater than 500 to 800 feet above ground level. One hundred percent oxygen breathing and fluid therapy must be maintained during flight [21]. If the patient is experiencing obvious distress (equalization problems or otherwise), suggest that the helicopter pilot select an appropriate safe altitude that can be maintained for a level flight instead of attempting to follow the ground terrain.

The DAN Manual. The DAN Manual is intended to serve as a guide for the diver, paramedic, and physician in the recognition and initial management of a diving accident victim [43]. The diver should keep a copy of the DAN Manual in her dive kit so that it is always available. In the event of an accident, record the details of the accident and initial first aid management in the back of the injured diver's DAN Manual and assure that the manual remains with the diver as she moves through the emergency medical system.

Fluid Therapy and Drugs. In unconscious patients and in patients with manifestations more serious than limb pain bends, intravenous fluid replacement is preferred. Ringer's lactate, normal saline solution, or 5% dextrose in saline solution should be given [43] to maintain urine output at 1 to 2 ml/kg/hr (or approximately 1/3 to 2/3 fluid ounces per 22 pounds body weight per hour) [21]. Do not use 5% dextrose in water. If there is evidence of neurologic involvement, give steroids, hydrocortisone sodium succinate, 1.0 gm. i.v. or dexamethasone, 20-30 mgm. i.v. [21, 43]. With spinal cord involvement, an in-dwelling urinary catheter should be considered [21].

The use of intravenous fluids, drugs, and catheter is only applicable for qualified medical personnel.

In 1979 Fructus reported on the benefits of a first aid/enroute protocol for management of decompression sickness [34]. This protocol with minor clarification by Anderson [10] included:

1. 100% oxygen by mask;

2. Steroids, i.v., single administration (1000 mg hydrocortisone hemisuccinate *or* 30 mg dextamethasone *or* 160 mg methylprednisolone);

3. Aspirin, 10 grains orally if patient is conscious; and

4. Fluid volume replacement, i.v. infusion, 1 liter per hour for three to four hours (i.e., Ringer's lactate, normal saline, or dextrose 5% in saline) +/- plasma expanders (i.e., dextran 40, 500 ml)

Fructus reported on 67 cases of decompression sickness of which 14 were transported without first aid and 53 received first aid management which included oxygen, aspirin, and/or fluids [34]. Of the 53 victims receiving first aid, 38 (or 72%) showed improvement or were asymptomatic by the time they arrived at a treatment facility. All of these cases involved neurologic decompression sickness with delays of 3 to 24 hours between onset of symptoms and beginning of hyperbaric therapy (mean delay of about 10 hours). As previously stated, most authorities now discourage the use of anticoagulants (aspirin) by first aid personnel.

***In their most recent manual the Divers Alert Network encourages physicians and paramedics to "insert an I.V. line of normal saline or Ringers Lactate as soon as possible." They state that the use of glucose "should be avoided in I.V. fluids." Physicians and paramedics are encouraged to contact DAN directly for instructions in fluid and drug therapy** (The DAN Emergency Handbook, 1989 edition.)*

COLD INJURY

If a victim is cold and has *any* of the following signs or symptoms, consider that person to have severe hypothermia:

* Depressed vital signs.
* Altered level of consciousness, including slurred speech, staggering gait, and decreased mental skills.
* Core temperature of 90° F. or less.
* No shivering in spite of being very cold.
* Associated significant illness or injury that is present or that may have permitted the hypothermia to develop.

If the victim is cold and does not have any of these signs or symptoms, he/she is considered to have mild hypothermia.

The basic treatment for a hypothermic victim is as follows:

* Treat very gently.
* Remove wet clothing/diving suits. Replace with dry clothing or dry coverings of some kind.
* Insulate from the cold.
* Add heat to the head, neck, chest, and groin externally, or internally if a system for breathing warm moist air is available. Avoid attempts to warm the extremities. The first responder must prevent further heat loss at the core. This can only be done by insulating the entire patient, plus adding heat to the core area. Application of heat can be accomplished by placing warm objects such as hot water bottles, chemical heat packs (wrapped in a towel), warmed rocks (wrapped in a towel), human bodies, etc. Monitor closely and be certain to protect patient's skin from burns.
* Do not rub or manipulate the extremities.
* Do not give coffee or alcohol.
* Do not put the patient in a shower or bath.
* Warm liquids may be given only after uncontrollable shivering stops and the victim has a clear level of consciousness, the ability to swallow, and evidence of rewarming already.
* If *severe* hypothermia is present, treat as above and transport to a medical facility.

Treatment for severe hypothermia with no life signs is as follows:

* Provide the basic treatment as indicated above.
* Carefully assess the presence or absence of pulse or respiration for one to two minutes.
* If no pulse or respiration, start CPR.
* Obtain a rectal temperature if possible.
* If you are less than 15 minutes from a medical facility, do not bother trying to add heat.
* If you are greater than 15 minutes from a medical facility, add heat gradually and gently.
* Reassess the physical status periodically.
* Transfer to a medical facility in all cases.

The above procedures were taken from a booklet titled, "State of Alaska Hypothermia and Cold Water Near Drowning Guidelines" [9]. For additional information consult this booklet or Forgey [33]. At present there is some degree of controversy within the medical community regarding administering CPR to a hypothermic individual. Some authorities specifically state that a hypothermic person should not be given CPR in the field [7]. In a recent discussion Martin J. Nemiroff, M. D. indicated that the Alaska Guidelines [9] remain as the most acceptable alternative for the first responder to follow. The general management of cold-related injuries is also discussed by Somers [50] and Lentz, et. al. [39].

RESPIRATORY PROBLEMS

Diver maladies involving respiration include asphyxia, carbon dioxide excess, carbon monoxide poisoning, oil-vapor inhalation, and near-drowning. Low level contamination of a diver's air supply during scuba cylinder filling is possible, but uncommon. *Carbon monoxide (CO) contamination is probably the most serious potential problem.* A diver breathing air containing CO may lose consciousness without warning or experience severe headache, dizziness, weakness, nausea, confusion, clumsiness, or a feeling of tightness in the head. There may be an abnormal blueness or redness of lips, fingernails, and skin. However, the classic "cherry red" sign may or may not be evident and is, therefore, not a reliable diagnostic aid.

Unlike carbon monoxide which is difficult, if not impossible, to detect without special testing equipment, the *presence of oil in an air supply* is generally quite evident by taste or odor. If oil presence is suspected, immediately discontinue use of the air supply.

Carbon dioxide may be rarely introduced during filling of the scuba cylinder. It is more frequently retained in the body through abnormal breathing patterns (skip-breathing). Occasionally a diver will lose consciousness without respiratory warning. On the other hand, there may be headache, dizziness, confusion, slowing of response, and/or nausea.

Open circuit scuba divers have lost consciousness from anoxia (lack of oxygen). Moisture accidentally introduced into a steel scuba cylinder can combine with oxygen in the air to form rust. This oxidation process consumes the oxygen in the cylinder. If a diver uses this air cylinder, he/she may breathe the remaining gas, primarily nitrogen, and lose consciousness from anoxia or lack of oxygen. Drowning is one of the major causes of diving fatalities and is usually caused by hypoxia (insufficient oxygen), followed by asphyxia, as a result of loss of air supply or submergence without an air supply.

The primary first aid procedure for respiratory problems is breathing fresh air. If breathing has ceased, start artificial respiration or CPR immediately. All victims must receive first aid for prevention/management of shock, and must receive medical attention even if revived without medical assistance. Carbon monoxide poisoning victims must be treated with oxygen, preferably under hyperbaric conditions. Oil-vapor inhalation victims may be retained for medical observation and managed similiarly to pneumonia cases depending upon the severity of dosage.

EAR AND SINUS BAROTRAUMA

Damage to ears and sinuses can result from attempting to dive with a cold or allergy or simply failing to equalize pressure during descent/ascent. Such barotrauma is evident by pain at the time of injury and discharge of bloody mucus during/following ascent. Spitting blood generally indicates middle ear barotrauma and discharge from the nose is characteristic of sinus injury. Most diving authorities concur that a *hands-off* policy for first aiders results in fewer complications and more rapid healing. *Do not attempt to clean damaged ears and do not resume diving until the injury has healed.* Seek medical attention if discharge or tenderness persist or if you suspect the development of infection. If in doubt, consult a physician. Serious injury and infection can result in hearing impairment and other complications.

OTHER PROBLEMS

Nitrogen narcosis and oxygen toxicity are avoidable problems in recreational scuba diving. By limiting depths to less than 100 feet, the recreational diver can avoid the potential problems associated with breathing nitrogen under high pressure. The responses of a diver under the influence of nitrogen narcosis are not dissimilar to those associated with alcohol intoxication. Simply ascending to a shallower depth, preferably to the surface, with a controlled ascent relieves the problem.

Oxygen toxicity is generally associated with breathing *pure* oxygen at depths in excess of 25 feet or compressed air at depths in excess of 220 feet. This condition is preventable by assuring that a scuba cylinder is *not* filled with pure oxygen and by *not* using closed-circuit oxygen/mixed gas scuba without proper training and maintenance. Obviously, deep diving on compressed air should also be avoided. Today, an increasing number of divers are using gas mixtures with elevated percentages of oxygen (i.e., greater that 21%). Diving with mixed gases requires special training and has specific limitations. Consult the U.S. Navy Diving Manual or NOAA Diving Manual for further information [44, 54, 55].

MARINE LIFE INJURIES

The first aid procedures given below are for those animals commonly encountered by divers in the tropical Western Atlantic Ocean (including the Bahamian, Caribbean, and Florida waters) and on the Pacific Coast of the United States. Additional information on the nature and management of injuries caused by marine animals and on first aid procedures for injuries caused by marine animals of the South Pacific Ocean, Red Sea, and other regions can be obtained from Somers [51] and selected medical textbooks [11, 13, 26, 37].

Marine Life Stings

The first aid procedures recommended for commom jellyfish and hydrozoan (Portugese man-of-war) stings that are considered non-life-threatening in healthy individuals vary with author and geographic area. Many authorities suggest immediate liberal use of a solution with high alcohol content (e.g., isopropyl rubbing alcohol) or vinegar since they allegedly inactivate the nematocysts. If these rinsing solutions are unavailable, the injured area should immediately be flushed with sea water and carefully cleaned of debris. Other inactivating solutions cited in various publications include formalin, household ammonia, urine, petroleum products (gasoline, kerosene, etc.), and beer. However, recent studies suggest that these solutions may be ineffective [27].

Never rinse the sting area with fresh water to remove tentacles. Fresh water has an osmotic effect on the nematocysts causing them to discharge. Beer apparently has the same effect as fresh water. Also, never rub the area with sand since this procedure will cause discharge of more nematocysts. Most authorities also discourage the use of petroleum products.

Research at James Cook University (Australia) and by the Royal Australian Navy School of Underwater Medicine has revealed that application of methylated spirits, 100% alcohol, and alcohol mixtures with seawater *produced dramatic, instantaneous discharge of the nematocysts, and this was associated with increased clinical sensitivity* [27]. The James Cook University group found that the application of 3% to 10% acetic acid (or vinegar) was most effective in preventing the massive discharge of nematocysts associated with the application of alcohol and other common solutions tested. Further studies by Carl Edmonds, M.D., of the Diving Medical Center in Australia (one of the foremost world authorities on marine life injuries) concluded that *vinegar* and Xylocaine (lidocaine) will prevent further nematocysts discharge. Surprisingly, Edmonds also found that selected commercial preparations, anti-sting lotions, and the enzymatic product, Adolf's meat tenderizer, were *clinically ineffective* [27]. The same was found for other common solutions such as urine, household ammonia, and so on.

Studies have also revealed that some U.S. species should be treated with alcohol rather than vinegar (South Pacific Underwater Medical Journal, 16(3), 1986). These include the hair jelly (*Cyanea*), sea nettle (*Chrysaora*), and little mauve stinger (*Pelogia*).

Next, the tentacles that didn't rinse off must be carefully removed with a towel, stick, knife blade, etc. These residual tentacles may also be removed by coalescing them with a drying agent (e.g., flour, baking soda, talc, etc.) and then scraping them from the skin with a thin knife blade. *Avoid personal contact with the tentacles.*

After tentacles have been removed, some authors recommend neutralizing the toxins by applying one of the compounds/solutions mentioned above and thoroughly scrubbing with an antibacterial soap and water. The sting site is dried and an analgesic-antihistamine ointment applied. To the contrary, Australian authorities specifically state that the affected area must *not* be washed with soap and water for 24 hours [6, 58].

Local anesthetic ointments (lidocaine HCl) or sprays (Benzocaine, 14%), antihistaminic creams, or mild steroid lotions (hydrocortisone, 1%) may be soothing [11]. They are used after the toxin is inactivated. A lidocaine spray (Clinicaine by Johnson and Johnson) may be beneficial as an initial inactivating agent as well as a soothing solution [personal experience].

Observe the victim for general reactions and shock. *Keep in mind that physiologically or emotionally induced shock may be associated with any marine life injury.*

Simple pain relief measures (e.g., aspirin tablets, or equivalent, in accord with dosage instructions on container) are considered acceptable. Do not attempt to administer medications if the victim is unconscious or nauseated/vomiting.

Naturally, all stings will not result in severe reaction or shock and require such aggressive first aid measures. For example, fire coral encounters do not involve tentacle removal, and some small jellyfish stings give only minor, momentary irritation. After minor encounters the diver may continue to dive. However, the victim and his buddies must maintain an awareness for more serious reactions. In rare cases, respiratory or cardiac arrest may occur and require immediate life saving action.

Sponges

The fire sponge (*Tedania ignis*), found off Hawaii and the Florida Keys, and the "Do-Not-Touch-Me" sponge (*Neofibularia nolitangere*), common to the Caribbean, are typical offenders. Reactions are characterized by itching and burning, which may progress to local joint swelling, blisters, and stiffness. Soaks in dilute (5%) acetic acid (vinegar) are considered beneficial [11].

Coral

Wounds inflicted by contact with stony coral are an ever-present annoyance to divers in the tropics. The sharp calcareous edges produce wounds which are generally superficial but notoriously slow to heal. Coral cuts, if left untreated, may become ulcerous. Sting cells may further complicate conditions. The initial effects of coral poisoning are pain and an itching sensation in and around the wound, accompanied by reddening and welt formation in the surrounding areas. Secondary infection is common.

First aid involves prompt removal of visible debris and cleansing of the wound with hot water and antibacterial soap. It is occasionally helpful to use hydrogen peroxide to bubble out coral "dust." Promote free bleeding; however, keep in mind that excessive probing can cause unnecessary tissue damage. Deeply embedded materials may require removal by a physician. Elevation of the involved limb is strongly recommended. The use of antiseptic creams is a matter of personal preference. Monitor the wound closely and cleanse/change dressings as soon as possible upon return from subsequent dives. Even minor wounds can become seriously infected. Current tetanus immunization is recommended for all divers. For severe wounds, or if complications appear, seek immediate medical attention.

Sea Urchin

The sea urchin most familiar to the United States diver is the genus *Diadema*, which includes the long-spined or black sea urchin common to the Bahamas, Florida Keys, and West Indies. These sea urchins with long, brittle spines are not considered to be a serious hazard by most divers; however, they may produce a painful puncture wound with redness and swelling. The fragments of the spine will produce a purple discoloration in the area of the wound. In minor injuries, the spines of some species will dissolve with few complications besides localized discomfort. However, deeply embedded spines will cause irritating discomfort of long duration if not removed. These should be removed with a fine tweezer or small needle (sterilized), the area thoroughly scrubbed with hot water and antibacterial soap, and a sterile dressing applied. Medication to control pain, inflammation, and infection may be required. Consult a physician immediately if symptoms of infection or other complications appear. Surgical removal of deeply embedded spines may be necessary.

Venomous Fish

First aid for venomous fish wounds (such as scorpion fish) includes alleviating pain, combating shock and the effects of the venom, and preventing infection. Since unconsciousness is common, the victim should be removed from the water promptly. Pain will be severe. Have the victim lie down and apply measures to prevent/combat shock. Keep the affected limb level with the body and as still as possible to minimize the spread of venom. Carefully wash out or irrigate the wound with cold salt water or with sterile saline. Although the use of a tourniquet is indicated in some manuals, the practice is considered to be of limited value [26, 37]. However, Auerbach and Halstead do indicate that the application of a *loose tourniquet* which occludes only superficial venous and lymphatic return may be of some value [11]. This "loose tourniquet" should be released for 90 seconds every 10 minutes in order to preserve circulation. *Considering the inherent risk associated with the use of tourniquets and the potential for improper application of loose tourniquets, this practice is generally discouraged for first aiders.* Attempt to remove any remaining portions of the spine sheath.

Soak in plain water, as hot as can be tolerated (up to 50°C/122°F), for at least 30 minutes. Use hot compresses on areas that cannot be immersed. Heat may produce rapid pain relief and is believed to destroy the venom. Be careful not to scald the tissue. Immersion in hot water appears to be the most important first aid procedure for venomous fish injuries universally agreed upon by authorities.

Although some diving manuals recommend that the first aider make a small incision at the site to encourage bleeding and facilitate irrigation, Halstead [37] indicates that the incision may be of limited value, and Edmonds [26] indicates that a small incision can be made across the wound and parallel to the axis of the limb, to encourage mild bleeding and pain relief *if other methods are not available. In light of modern trends in first aid and the potentially limited value of the incision method indicated by physicians, this author is inclined to not recommend this procedure unless future evidence supports its benefit.*

Visible foreign material should be removed. Auerbach and Halstead suggest that local suction may be of some value; however, they do not indicate the use of incision [11]. Medical attention will be needed for further treatment of the wound and prevention of infection.

Bites

Injuries inflicted by moray eels, barracuda, and sharks are generally severe lacerations with profuse bleeding. First aid procedures for controlling bleeding and subsequent shock should be started immediately [1]. In severe injuries such as shark bites resulting in extensive tissue damage and severing of major arteries, the immediate application of a tourniquet may be necessary. *However, in applying a tourniquet you must keep in mind that you may be electing to sacrifice a limb in order to save a life.* Prompt medical attention will usually be required.

Octopus

The bite is similar for all species and usually consists of two small puncture wounds. A burning sensation with localized discomfort may later spread from the bite. Bleeding is usually profuse, and swelling and redness are common in the immediate area. First-aid measures include scrubbing the bite with antibacterial soap. Measures to combat shock should be taken, and medical attention may be required.

Annelid Worms

The segmented marine bristleworm, *Eurythoe complanata*, possesses tufted, silky, chitinous bristles in a row along each side. Upon contact or stimulation of any kind, the bristles rise on edge as a defensive mechanism. The fine bristles penetrate the skin and are very difficult to remove. This results in a burning sensation, inflammation, and possibly local swelling and numbness. Bristleworms are found in the Bahamas, Florida Keys, Gulf of Mexico, and throughout the tropical Pacific.

HELICOPTER EVACUATION

Helicopters are becoming a major means of transporting seriously injured persons. Most major medical centers have helicopters and/or landing areas. Each helicopter evacuation is different. In some situations, helicopter personnel will give directions by radio. In others, ground support personnel such as law enforcement officers and emergency rescue persons who are familiar with helicopters will take charge of the landing area. Knowledge of basic procedures and what to expect will improve the safety and efficiency of a helicopter evacuation. The following procedures for evacuating a patient from a boat have been modified from the NOAA Diving Accident Manual [48]:

1. Try to establish communications with the helicopter. If your boat is unable to furnish the necessary frequency, try to work through another boat.

2. Maintain speed of 10 to 15 knots; do not slow down or stop.

3. Maintain course into the wind about 20 degrees on port bow.

4. Put all antennas down, if possible, without losing communications.

5. Secure all loose objects on or around the deck.

6. Always let the lifting device (stretcher) touch the boat before handling it to prevent electric shock.

7. Place the patient in a lifejacket.

8. Tie/strap the patient in the basket face up.

9. If the patient cannot communicate, secure to the patient or place in the basket written information about the patient and the accident situation including name, age, address, description of the accident or circumstances preceding the injury/illness, first aid provided and so on.

10. If the patient is a diving accident victim, insure that the flight crew has a copy of, or instructions on, medical/first aid procedures for diving accidents. A copy of the DAN manual is beneficial.

11. If the patient is a diving accident victim, insure that the flight crew will deliver the victim to an appropriate medical facility with a hyperbaric chamber if possible.

12. If the patient dies prior to pick-up, inform the fight crew so that they do not take unnecessary risk.

If the helicopter is making a pick-up on land, clear the area of loose debris if possible, devise a signal that will enable the pilot to determine wind direction (smoke flare), and be sure that the landing area is clear of people. Do not approach the helicopter until directed by the flight crew. Be especially careful of the tail rotor.

CONCLUSIONS

The actions of the *first responder* are the key elements in the successful management of a diving accident victim. Failure to take immediate and appropriate steps to deal with the injured diver's condition can cost a life or contribute to serious disability. All divers are encourage to acquire a copy of:

> Lippmann, J. and Buggs, S., The DAN Emergency Handbook, 2nd Edition (Carnegie, Victoria, Australia: J.L. Publications, 1989). (This waterproof book may be purchased from the Divers Alert Network for $14.50; mail orders to DAN, Box 3823 DUMC, Durham, NC 22710.)

It is every diver's responsibility to remain abreast of the most recent developments in diving accident management. Remember, when you approach an injured diver, "You are part of the beginning of the rest of that diver's life!"

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ACKNOWLEDGMENTS

This paper was originally published by the Michigan Sea Grant College Program as part of the Diver Education Series — Publication No. MICHU-SG-86-512. It is the result of work sponsored by the Michigan Sea Grant College Program with grants form the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and funds from the State of Michigan.

Manuscript published: 1986
Manuscript Revised: 8 December 1989
Manuscript Revised: 14 January 1990
Manuscript Revised: 16 June 1990

NOTES:

SECTION 6

ENVIRONMENTAL FACTORS IN DIVE PLANNING AND OPERATIONS

ENVIRONMENTAL FACTORS IN DIVE PLANNING

PRELIMINARY PLANNING

Preliminary planning is vital for the success of any diving operation. Without adequate preparation the entire diving operation may fail and, even more seriously, the safety and well-being of the divers may be jeopardized. The diver must be placed in the water under optimum conditions, including sufficient knowledge, training, experience, equipment, and safety. Surface support must be capable and well organized. Although the diving supervisor (dive master) is responsible for preliminary planning and organization, the diving team and ship's crew must render all possible assistance.

The preliminary planning phase of a diving operation is divided into the following steps:

1. Survey of activity or task
2. Evaluation of environmental conditions
3. Selection of diving techniques
4. Selection of divers and assignment of responsibilities
5. Selection of equipment
6. Fulfillment of safety precautions
7. Establishment of procedures and briefing of personnel

SURVEY OF ACTIVITY OR TASK

The first step in planning a diving operation is to assess the dive activity or task and to formulate a general approach. It should be determined if the dive is feasible and if the proper equipment and personnel are available to undertake the activity or task. All factors that might constitute a specific hazard should be noted.

EVALUATION OF ENVIRONMENTAL CONDITIONS

Diver safety, especially for self-contained divers, is influenced considerably by environmental conditions. Careful consideration must be given to both surface and underwater conditions and appropriate arrangements made for diving under these conditions. Surface conditions to be considered include sea state, weather (present and predicted), tides, currents, ship traffic, etc. Underwater conditions include depth, bottom type or condition, visibility, and temperature.

Weather conditions will generally be the first factor to consider in planning a dive. When possible, diving operations should be canceled or delayed during bad weather. Generally, rough seas can be expected during storms and high winds. Weather forecasts must be reviewed to determine if proper weather conditions will last for a sufficient amount of time to complete the diving activity. Critical weather changes and a wind shift can jeopardize safety of personnel and vessels. Conditions must be such that adequate mooring may be maintained for the duration of the diving operation.

Do not attempt self-contained or surface-supplied diving in rough seas (Sea State 4: 5- to 8-ft waves), and when possible, avoid or limit diving in moderate seas (Sea State 3: 3- to 5-;ft waves). Naturally, sea-state limitations will be dependent to a large degree on the type and size of diving vessel. Diving operations may be conducted in rougher seas from properly moored, larger vessels or fixed structures. Land-based, self-contained divers should avoid entering the ocean in heavy surf.

Current and tidal conditions must be considered before commencing with diving operations. Current direction and magnitude are important considerations when mooring a diving vessel. When currents exceed 1 knot, self-contained diving operations should be avoided unless adequate provisions are made for a diver pickup boat to operate down current. Also, divers should carry signaling devices. Heavily weighted, surface-supplied divers are frequently required for work in currents. Tidal currents may prohibit diving at some locations except during periods of tidal current direction change. Consult tide tables when necessary and determine magnitude of tidal currents prior to diving.

Self-contained diving operations should not be conducted during periods of low visibility (fog, snow, rain, etc.). Self-contained divers are particularly vulnerable during periods of low visibility since they may lose orientation and be unable to relocate the diving vessel or shore base. Also, the diving vessel may be in danger when anchored during periods of limited visibility. Surface-supplied diving is permissible under limited surface visibility conditions, providing the diving vessel can safely anchor and vessel traffic in the area is warned to stay clear of the operation.

Ship traffic may constitute a hazard to divers, particularly self-contained divers. It is necessary to display proper visual signals in a prominent location on the diving vessel during operations in order to notify approaching vessels that divers are in the water. The following signals are appropriate:

* American Diver's Flag: This is a red flag 4 units wide by 5 units long with a one-unit wide white diagonal from the upper-left to lower-right corners. Sizes are not standardized and will vary with the size of the vessel.
* NATO Navies, Flag Numeral 4: This flag (a red flag with a white St. Andrew's Cross) flown alone means, "Divers or friendly underwater demolition personnel down."
* United Nations Maritime Group International Divers Flag: The single-letter signal "A" or alfa flag (blue and white) is recommended for international waters and is currently used by the US Navy and the major nations of the world.

Self-contained divers must tow a float on which a diver's flag is displayed or be accompanied by a chase boat with a diver's flag if they operate out of the immediate vicinity of the support ship. The flag must be at least 3 feet above the water.

Diving personnel must be protected from excessive exposure to adverse surface weather conditions. When working in tropical areas, the staging area should be shaded to prevent overexposure to sun. During cold weather in northern waters, divers and surface personnel must be protected from cold air temperatures and wind. Divers should not be expected to dress in an open, unprotected vessel. When working from small craft, divers should dress prior to leaving the shore base. If under-ice dives are required, dress in heated, shore facilities or heated, portable structures on the ice. Do not submit divers to excessive exposure prior to the dive. Heated quarters and warm showers should be available immediately after surfacing.

The selection of diving dress and equipment will depend on the activity, weather conditions, and type of vessel. For example, even though water temperatures may permit the use of wet-type suits, cold air temperature and wind would dictate a variable-volume dry suit (or equivalent) when diving from from an open or unheated vessel.

The type of bottom affects the diver's ability to work and is a factor in determining visibility. Consequently, this must be considered in the preliminary dive plan and certain precautionary measures may be necessary to ensure the diver's safety and efficiency. Mud (silt and clay) bottoms are generally the most restrictive for divers. The slightest movement will stir sediment into suspension and restrict the diver's visibility. The diver must establish orientation so that the current, if any, will carry the suspended sediment away from the work area.

Since the self-contained diver is more hampered by the limited visibility, surface-supplied diving techniques should be considered for work. For general survey work, self-contained diving techniques have certain advantages. The diver is properly weighted and a BCD allows maintenance of neutral buoyancy at survey depth and move about without touching the bottom.

Sand bottoms present little problem for divers. Visibility restrictions from suspended sediment are less and footing is firm. In marine areas the diver must be alert for sting rays buried in the sand.

Coral reefs are solid with many sharp protrusions. The diver may wish to wear reef gloves and some form of environmental protection garment for protection especially if the activity involves possible contact with the coral. Survey divers and photographers have to be cautious to avoid injury. Learn to identify and avoid corals and any marine organisms that might inflict injury.

Water depth is a basic consideration in the selection of personnel, equipment, and techniques. When possible, determine the depth accurately prior to diving and plan the dive duration, air requirements, and decompression schedule accordingly.

Water temperature is a major factor to be considered in dive planning since it will determine the type of equipment (diving suits) and, in some cases, the practical dive duration. Cold-water diving procedures and equipment are discussed in Section 10.

Underwater visibility depends on locality, water conditions, season, bottom type, weather, tides, and currents. Dark or murky water is a disadvantage in all underwater operations. Self-contained diving should be avoided under zero to limited visibility conditions when possible and a surface-supplied diver used. If self-contained divers must work in limited visibility water, a *buddy line is recommended.*

Self-contained divers are at a considerable disadvantage when surfacing in open water, especially if a stop is required. Ideally, divers operating from a vessel should descend and ascend on a fixed line. Some divers will use the anchor line for descent; others will deploy a separate ascent-descent control line (or shot line). In addition to the descent line, some divers carry a distance line on a reel when working in very poor visibility. This enables the divers to return to the shot line for controlled ascent.

An alternate method of controlling ascent and a stop is by the use of an inflatable float attached to a line marked at 10-ft intervals below the float and which is twice as long as the diving depth. At the end of the dive, the diver releases the float and secures the line to an object on the bottom with a releasing knot. The diver may then ascend to the appropriate stop level, unreeling the remaining line. Upon surfacing, the diver simply tugs on the free end of the line to release the knot and to retrieve the line.

Self-contained divers must establish a procedure for reunion of separated divers. Generally, the best procedure is to surface or return to a predetermined bottom location if separated. Striking the SCUBA cylinder with a rock or knife has only limited value in reuniting separated divers.

SELECTION OF DIVING TECHNIQUE AND EQUIPMENT

In scientific diving, the diving technique or mode used for a give operation, scuba, tethered scuba, or surface-supplied, is based on the mission requirements, environmental conditions, and available personnel. It is the responsibility of the diving supervisor and divers to review the task and environmental conditions and determine which technique to use. Each technique has advantages and limitations. Limited visibility diving is best conducted using tethered scuba or surface-supplied diving equipment.

When selecting equipment, divers should not overburden themselves with accessories. Use only the equipment required for safety and completion of the task. When the diver is encumbered with excess equipment, the possibility of entanglement and fatigue increases.

SELECTION OF DIVERS AND ASSIGNMENT OF JOBS

A diver must be qualified to make a particular dive. This qualification training and experience for the dive depth and environmental conditions. The diving supervisor (dive master) is responsible for determining the qualifications of divers before assigning them to a task or allowing them to dive.

FULFILLMENT OF SAFETY PRECAUTIONS

All personnel associated with the diving operation are responsible for maintaining proper safety standards. Ultimately, the diving supervisor (or team leader) must assume responsibility for the safety of the divers. He must evaluate each and every aspect of the operation. Safety is considered in all aspects of preliminary planning. Divers must not be committed to an activity or task which is unreasonably hazardous or for which they are not sufficiently trained or equipped.

In evaluating environmental conditions and the dive site, the diving supervisor (dive master) must anticipate potential hazards and take appropriate measures to protect the divers from these conditions. Naturally, all hazards cannot be eliminated from any diving operation; however, they can be minimized. If a particular hazard is foreseeable, it can usually be eliminated. The diving supervisor may wish to prepare a list of potential hazards, including precautionary measures to use when setting up the operation and briefing the measures to use when setting up the operation and briefing the personnel.

ESTABLISH PROCEDURES AND BRIEF PERSONNEL

The diving supervisor or team leader, after careful evaluation of the above factors, will establish the operational procedure and brief all personnel. The procedure and briefing should include:

Objectives and scope of the activity,
Conditions in the diving area,
Dive plans and schedules,
Assignment of personnel: buddy teams, divers, tenders, and specific tasks for each,
Safety precautions, and
Special considerations.

DIVING VESSEL

Divers will be required to operate from vessels (or boats) of various sizes and descriptions, ranging from small, inflatable, rubber boats such as the Zodiac to large research vessels 300-400 ft in length. The type and magnitude of diving, operation, and environmental conditions will determine the type of vessel.

For example, near shore, self-contained diving in relatively calm water may be accomplished without much difficult from a good quality, rubber, inflatable boat or small, wood, metal, or fiberglass boat equipped with a dependable outboard engine. More extensive offshore, self-contained diving operations or surface-supplied diving must be undertake from a large vessel with adequate deck space and seaworthiness. The following factors must be considered relative to the mission requirements:

1. Adequate size to comfortably accommodate divers, surface personnel, and equipment.
2. Sufficient stability and seaworthiness to function as a platform for diving operations.
3. Vessel well maintained, in satisfactory operating condition, and equipped with proper safety equipment as required by state and/or federal laws.
4. Large, open work areas.
5. Adequate protection from sun or cold.
6. Mooring capability (3- or 4-point moorings may be required).
7. Sufficient storage space to accommodate diving equipment when not in use.
8. An adequate ladder to facilitate entering and leaving the water.

CONCLUSIONS

In many respects a diving operation or activity is only as safe as the dive plan upon which the operation is based. Divers must make a complete evaluation of environmental condition and use this information in all aspects of dive planning. Divers must be matched with the environment. Unfortunately, many divers have lost their lives because they did not understand or consider the environment into which they were about to enter. The environment does not kill or injure divers. Divers are injured or die because they overestimate their abilities, let peer pressure guide them into hazardous environmental situations, or simple lack the training and experience for a given set of environmental conditions.

Manuscript completed: 3 January 1990

CHAPTER 6-2

HAZARDOUS MARINE LIFE

INTRODUCTION

The life of the marine environment is beautiful and fascinating. Of the thousands of marine animals and plants, relatively few constitute a real hazard to the diver. Although some species are dangerous and may, in some instances, inflict serious wounds, with a few exceptions marine animals are not aggressive. Generally, it is through the diver's own carelessness that injury results. The diver should respect, not fear, marine animals. He must be able to recognize animals that are capable of inflicting damage, know how to avoid injury, and be able to administer proper first aid in event of injury inflicted by marine organisms. *In addition to specialized training in diving related accident management/first aid, all divers are encouraged to acquire training in standard American Red Cross first aid practices or the equivalent.*

This discussion will characterize the major groups of marine animals that are known hazards to the diver. No attempt will be made to discuss individual species in detail. Geographically, the discussion will concentrate on the tropical waters of Florida, the Caribbean, and the Bahamas; however, reference will also be made to animals of the western coast of the United States and the South Seas (including Australia's Great Barrier Reef). ***Divers are encouraged to consult with local authorities regarding marine hazards whenever they travel to unfamiliar diving areas.***

This chapter has been developed as a support document for lectures which include a visual presentation of all organisms discussed. To reduce printing cost, illustrations of the organisms have not been included. Readers are encouraged to consult any of a number of popular publications such as National Geographic Magazine, Cousteau publications, nature guides, and the many excellent pictorial publications by various noted photographers [4, 5, 8, 21, 25, 26].

For convenience, the marine animals will be divided into the following categories:

marine animals that sting;
marine animals that abrade, lacerate, or puncture;
marine animals that bite;
marine animals that have venomous bites; and
miscellaneous hazardous marine animals.

MARINE ANIMALS THAT STING

Most marine animals that inflict injury by stinging their victim belong to the phylum Coelenterata. This phylum includes about 10,000 species in three major classes: Hydrozoa (hydroids, fire coral, and Portuguese man-of-war), Scyphozoa (jellyfish), and Anthozoa (sea anemones and corals). Although all coelenterates have stinging tentacles, only about 70 species have been involved in human injuries. However, over 90% of the venomous wounds and stings suffered by divers are from members of this phylum.

Coelenterates are characterized by their unique stinging cells, or nematocysts, which are situated in the outer layer of tentacle tissue. This apparatus consists of a trigger hair which, when touched, actuates a spine, followed by a hollow thread through which a paralyzing drug is injected into the victim. When a diver brushes against or becomes entangled in the tentacles of some coelenterates, thousands of tiny nematocysts may release their stinging mechanisms and inject venom.

Symptoms produced by the stings will vary according to the species, locality, extent and duration of contact, and individual reaction variations. Chemical toxins promote an allergic reaction in the skin. Some individuals are more sensitive than others to stings and will exhibit more severe reactions. The more nematocysts that strike the victim, the greater the impact. Thus, it stands to reason that larger specimens can be more dangerous than smaller ones. Conceivably, a sensitive individual in contact with a large *Cyanea* could suffer physiological shock and then drown. On the other hand, an encounter with *Cyanea* as well as many other jellyfish species may result in little or no discomfort for some individuals.

Symptoms may range from a mild prickly or stinging sensation to a throbbing pain which may render the victim unconscious. The pain may be localized or radiate to the armpit, groin, or abdomen. Local redness may be followed by inflammatory swelling, blistering, or minute skin hemorrhage. Following contact with some large species, certain individuals may experience shock, muscular cramps, loss of sensation, nausea, vomiting, severe backache, frothing at the mouth, constriction of the throat, loss of speech, breathing difficulty, paralysis, delirium, convulsion, and possibly death.

Stinging Coral

Stinging coral or fire coral is actually not a coral, but a member of the class Hydrozoa. Members of the genus *Millepora* are found among the true corals in warm waters throughout the tropical Indo-Pacific and Atlantic Oceans, Red Sea, and Caribbean. Common Florida and Bahamas species are *Millepora_complanta* or *Millepora alcicornis* which have a characteristic tan-colored, bladed-type growth with lighter (almost white) upper portions. *Millepora* may appear in a bladed growth form or an encrusting form over rock surfaces or on the branches of soft corals such as alcyonarians. The *Millepora* zone of the outer Florida Keys reefs ranges from 10 to 25 feet deep. Contacts with Millepora are relatively common, with symptoms generally limited to a stinging sensation and reddening of the skin.

Portuguese Man-of-War

The Portuguese man-of-war *(Physalia physalis)* is often mistaken for a jellyfish. This hydroid, also called blue bottle, floats on the water's surface in all tropical oceans and the Mediterranean Sea. It appears as a blue transparent jellylike mass with tentacles bearing large numbers of nematocysts trailing several feet down into the water. A single tentacle may have as many as 75,000 nematocysts. The Portuguese man-of-war drifts with the currents and may be found in localized large concentrations. This hydroid, producing a cobra-like toxin, has been responsible for many injuries in Florida and Bahamian waters, with symptoms ranging from minor irritation to shock and respiratory arrest. Other species that produce similar injuries include the *Velella velella* (purple sail) and *Porpita umbella*.

Jellyfish

The class Scyphozoa includes the large, bell-shaped medusae, having eight notches on the margin, and many other species that constitute potential danger for the diver. The sea wasp, represented by several species, including *Chiropsalmus quadregatus* and *Cheronex fleckeri*, is one of the most lethal venomous marine animals known to man. It is an especially dangerous inhabitant of Australian and Philippine areas and the Indian Ocean. Stings of the sea wasp have been responsible for a number of human deaths in Australian waters. Death may follow in 3-8 minutes after contact.

Cubomedusea (Caribbean sea wasps) can inflect a painful sting, however, they are not as potent as their South Pacific and Indian Ocean counterparts and do not cause death. *Carybdea marsupialis* and *Carybdea alata* (the more potent species) abundance will very with time and location. Along the north coast of Jamaica large concentrations may be encountered a few meters below the surface at night.

Less dangerous, but still painful, are the stings of the sea nettle (e.g., *Dactylometra quinquecirrha*) and the sea blubber (e.g., *Cyanea capillata*). The sea nettle is a widely distributed form which has been found as far north as New England coastal waters, as well as in all tropical sea areas. Sea blubbers inhabit areas from the north Atlantic and Pacific Oceans to the Arctic Ocean. Sea bladders increase in size in northern latitudes. The Carolina *Cyanea* are about as wide as saucers; those off southern New England may measure one to two feet across; and farther north the Arctic specimens approach gigantic sizes.

Sea Anemones and Corals

The sea anemones and corals include venomous members which may produce sting symptoms when contacted. The sponge fisherman's disease, for example, has been found to be caused by the tentacles of very small sea anemones which adhere to the sponge, and not by the sponge itself. Although some forms of coral produce only lacerations, others, such as elk horn coral (*Acropora palmata*), which inhabits the Florida Keys, Bahamas, and West Indies, produce added reaction by means of stinging cells.

Preventive Measures

Complete body coverage with a foamed neoprene diving suits or tight-fitting Lycra nylon body suits have proven to be useful protection. Persons diving in areas of known jellyfish concentration often wear Lycra or neoprene hood, especially at night. Thin fabric gloves also reduce possibility of injury. However, avoidance of contact with the tentacles is most important. Divers must be able to identify the dangerous species. They should also avoid detached tentacles floating in the water and dead jellyfish found on the beach, since the nematocysts may remain potent for some time.

First Aid for Marine Life Stings

The first aid procedures recommended for common nonfatal jellyfish and hydrozan (Portugese man-of-war) stings that are considered nonlife threatening in healthy individuals vary with author and geographic area. If no other rinsing solutions are available, the injured area should immediately be flushed with *seawater and cleaned of debris*. In the past many authorities suggest liberal use of a solution with high alcohol content (e.g., isopropyl rubbing alcohol: 40%) instead of sea water since it allegedly immediately inactivates the nematocysts. Monosodium glutamate (meat tenderizer) has also been a standard item in many tropical diver's first aid kit for years. Formalin has also been considered effective. Other inactivating solutions cited in various publications include household ammonia, urine, petroleum products (gasoline, kerosene, etc.), and beer.

Never rinse the sting area with fresh water to remove tentacles. Freshwater has an osmotic effect on the nematocysts causing them to discharge. Beer apparently has the same effect as fresh water. Also, never rub the area with sand since this procedure will cause discharge of more nematocysts. Most authorities also discourage the use of petroleum products.

Recent research at James Cook University (Australia) and by the Royal Australian Navy School of Underwater Medicine has revealed that application of methylated spirits, 100% alcohol, and alcohol mixtures with seawater *produced dramatic, instantaneous discharge of the nematocysts, and this was associated with increased clinical sensitivity* [13]. The James Cook University group found that the application of 3% to 10% acetic acid (or vinegar) was most effective in preventing the massive discharge of nematocysts associated with the application of alcohol and other common solutions tested. Further studies by Carl Edmonds, M.D., of the Diving Medical Center in Australia (one of the foremost world authorities on marine life injuries) concluded that *vinegar* and Xylocaine (lidocaine) will prevent further nematocysts discharge. Surprisingly, Edmonds also found that selected *commercial preparations, anti-sting lotions, and the enzymatic product, Adolf's meat tenderizer were clinically ineffective* [13]. The same was found for other common solutions such as urine, household ammonia, and so on.

However, further studies have revealed that certain species of jellyfish common to the Eastern U.S. Coast should be treated with alcohol rather than vinegar (South Pacific Underwater Medical Journal, 16(3), 1986). These include the hair jelly *(Cyanea)*, Sea Nettle *(Chrysaora)*, and little mauve stinger *(Pelogia)*.

Next, the tentacles that didn't rinse off must be carefully removed with a towel, stick, knife blade, etc. These residual tentacles may also be removed by coalescing them with a drying agent (e.g., flour, baking soda, talc, etc.) and then scraping them from the skin with a thin knife blade. *Avoid personal contact with the tentacles.*

After tentacles have been removed, some authors recommend neutralizing the toxins by applying one of the compounds/solutions mentioned above and thoroughly scrubbing with an antibacterial soap and water. The sting site is dried and an analgesic-antihistamine ointment applied. To the contrary, Australian authorities specifically state that the affected area must *not* be washed with soap and water for 24 hours [3,32].

Local anesthetic ointments (lidocaine HCl) or sprays (Benzocaine, 14%), antihistaminic creams, or mild steroid lotions (hydrocortisone, 1%) may be soothing [6]. They are used after the toxin is inactivated. A lidocaine spray (Clinicaine by Johnson and Johnson) may be beneficial as an initial decontamination agent as well as a soothing solution [personal experience].

Observe the victim for general reactions and shock. It is advisable to lay the victim down and keep him/her as quiet as possible. The symptoms of *shock* include glassy eyes with dilated pupils; wet and clammy skin; weak and rapid pulse; pale or ashen skin tone; increased breathing rate (shallow or deep and irregular); and sensations of coldness [1]. First aid measures for prevention and management of shock [1] include keeping the victim lying down and covered *only* enough to prevent loss of body heat. No attempt should be made to add heat since raising the surface temperature of the body can be harmful. Elevate the feet or end of stretcher 8 to 12 inches.

Giving fluids by mouth has value in shock; however, fluids should only be given when medical assistance is not available within a reasonable amount of time (delay of more than one hour). Fluids *should not be given* when the victim is unconscious, vomiting/likely to vomit, or experiencing seizures, since such states may result in aspiration of fluids into the lungs. Water that is neither hot nor cold (preferably a salt-soda solution, 1 level teaspoon of salt and 1/2 level teaspoon of baking soda per quart of water) is given at about 4 ounces every 15 minutes. Do not give the victim sea water. Discontinue fluids if the victim becomes nauseated or vomits. Obtain medical assistance as soon as possible. Keep in mind that physiologically or emotionally induced shock may be associated with any marine life injury.

Simple pain relief measures (e.g., aspirin tablets, or equivalent, in accord with dosage instructions on container) are considered acceptable. Do not attempt to administer medications if the victim is unconscious or nauseated/vomiting.

Naturally, all stings will not result in severe reaction or shock and require such aggressive first aid measures. For example, fire coral encounters do not involve tentacle removal, and some small jellyfish stings give only minor, momentary irritation. After minor encounters the diver may continue to dive. However, the victims and their buddies must maintain an awareness for more serious reactions. In rare cases, respiratory or cardiac arrest may occur and require immediate life saving action.

The box jellyfish or sea wasp *(Chironex flecheri)* found in Australian and South East Asian waters is one of the most dangerous stinging animals in the world. Although records are far from complete, at least forty fatalities have been documented on Australian beaches [32]. Examination of records show that one-third of the fatal cases are said to have died within three minutes or less following encounter. If death does occur, it usually does so within the first ten minutes; survival is likely after the first hour [12]. However, the historical "death within seconds" phenomenon is now questioned by modern authorities. The fact remains that death can occur within minutes and immediate first aid is required. A specimen 7 cm in diameter is capable of killing a healthy child, while a specimen 10 cm or larger in diameter may kill an adult. In any event, contact with a sea wasp can result in excruciating pain, occurring immediately upon contact, and increasing in intensity. The victim may become confused, act irrationally, and, subsequently, drown. *Please do not confuse this species with the far less potent and nonfatal ones of the Caribbean (Cubomedusea).*

The first aid procedures discussed below are summarized primarily from Australian literature [3,12,32]. However, in accord with more recent research, vinegar or Xylocaine-containing spray has been substituted for alcohol (or methylated spirits) [13]; Auerback and Halstead recognized the use of either alcohol or vinegar in their 1983 publication [6].

Since serious, potentially fatal reaction can be anticipated within minutes, the victim must be removed from the water immediately. Avoid personal contact with any adhering tentacles. If at all possible, do not allow the injured area to come into contact with sand or boat surfaces.

Such contact may bring more stinging cells into contact with the skin and cause the release of more venom. Immediately and thoroughly douse the sting area and tentacles with liberal amounts of vinegar (or Xylocaine spray).

Isolate the envenomed part, if on limbs, from general circulation as soon as possible. Several Australian authorities and publications indicate that a tourniquet should be applied in the middle of the upper arm or thigh above the injury using the most suitable form of binding applied at a pressure sufficient to stop the flow of blood (pulse). This should be kept in place for 1.5 hours or until antivenin has been given, medical attention received, and/or the patient is conscious and breathing normally [3]. Most United States authorities on first aid maintain that once applied, the tourniquet should be removed only by medical personnel since "shock" caused by loosening a tourniquet can, in itself, be fatal. Note the time of day that the tourniquet is applied.

Keep in mind that first aid authorities in the United States specifically discourage the use of tourniquets except when absolutely necessary. For example, in the management of poisonous snakebites a constricting band applied with only enough pressure to reduce lymphatic flow, not blood flow, is recommended. ***The decision to apply a tourniquet is in reality a decision to risk sacrifice of a limb in order to save a life!***

In a more current publication, Auerback and Halstead recommend the immediate application of a "loose tourniquet" which only impedes the lymphatic and superficial venous return. This "loose tourniquet" is loosened for 90 seconds every 10 minutes and should be removed after one hour [6].

Respiratory failure is possible. The victim must be monitored continuously and artificial respiration begun immediately if the victim stops breathing; cardiopulmonary resuscitation may be required if there is no obvious pulse. Do not delay or interrupt this aspect of first aid for any reason if an unconscious victim requires it. Do not terminate resuscitation procedures until directed to do so by medical personnel or as indicated in accord with ARC/AHA procedures. Oxygen breathing is recommended if the equipment is available.

Remove any remaining tentacles by irrigating the area with more vinegar. Do not handle or rub the tentacles unless removal by irrigation technique is unsuccessful.

Send for medical assistance and antivenin as soon as possible. Australian literature specifically discourages moving a seriously affected victim. Maintain constant observation and keep the victim quiet even if his/her condition improves significantly. Transfer responsibility for the patient to qualified medical personnel upon arrival.

The Commonwealth Serum Laboratories have developed an antivenin for stings of the sea wasp, and sublethal stings have been successfully treated. Australian scientists have investigated the use of toxoid that will provide immunization against the sting.

Sponges

There are approximately 4000 species of the phylum Porifera, or sponges, of which a few can produce a serious dermatitis or skin irritation. Keep in mind that many sponges may be colonized by other sponges, coelenterates, and numerous other organisms. Contact with the sponge can result in coelenterate stings. Skin reactions termed **sponge diver's disease** are often attributed to these secondary inhabitants. A few sponges can induce either pruritic (itching) or irritant dermatitis.

The fire sponge *(Tedania ignis)*, found off Hawaii and the Florida Keys, and the "Do-Not-Touch-Me" sponge *(Neofibularia nolitangere)*, common to the Caribbean, are typical offenders. Reactions are characterized by itching and burning, which may progress to local joint swelling, blisters, and stiffness. Soaks in dilute (5%) acetic acid (vinegar) are considered beneficial [6].

Most sponges are composed, in part, of small silicon dioxide or calcium carbonate spicules. These spicules are tiny and difficult to detect with the naked eye. If penetration of the skin by these small spicules is suspected, the particles may be removed by gently applying adhesive tape to the injured area and then removing it. Many of the embedded spicules will adhere to the tape during removal. Toxic sponges may possess toxins which will enter the lesions caused by the spicules. Application of isopropyl alcohol or vinegar should follow this removal procedure. Steroid lotions may help to relieve secondary inflammation. Severe secondary reactions may require medical attention.

MARINE ANIMALS THAT ABRADE, LACERATE, OR PUNCTURE

A number of marine organisms cause abrasions, lacerations, or punctures when contacted by the diver. Some of these organisms possess venom injection structures and may cause serious complications.

Coral

Wounds inflicted by contact with stony coral are an ever present annoyance to divers in the tropics. The sharp calcareous edges produce wounds which are generally superficial but notoriously slow to heal. Coral cuts, if left untreated, may become ulcerous. Sting cells may further complicate conditions. The initial effects of coral poisoning are pain and an itching sensation in and around the wound accompanied by reddening and welt formation in the surrounding areas. Secondary infection is common.

First aid involves prompt removal of visible debris and cleansing of the wound with hot water and antibacterial soap. It is occasionally helpful to use hydrogen peroxide to bubble out coral "dust." Promote free bleeding; however, keep in mind that excessive probing can cause unnecessary tissue damage. Deeply embedded materials may require removal by a physician. Elevation of the involved limb is strongly recommended. The use of antiseptic creams is a matter of personal preference. Monitor the wound closely and cleanse/change dressings as soon as possible upon return from subsequent dives. Even minor wounds can become seriously infected. Current tetanus immunization is recommended for all divers. For severe wounds, or if complications appear, seek immediate medical attention.

In the past divers were encouraged to wear gloves and diving suits or cloth coveralls for protection when swimming in the vicinity of coral. Carelessness and curious touching of corals has done considerable damage to our tropical reefs. Today, divers are being schooled in proper weighting and buoyancy control as a *conservation measure* as well as safety and diving technique consideration. In fact, the use of gloves is now being discouraged in some tropical marine parks. The opinion is, "divers without gloves are less likely to touch delicate corals either accidentally or on purpose!"

Barnacles

Barnacles, a marine arthropod, in the adult shell form are found attached to rocks, timbers, ship hulls, etc., in and near the intertidal zone. These shells are sharp and especially hazardous to divers who must enter the water from rocky shore areas, work on ship hulls near the water line, or dive around pilings or offshore structures such as oil rigs. An abrasive injury may be further complicated by the presence of hydroids on and among the barnacles. Caution and protective clothing are recommended. First aid measures are the same as for coral lacerations.

Echinoderms

Most members of this group of marine organisms are characterized by radial symmetry and may bear a rigid or semirigid skeleton of calcareous plates or spines on a flexible body way. Included are starfishes, sea cucumbers, and sea urchins. Of all echinoderms, the sea urchins are probably responsible for most injuries to divers.

Sea urchins occur in large numbers and variety in the shallow coastal waters of the world. The spines, common to all sea urchins, vary greatly from species to species. Most spines are solid, with blunt or rounded tips, and are not venomous. Others, however, are long, slender, sharp, and brittle, permitting easy, deep entrance into the flesh. Because of the extreme brittleness, these spines may be difficult or impossible to withdraw in one piece. Some may secrete a painful, or even deadly, venom. In some species, small, delicate, globe-shaped seizing organs called pedicellariae are distributed among the spines. This globe-shaped head, in at least one type, serves as a venom organ and is armed with a set of pincer-like jaws. One such venomous genus, *Toxopneustes*, inhabits the Indo-Pacific and Japanese waters. Symptoms vary from radiating pain to paralysis and respiratory distress. Fatalities have been reported.

More familiar to the United States diver is the genus *Diadema*, which includes the long-spined or black sea urchin common to the Bahamas, Florida Keys, and West Indies. These sea urchins with long, brittle spines are not considered to be a serious hazard by most divers; however, they may produce a painful puncture-type wound with redness and swelling. The fragments of the spine will produce a purple discoloration in the area of the wound. In minor injuries, the spines of some species will dissolve with few complications besides localized discomfort. However, deeply embedded spines will cause irritating discomfort of long duration if not removed. These should be removed with a fine tweezers or small needle (sterilized), the area thoroughly scrubbed with hot water and antibacterial soap, and a sterile dressing applied. Medication to control pain, inflammation, and infection may be required. Consult a physician immediately if symptoms of infection or other complications appear. Surgical removal of deeply embedded spines may be necessary.

Sea urchins with long needlelike spines should not be handled. Ordinary foamed-neoprene, canvas, or leather gloves do *not* afford adequate protection. Divers must exercise extreme caution, especially at night.

Some sea urchins are venomous. It appears that those which can cause serious reactions in a human are more common to the South Pacific. One genus, *Tripneustes*, found in the Pacific Ocean, has a neurotoxin. Injury from the pedicellariae (small, delicate seizing organs scattered among the spines of some species) can cause serious reactions. The symptoms may include immediate intense radiating pain, local swelling, and hemorrhage. This may be accompanied by faintness, numbness, generalized muscular paralysis, loss of speech, respiratory distress, and occasionally death [6]. In such cases first aid/treatment is in accord with the severity of the symptoms. Hot water may provide pain relief [6]. Seek medical attention immediately in the event of such severe reactions.

Some species of starfish can produce a contact dermatitis from a slimy venomous substance produced in the animal's tissue. The "crown-of-thorns sea star" *(Acanthaster planci)* is a particularly venomous species found from Polynesian waters to the Red Sea. Envenomation can induce acute systematic reactions that include paresthesia (sensation of prickling and tingling), nausea, vomiting, and muscular paralysis. First aid measures include immediate application of hot water and subsequent use of a topical solution such as calamine with 0.5% menthol. Medical attention may be required for serious reactions [6].

Cone Shell

The family of marine gastropod Conida is comprised of more than 500 species distributed throughout the tropical seas of the world, but concentrated in the reef areas of the Indo-Pacific. Some species are highly valued by collectors, with *Conus_gloriamaris* being worth more than $1,000 per specimen. Every species of *Conus* makes a venom peculiar to that species, and most have a fully developed venom delivery apparatus near the shell opening. Radular teeth are thrust into the victim, and the venom is believed to be injected under pressure into the wound. The venom of a given species of *Conus* may only affect certain animals and be totally ineffective on others. Only about six species of *Conus* are considered deadly to man. *Conus geographus* has been officially indicated in human fatalities and other species such as *Conus magus* are just as deadly.

The sting of a *Conus* usually produces a numbness, tingling, or burning sensation which may spread rapidly and become particularly pronounced about the lips and mouth. Paralysis and coma may follow. Death from respiratory or heart failure may result. Unfortunately, many authorities list no specific treatment for cone shell injuries. Some manuals suggest that cone shell injuries be managed the same as venomous fish injuries. Edmonds suggests that the use of a constricting band with incision and removal of venom, as in the treatment of a snake bite, may be of value if performed early [12]. This procedure is also supported by other authorities

[6,32]. In light of the recommendations in the literature, the procedure given below should be considered in the first aid management of cone shell injuries.

The first-aider should immediately immobilize the victim and take measures to combat shock. Elevate the affected limb if possible. Apply a venoconstrictive tourniquet or constricting band sufficient to reduce lymphatic and superficial venous return [6]. Sterilize area (and instrument) and make a small incision over the wound. Suction (using components of a snakebite kit, not by mouth) may be applied to promote bleeding and remove poison. This procedure should be started as soon as possible. Soaking the site of injury in hot water or applying hot compresses for 30 minutes can be effective in inactivating the venom and reducing pain or other symptoms. Paralysis and respiratory/cardiac failure may occur. Make routine observations of respiration and circulation continuously. Employ resuscitation or CPR if and when indicated. Immediate medical attention and hospitalization is generally required.

Specific precautions and ample protection for the hands are necessary when handling cone shells. Avoid contact with the fleshy portion of the animal. Divers must learn to identify dangerous species peculiar to their locality, and specific precautions must be taken in Indo-Pacific waters.

Venomous Fish

Fish that inflict poisonous puncture-type wounds are found throughout the world, but are most common in tropical waters. They are generally nonaggressive, and injury generally results from careless contact with venom-bearing spines, commonly located on or associated with the fins of the fish.

The common spiny dogfish is a small (up to 3.5 feet in length) shark found along the coast of the Atlantic and Pacific Oceans throughout temperate and tropical seas. Two short, stout spines, one situated immediately in front of each dorsal fin, can cause painful wounds. The venom is found in a shallow groove of the spines and enters the victim with the spine. Injury is immediately followed by an intense, stabbing pain of long duration (possibly 6 hours), severe swelling, and redness. Handle dogfish with caution.

Stingrays of many kinds inhabit tropical and subtropical seas at moderate to shallow depths. They are common in sheltered sandy bays and lagoons where they lie in shallow water on top of or partially buried in the sand or mud. Most rays have a sharp spine near the base of a whiplike tail. Deep, glandular grooves of the spine contain poisonous tissue. The menace is most serious to persons wading or crawling on the bottom in very shallow, protected waters. When stepped on, the ray strikes upward with its tail and may drive the spine deeply into the foot or leg. This usually produces a ragged, dirty wound. The wound usually causes immediate and severe pain. Swelling of the wound area is accompanied by an ashy appearance which later turns red. Symptoms of shock along with fainting, nausea, and weakness may follow, depending on the severity of the injury and the species of stingray. Medical attention is recommended. Wounds in the chest or abdomen are extremely serious and may be fatal. Deaths have been reported. Immediate hospitalization is necessary.

The diver can avoid contact by entering the water cautiously and shuffling his feet as he moves through shallow water and never lying on the bottom without first looking for rays. Fins and foamed rubber boots offer only limited protection.

About 1,000 species of catfish are found primarily in fresh water and may assume many sizes and shapes. Generally, the body is elongated with oversized head, and the mouth area usually has long barbels or feelers. The skin is usually thick and slimy, without scales, although bony outer plates may exist in some.

Some species have a stiff spine in the front part of the dorsal and pectoral fins. Venom glands are located in the outer skin or sheath of the spine. The venomous spine is equipped with a device which can lock it into an erect position. The wound is generally accompanied by an almost instant stinging, throbbing, or scalding sensation, with radiating pain and numbing; redness and swelling follow. Bacterial infection is possible. Care must be taken to avoid injury when handling venomous species.

Weeverfish, of the family Trachinidae, are small but extremely venomous fish found along the eastern Atlantic and Mediterranean coasts. Because of an aggressive temperament, combined with a well-developed venom apparatus, they present a specific danger to divers. Weevers habitually bury themselves with only part of the head exposed. With little or no provocation, they dart out with fins erect and gill covers expanded and strike at any offending target.

The dorsal and opercular spines are venomous. This venom is similar to some snake venoms and acts both as a neurotoxin and a hemotoxin. A weever wound normally produces instant burning or stabbing pain that intensifies and spreads. Within 30 minutes the pain may be severe, and the victim may lose consciousness. A large spectrum of symptoms includes headache, fever, chills, delirium, nausea, vomiting, sweating, palpitations, and convulsions.

Weevers are commonly encountered while wading in shallow water; care must be taken to avoid contact. Adequate footwear (high-top tennis shoes) may provide some protection. This fish should neither be antagonized into an attack or handled in a careless manner.

The members of the scorpionfish family can be found in all tropical and temperate seas. The wound from any of these fish will produce serious results, and a few of the stonefish group, *Synanceja*, may rank with the cobra in the deadliness of the poison secreted. Most species have venomous dorsal spines; some have venomous anal and pelvic spines. These fish are divided into three main groups — scorpionfish *(Scorpaena)*, zebrafish *(Pterois)*, and stonefish *(Synanceja)*.

Scorpionfish inhabit shallow-water bays, lagoons, and reefs—and have also been observed 60-80 feet deep in the waters of the Bahamas. *Scorpaena guttata* ranges from central California south into the Gulf of California and *Scorpaena plumieri* (and related species) are found on the Atlantic coast from Massachusetts to the West Indies and Brazil. They may be found among debris, rock, or seaweed. Scorpionfish have nearly perfect protective coloration which enables them to blend into their background and become almost invisible.

Zebrafish are beautiful and ornate fish which swim about coral reefs of the Red Sea and Indo-Pacific seas with their fanlike fins extended in a display fashion. Although extremely beautiful and prized by fish collectors, the fins of this fish contain 18 potentially lethal spines, each equipped with venom.

Stonefish are encountered in tide pools and shoal areas of the Indo-Pacific [16]. They lie motionless while concealed or partly buried and appear to be fearless. The fish is equipped with as many as 18 spines with enlarged venom glands. In natural concealment, the fish looks like a piece of mud or debris. They present a particularly dangerous hazard to a barefooted wader.

Other fish which may inflict venomous wounds include toadfish, surgeonfish, dragonets, rabbitfish, and star-gazers. For a detailed account of these fishes, consult Halstead (18,20).

Prevention of injury from all venomous fish is based on the diver having a healthy respect for the potential serious wound, being aware of the habits of particular species common to the waters in which he is swimming, and being alert and observant to avoid contact with concealed or camouflaged fish. ***When diving in an unfamiliar area, it is recommended that divers consult with local authorities.***

First aid for venomous fish wounds includes alleviating pain, combating shock and the effects of the venom, and preventing infection. Since unconsciousness is common, the victim should be removed from the water promptly. Pain will be severe. Have the victim lie down and apply measures to prevent/combat shock. Keep the affected limb level with the body and as still as possible to minimize the spread of venom. Carefully wash out or irrigate the wound with cold salt water or with sterile saline.

Although the use of a tourniquet is indicated in some manuals, the practice is considered to be of limited value [12,17]. However, Auerbach and Halstead do indicate that the application of a "loose tourniquet" which occludes only superficial venous and lymphatic return may be of some value [6]. This "loose tourniquet should be released for 90 seconds every 10 minutes in order to preserve circulation. Considering the inherent risk associated with the use of tourniquets, this practice is generally discouraged for first aiders. Attempt to remove any remaining portions of the spine sheath.

Soak in plain water, as hot as can be tolerated (up to 50° C/122°), for at least 30 minutes. Use hot compresses on areas that cannot be immersed. Heat may produce rapid pain relief and is believed to destroy the venom. Be careful not to scald the tissue. ***Immersion in hot water appears to be the most important first aid procedure for venomous fish injuries universally agreed upon by authors/authorities.***

Although some diving manuals recommend that the first aider make a small incision at the site to encourage bleeding and facilitate irrigation, Halstead [17] indicates that the incision may be of limited value, and Edmonds [12] indicates that a small incision can be made across the wound and parallel to the axis of the limb, to encourage mild bleeding, and pain relief if other methods are not available. In light of modern trends in first aid and the potentially limited value of the incision method indicated by physicians, this author is inclined to not recommend this procedure unless future evidence supports its benefit.

Visible foreign material should be removed. Auerbach and Halstead suggest that local suction may be of some value, however, they do not indicate the use of incision [6]. Medical attention will be needed for further treatment of the wound and prevention of infection.

MARINE ANIMALS THAT BITE

Moray Eels, family Munaenidae, are represented by about 20 species and are confined primarily to tropical and subtropical seas, although several temperate-zone species do exist in Californian and European waters. Morays dwell mostly on the bottom in crevices and holes under rocks or in coral. They possess powerful jaws with strong, sharp teeth capable of inflicting severe lacerations. The morays seldom attack unless provoked; however, several unprovoked attacks have occurred. Their bite is of the tearing, jagged type.

The diver should exercise due diligence and caution when exploring crevices and holes in areas where morays are known to exist. A moray should not be agitated. Though some divers successfully hand-feed morays, this activity is not recommended. In some dive resort waters moray eels aggressively approach divers in search for a "handout." If approached, do not strike at the eel; remain calm, do not hold out your hand as if offering food. A moray may become aggressive in defense of its territory.

Barracuda

Barracudas are potentially dangerous fish found widely distributed throughout the tropical and subtropical waters of the Atlantic and Indo-Pacific. Their size (which may exceed 6 feet); knifelike, canine teeth; and failure to exhibit any undue fear of man have earned barracudas the false reputation of an extremely pugnacious and dangerous fish that will attack rapidly and ferociously. Although several spearfishermen have been severely injured when attempting to handle speared barracuda, it must also be noted that there are few, if any, documented unprovoked barracuda attacks on divers.

Barracudas are curious fish that may be attracted by excessive movement, bright or colored objects, and, particularly, shiny metal objects that reflect light (i.e., jewelry). It is not unlikely that a barracuda would strike at a speared fish. This is a particular hazard for spearfishermen who carry fish on a stringer attached to their belts. The potential of an accidental encounter with subsequent injury is probably higher in murky water where the barracuda is less likely to see the entire diver and strike at a portion of the diver or the movement which resembles prey.

Prevention of attack appears to be one of respect and caution when diving in waters inhabited by barracuda. Divers should avoid wearing bright or shiny objects. Unnecessary agitating and hand-feeding of barracuda are discouraged, as is spearing.

Sharks

Sharks are probably the most feared of all marine animals. There are about 250 species of sharks which inhabit all the oceans of the world; however, only 32 have been implicated in attacks on humans and are considered potentially dangerous to divers and underwater swimmers. There are considerable differences of opinion regarding the potential risk of a shark attack. Myth and public opinion fostered by popular film productions such as "JAWS" has resulted in unwarranted anxiety for many novice divers. There are only 50 to 100 shark attacks reported annually worldwide [8].

Cross (1967) gave the following figures on the frequency of shark attacks. During 1959 there were 11 authenticated attacks in the vicinity of the United States, of which three were fatal. By comparison, in the same year in the United States there were over 400 people killed by lightning and another 1,000 injured. In 1960, there were 42 reported shark attacks on humans throughout the world; none were fatal. Of all reported shark attacks during these two years, none have involved helmet-equipped divers, and only a few have involved scuba divers. Almost all attacks have been on swimmers, waders, or persons dangling their arms or legs from surface floats or rafts. However, in more recent years the incidence of shark attacks on scuba divers appears to be progressively increasing and now accounts for one-third of all shark attacks [12].

Statistically, the greatest danger of shark attack exists in tropical and subtropical seas, between 30 degrees north and 30 degrees south of the equator. Particularly dangerous areas are Queensland, Australia, and South Africa. Seventy percent of all the attacks have occurred within 5 feet of the surface and 62.2 percent within 300 feet of shore. Most attacks have occurred when the water temperature was greater that 70° F, with January as the peak attack month in tropical waters. The greatest risk appears to be between 1500 and 1600 hours (3:00-4:00 pm).

Sharks appear to be attracted by blood (fish or human), flashing lights, colored material, thrashing about, explosions, or unusual noises. The presence of blood highly excites sharks and may radically alter their normal habits. The diver is certainly in most danger if he is injured, bleeding, or carrying speared fish that are bleeding. Sharks apparently have a well-developed sense of smell and will "home in" on blood. They have unique sensory mechanisms which enable them to hear (feel) vibrations from a considerable distance. Thus, they are more apt to "home in" on surface splashing or underwater noises. Erratic, panic-like movements executed by a frightened swimmer are believed to excite sharks and increase the probability of attack.

In spite of differences of opinion about many aspects of sharks, *all authorities agree that sharks are completely unpredictable.* Although sharks usually seem aloof and quiet, they can become viciously aggressive, and for no apparent reason. Although nurse sharks, sand sharks, and leopard sharks are considered harmless by some divers, attacks have been reported. A University of Michigan scientist was bitten on the leg during July 1972 while diving in the Florida Keys; the attack was without warning or provocation.

Many opinions have been expressed on how to chase sharks away; however, it has been fairly well established that procedures such as shouting underwater, blowing bubbles, striking on SCUBA cylinders, striking rocks together, or, if on the surface, splashing with a cupped hand will not frighten a shark. In fact, it is believed by some authorities that these actions will actually attract sharks. Although several chemical and electronic shark repellents have been developed and used with some success, most authorities feel that there is still no guaranteed effective repellent.

Many divers use a pole (4-8 feet) equipped with an explosive power head for protection or to kill sharks. The power head consists of a chamber and firing device which detonates a 12-gauge shotgun shell or 38- to 45-caliber bullet when pressed against the target. This type of weapon is popular in Australia and said to be extremely effective in killing sharks. A certain degree of accuracy is required to hit the shark behind the eyes and dead center over the base of the spine for an effective kill. A wounded shark may be more dangerous, and the blood and thrashing movements may attract more sharks. The power head is also an extremely dangerous weapon, and accidental firing could result in considerable injury to the diver or other swimmers. Some authorities feel that the hazard of the weapon is greater than the hazard of shark attack. Keep in mind that some states and countries have strict laws regulating the possession and transport of firearms and that some authorities may consider such devices to be illegal.

Many authorities advocate the use of a "shark bully," constructed to meet personal preference. This defensive weapon consists of a short pole (3-4 feet) made of hardwood, metal, or weighted plastic with a blunt end fitted with a roughened material to prevent slipping on the shark's skin. The best place to strike an aggressive shark is on the snout, or nose. The strike or blow should be as hard as possible. This blow may discourage the shark, and the reactive force pushes the diver aside as the shark passes.

Some divers prefer the use of a gas injection device or "shark dart" [24]. The device consists of a CO_2 cylinder contained in the holder; a firing mechanism; a sharply pointed, stainless steel, 5/16-inch, hollow needle; and a pole (length varies depending on the model). The size of CO_2 cylinder also varies with the model. This weapon is effective to depths of 25 feet with a 12-gm CO_2 cylinder, 40 feet with a 16-gm cylinder, and 100 feet with a 26-gm cylinder. A multiple-shot, compressed-air model is also available. Divers must handle these devices with care in order to prevent injury to themselves or others. Keep in mind that a gas injection weapon may also be subject to local laws and regulations. For example, under strict interpretation of Michigan law, a shark dart (gas injection weapon) is illegal to possess.

To disable a shark, the diver thrusts the needle of the shark dart into the shark's abdominal area. The needle easily punctures the skin and, subsequently, the CO_2 cylinder is punctured by the firing mechanism, and the gas is released. This small volume of high-pressure gas entering the shark suddenly displaces the water inside him and forces it to take the path of least resistance. The pressure wave reverberates throughout the shark, blows the stomach out his mouth, and destroys his internal organs. The expanding gas forces the shark to the surface. He is instantly immobilized.

When diving in water known to be inhabited by sharks, the diver should observe the following:

* Avoid solo skin or scuba diving. Visual sighting and early warning will allow the divers time to leave the water at signs of aggression. One of the two divers is more apt to sight the shark immediately. Also, in the event of an attack, help is immediately available.

* The diver should leave the water immediately if injured or bleeding.

* Diving or swimming in turbid, shark-infested waters should be avoided, if possible. A portion of a diver's leg and fin might have the appearance of a fish on which the shark would feed whereas a fully visible diver might be discouraging. Moreover, if the diver is aware of the shark's presence and activities, he has a better chance of taking defensive measures, if necessary.

* Light-colored clothing and bright, flashing equipment are more likely to attract sharks according to some authorities and should be worn with caution or avoided in high shark risk areas. *However, we have not noted an increase in the number of shark attacks associated with modern trends in brightly-colored diving equipment.*

* Panic must be avoided if a shark is sighted. Half the battle of shark safety is over once the shark is sighted. Rapid movements or immediate ascent to swim on the surface may excite the shark and cause it to move in and investigate. The diver should remain calm and face the shark. If the shark appears to simply be passing by (most of them do), leave it alone. If the shark moves in and is persistent, the diver should stay on the bottom and move slowly and quietly out of the area, preferably toward the boat or other safe place (i.e., shark cage). The diver should not surface but stay on the bottom as he moves toward his boat position. Safe refuge may be sought in a crevice or behind rocks.

* The diver should never attempt to wound the shark with a spear gun or knife. These actions are virtually useless and may make matters worse.

* Teasing and spearing sharks is discouraged. They are difficult to kill and can react in a fantastic frenzy if hurt.

* Speared fish should never be carried on a stringer attached to the diver.

* A "shark bully" or "shark dart" is recommended for defense in areas of exceptionally large shark populations or where sharks are noted for aggressive behavior. Striking a shark with the bare hand can result in lacerations and bleeding.

* Divers should not dangle arms and legs from surface floats.

* Since the shark is unpredictable, he must be respected, and the diver must be prepared to abort the dive in some instances.

The diver should not give up diving just because there are sharks in the ocean. He should learn to respect them, not fear or dislike them. For additional information about sharks and shark attacks, consult Gilbert [15], Cross [9], Baldridge [7], and the U.S. Navy [29,30].

Killer Whale

The killer whale, *Orcinus orca*, is found in all seas and oceans from the Barent Sea or Bering Straits to beyond the Antarctic Circle. This species is characterized by a bluntly rounded snout; high, black, dorsal fin; white patch behind the eye and a striking jet-black color above the eye; and contrasting white underparts. They are swift swimmers with a reputation of being ruthless and ferocious killers. Killer whales are reported to hunt in packs and are serious enemies of the seal, walrus, and penguin. In spite of recent notoriety of trained killer whales in marine exhibits/seaquariums and various published pictures of divers riding them in the ocean, they must still be considered an unpredictable, potentially serious hazard. They should be treated with respect and at a distance. A human, mistaken for a sea lion, would be a nice snack for a killer whale. Divers are encouraged to leave the water immediately when killer whales are sighted in the area.

First Aid

Injuries inflicted by moray eels, barracuda, and sharks are generally severe lacerations with profuse bleeding. First aid procedures for controlling bleeding and subsequent shock should be started immediately [1]. Prompt medical attention will usually be required.

MARINE ANIMALS THAT INFLECT VENOMOUS BITES

Octopus

Along with squid, nautilus, and cuttlefish, the octopus belongs to the class Cephalapoda, phylum Mollusca. The octopus has a powerful, parrot-like beak concealed in the mouth, and, in some species, a well-developed venom apparatus associated with the salivary glands. Because of public notoriety and myth, the octopus is vastly overrated as a hazard. Actually, the octopus is timid and prefers to stay concealed in holes. In the northwestern United States, skin and scuba divers actually hunt large octopi (up to 20 feet in overall length) and "wrestle" them for sport. Certainly, some precautions are required if the octopus must be handled; heavy gloves are recommended. In Florida and the Bahamas the octopi are much smaller, generally not exceeding 2 feet in length.

The bite is similar for all species and usually consists of two small puncture wounds. A burning sensation with localized discomfort may later spread from the bite. Bleeding is usually profuse, and swelling and redness are common in the immediate area. First-aid measures include scrubbing the bite with antibacterial soap. Measures to combat shock should be taken, and medical attention may be required. Recovery is fairly certain.

The Australian blue-ringed octopus *(Octopus maculosus)* and spotted octopus *(Octopus lunulatus)* could inflict a fatal bite. The blue-ringed octopus is being found in ever increasing numbers off the beaches of South Queensland and other areas of Australia, and several fatalities have been recorded [10,19]. It rarely exceeds a length of 4 inches, and has dark brown to ocher bands over the body and tentacles. Brilliant blue circles are scattered over the animal. The venom of this octopus is a neurotoxin and a neuromuscular blocker which can cause painless muscular paralysis.

The initial bite is usually painless and may go unnoticed. The area around the bite will begin to swell within 15 minutes, and the victim will experience abnormal sensations around the mouth, neck, and head; mouth dryness; nausea and/or vomiting; visual disturbances; respiratory distress; and a variety of neurological disorder symptoms. The victim's conscious state is initially normal, even though he may not be able to open his eyes or respond to his environment. Respiratory paralysis finally results in unconsciousness (as a result of hypoxia and hypercapnia) and death occurs unless resuscitation procedures are begun and continued.

If the victim is still breathing, immediately have the victim lie down and immobilize the limb. Apply a constricting bandage between the wound site and the heart [12] and make a small incision over the wound to encourage bleeding and venom removal [12,32]. Take appropriate measures to prevent/manage shock, and place the victim on his side in case of vomiting. *Maintain the victim under constant observation!* Be prepared to begin mouth-to-mouth artificial respiration if respiratory paralysis occurs. Artificial respiration may have to be continued for hours and CPR may be necessary. Reassure the victim who can hear but cannot communicate that he will be alright, and that you understand his condition. Transport to a hospital and/or obtain on-site medical assistance as soon as possible.

Sea Snake

About 50 species of sea snakes are found primarily in the tropical Indian and Pacific Oceans. At least one species is found on the Pacific coast of Central America and in the Gulf of California. The sea snakes are closely allied to the cobra and form a specialized group adapted by structure and habit to a marine existence. All are poisonous and many are deadly; however, they will generally not attack without provocation and have often been described as docile in habit although aggressiveness has been observed in some specimens. Only a few appear to be of significant danger to humans. They have been noted to be attracted by fast-moving objects such as divers being towed by boats [12]. Bites usually result from unintentional contact; fatalities are most common in the Gulf of Siam and the Philippine area.

Few sea snakes exceed a length of 4 feet. They are distinguished from land snakes by a paddle-shaped tail. Coloration is dark above and light below with cross-bands of black, purple, brown, gray, green, or yellow. They inhabit sheltered coastal waters, particularly the areas near river mouths, and may penetrate upstream to the limits of brackish water; a few species are found in fresh water. Sea snakes tend to collect close to shore and among coral reefs in breeding season. The sea snakes generally float on the surface for extended periods of time. Although they are air breathers, they are capable of remaining submerged for long periods.

The bite is usually small with considerable delay (average of 1 hour) between the injection of venom and the reaction. Some victims fail to notice the connection between the bite and the illness since there is no pain or reaction at the site of the bite. Sea snake venom is approximately 2 to 10 times as toxic as that of the cobra; however, they tend to deliver less of it. Only about one-quarter of those persons bitten by sea snakes ever exhibit signs of poisoning [12]. Symptom onset progresses from mild to severe, generally beginning with an ill feeling or anxiety, thickening of the tongue, muscular stiffness, and aching. Later symptoms include shock, general weakness, paralysis, thirst, muscle spasms, respiration difficulties, convulsions, and unconsciousness. Deaths have been reported. Sea snake venom appears to block neuromuscular transmission, inducing generalized and painless skeletal paralysis. The diver should avoid aggravating the sea snake, and, in water known to be inhabited by the snake, he should be alert to avoid accidental contact. Wet suits will offer some protection since, in the average size snake, the mouth and fangs are relatively small.

First-aid measures include keeping the victim quiet, taking measures to combat shock, and applying a constricting band above the bite, if bitten on the arm or leg, with sufficient pressure to restrict superficial venous and lymphatic return (this band should not restrict arterial blood flow). Release the band for 90 seconds every 10 minutes and do not use for more than 4 hours [6,17]. Monitor the victim continuously and be prepare to begin artificial respiration/CPR if indicated. Transport the victim *immediately* to the nearest medical facility since antivenin treatment must be started as soon as possible. If possible, accurately identify the offending snake or capture and kill it for later identification. This is helpful for determining treatment procedures. For further details, consult medical references [6,12,18].

OTHER POTENTIALLY HAZARDOUS MARINE ANIMALS

Sea Lions

Sea lions and harbor seals are normally curious but nonaggressive as they swim about divers. There are reports of playful but potentially damaging "nips" and loss of a swim fin. During the breeding season, the large bulls become irritable and may take exception to any intruder. Also, a female may exhibit protective reactions toward a diver molesting her young. Divers have been bitten and should avoid ill-behaved animals. One California diver has indicated that a potentially greater danger when swimming with seals is that of being shot with a rifle by a person sitting on a cliff. Some divers wear bright markings on their hoods for this reason.

If bitten by a seal or sea lion, cleanse the wound with soap and water and be aware of the possibility of infection. The diver should consult a physician.

Giant Clam

The giant clam, *Tridacna gigas*, abounds in the reefs of Pacific tropical waters. Specimens may attain a length of 4 feet and weigh several hundred pounds. Some authorities claim that *Tridacna* have trapped divers by closing on a hand or foot with a vice-like grip. However, discussions with several scientists who have worked on the Great Barrier Reef of Australia indicate that "trapping of divers by giant clams" is questionable and probably fears are unfounded. In any event, the grip can be released by inserting a knife between the valves and severing the two adductor muscles which hold the valves together. The diver is, however, discouraged from experimenting with his own foot.

Groupers and Jewfish

Some species of giant grouper and jewfish may attain a length of 12 feet and weigh more than 700 pounds. They are frequently found around rocks, caverns, and submarine structures such as offshore oil rigs. These fish are not considered vicious but can be unintentionally dangerous because of their curious nature and huge size. One of the most interesting accounts of an aggressive jewfish is given by Zinkowski [33].

Annelid Worms

The segmented marine bristleworm, *Eurythoe complanata*, possesses tufted, silky, chitinous bristles in a row along each side. Upon contact or stimulation of any kind, the bristles rise on edge as a defensive mechanism. The fine bristles penetrate the skin and are very difficult to remove. This results in a burning sensation, inflammation, and possibly local swelling and numbness. Bristleworms are found in the Bahamas, Florida Keys, Gulf of Mexico, and throughout the tropical Pacific.

Bristles are best removed with forceps or, if exceptionally small, by applying tape to the area and gently removing. After removal, application of ammonia or alcohol will alleviate the discomfort. Divers should avoid contact or take special precautions in handling.

The bloodworm, *Glycera dibrochiata*, is found on the Carolina coast northward into Canadian waters. These worms, up to 12 inches long, may be encountered under rocks or coral. They possess strong jaws and may inflict a painful bite. Swelling, numbness, and itching follow the bite.

Electric Rays

Electric rays, or torpedo rays, grow from 1 to 6 feet in length and weigh up to 200 pounds. They may be found on both the Atlantic and Pacific coasts of the United States, as well as other areas of the world. They are shaped somewhat like a normal sting ray; however, their wings are thick and heavy, and their tails are modified for swimming. The giant Atlantic torpedo ray can produce a current of 50 amp at 60 v, enough to electrocute a large fish or knock down a full-grown man. Needless to say, divers must be cautious when approaching or attempting to handle specimens from this group.

Sawfish

Sawfish are members of the ray family that have sharklike shapes and swim by sculling their tails. They are sluggish but powerful and commonly reach a length of 16 feet. The cartilaginous snout is extended in a long, flat "saw," equipped on both sides with sharp scales or denticles which have been enlarged into teeth. Large specimens have been recorded at a length of 22 feet with a 6-foot snout. The snout is swung from side to side to impale fish. The size and snout make this ray a potential hazard for divers; however, it is not likely to attack unless provoked. Caution is recommended.

Marine Turtles

Recently, divers in the Florida Keys have reported minor injuries resulting from aggressiveness by large marine turtles. Several divers were "nipped." Authorities feel that these "nips" were of a playful nature. Still, the size and power of a swimming turtle must be respected by the scuba diver. If you grab on to the shell of a large turtle, the turtle may struggle to escape and injure the diver in the process.

Paralytic Shellfish Poisoning

Paralytic shellfish poisoning is a well-recognized annual problem on the Pacific coast and occurs occasionally along the Gulf of Mexico. Under environmental conditions of warm weather in summer months (March to November on the West Coast) and an influx of nutrients, the toxic dinoflagellates, *Gonyaulax* sp., undergo a population explosion or "bloom," resulting in the "red tide." The waters abound with patches of planktonic algae that turn the water into a variety of colors including red, yellow, brown, green, black, blue, or milky white.

Unlike many marine animals, mussels and clams ingest and sequester the poison without damage to themselves. Contrary to popular belief, there is no practical method of distinguishing contaminated (or poisonous) mussels and clams from edible ones. Usual cooking methods do not remove the toxin. In some areas, taking of certain clams and mussels is banned during critical months. Abalone, as well as crabs, do not feed on plankton nor are their viscera usually consumed; for both reasons, there is no danger of shellfish poisoning from them. Divers must be especially cautious and consult with local authorities before collecting marine animals for human consumption. All plankton feeders may, at times, become poisonous.

When consumed by humans, the toxin acts directly on the central nervous system, affecting respiratory and vasomotor centers, and on the peripheral nervous system, producing complete depression. With large doses, respiration may cease instantaneously; with smaller doses, symptoms of nervous system involvement are slow and progressively worsen. Gastrointestinal symptoms (nausea, vomiting, etc.) are less common. Death in severe cases is almost invariably the result of respiratory paralysis and usually occurs within 12 hours. Medical attention should be sought immediately if unusual illness occurs after eating mussels or clams. For details of treatment, consult medical references [6,12].

Fish Poisoning

Ciguatera poisoning results from eating a wide variety of unrelated fish that contain ciguatoxin. Ciguatoxic fish feed on certain plants or bottom fish, implicating specific species of algae. It has been suggested that the proliferation of toxic algae may be triggered by contamination of the water by industrial waste, metallic compounds, ship wreckage, and other pollutants. As the feeding progression develops, the toxins appear to accumulate in the fish. Larger and older fish are more toxic [8]. More than 400 species have been implicated. Over 75% of the cases reported involve barracuda, snapper, jack, or grouper. Hawaiian carriers also involve the parrot-beaked bottom feeders.

Approximately 24 persons are hospitalized annually in southern Florida for ciguatera poisoning from barracuda. There is no seasonal variation, but larger specimens are believed more likely to be toxic.

The onset of symptoms is generally within 15 to 30 minutes of ingestion, with an increase in severity over the following 4 to 6 hours. Rarely, the onset may be delayed for up to 24 hours. Many (about 40-70%) victims have a sudden onset of abdominal pain followed by nausea and vomiting, a watery diarrhea, and a metallic taste in the mouth. There is a wide spectrum of other symptoms, from numbness of the lips, tongue, and throat to fever and chilling sensations. If poisoning is untreated, death from respiratory failure may occur. Divers must be cautious about fish they eat. Unusual illness following consumption of fish, especially barracuda, should receive immediate medical attention. The attending physician should be informed that fish has been consumed within the last 30 hours.

Tetrodotoxin poison is one of the most potent poisons found in nature and is characteristic of pufferfish, porcupine fish and sun fish. The toxin is distributed throughout the entire fish with the greatest concentrations in the liver, gonads, intestine, and skin. In Japan, eating *fugu* has been a gastronomic version of Russian roulette for centuries. The meat has no fiber; it is almost like gelatin — light in taste, like chicken — a gourmet's delight. The consumer is said to experience extraordinary neurological sensations. In a 10-year period the toxin claimed nearly 200 lives in Japan with about 60% of the puffer poisonings proving to be fatal. Yet fugu is the epitome of gourmet dining in Japan [31].

The onset of symptoms is as rapid as 10 minutes or can be delayed up to 4 hours. Initially, the victim develops oral tingling (paresthesia), which rapidly progresses to light-headedness and generalized tingling sensation. These sensations are rapidly followed by nausea, vomiting, and paralysis. Monitor victims continuously and acquire immediate medical attention. Resuscitation procedures may be required shortly after the onset of symptoms [6]. Most western authorities feel that it is best to avoid consumption of all puffers, even when prepared by experts. Keep in mind that toxic puffers are found in the Indian Ocean, South Pacific, Hawaiian waters, Sea of Cortez, tropical Western Atlantic (including Florida, Bahamian, and Caribbean waters) and in other waters throughout the world. A few non- toxic northern puffers are used as food fish [31].

Scombroid poisoning is possible from fish tissue that has been exposed to the sun or left to stand at room temperature for extended periods. Within a few minutes of eating the toxic fish, which has a peppery or sharp taste, the victims develop nausea and vomiting. Various other symptoms, such as intense headache, massive red welt development, and intensive itching, follow. Immediate medical attention is needed.

FRESHWATER LIFE HAZARDS

Compared to the oceans, freshwater streams, ponds, and lakes have relatively few forms of animal life that present a specific danger to divers. The diver must, however, be aware of those few species that can inflict considerable harm. Shelby and Devine were among the first to emphasize aquatic hazards to the diving community [27].

Reptiles

The venomous cottonmouth water snake, *Agkistrodon piscivorus*, is found in lakes and rivers south of latitude 38 degrees north. This snake is probably the diver's most serious aquatic hazard. It predominantly inhabits stagnant or sluggish water but has been observed in clear and moving water.

There has been a persistent notion that the cottonmouth would not bite underwater; however, Shelby and Devine documented two fatalities caused by cottonmouth bites [27]. The cottonmouth is considered pugnacious, adamant, and vindictive when disturbed and will attack unprovoked. It does not show fear toward the human as most other aquatic snakes do; its behavior is unpredictable. Attack is more likely to occur in the evening.

Recognition is difficult since its color varies from jet black to green with markings absent or vaguely similar to the copperhead *(Agkistrodon contortrix)*. Consequently, in areas where the cottonmouth is known to exist, it is advisable for the diver to regard any snake that does not swim away when encountered as a cottonmouth. The best defense is a noiseless, deliberate retreat. Wet suits afford reasonably good protection but can be penetrated by larger specimens. Bare hands should be tucked under the armpits. The diver should never attempt to fight since this will probably only result in multiple bites. Although evidence is inconclusive, it appears that the snake will not dive deeper than about 6 feet.

The timber rattlesnake *(Crotalus horridus)* is an excellent swimmer on the surface. Skin divers should be alert and avoid contact.

First aid for venomous snake bites includes:

Keep the victim quiet and take measures to combat shock.

Immobilize the bitten extremity and keep it at or below heart level.

NOTE: If the victim can be hospitalized within 4 to 5 hours and no other symptoms develop, no further first aid measures need be applied.

If mild to moderate symptoms develop and the bite is on an extremity, immediately apply a constricting band about 2 to 4 inches above the bite. Periodically check the pulse in the area beyond the band to insure that the flow of blood has not stopped. Loosen the band, if necessary, but do not remove.

If severe symptoms develop, apply skin antiseptic over and around the bite and incise (about 1/2 inch long and not too deep; cut along the long axis of the limb) with a sharp blade.

Apply suction with devices available with snakebite kits if available.

Acquire immediate medical attention. Antivenin treatment may be required.

Consult American Red Cross first aid manuals for further information [1].

Turtles

Three species of aquatic turtles may be hazards to the diver if provoked and mishandled, especially large specimens. Though not venomous, they may inflict a serious, dirty wound. The alligator snapping turtle (*Macrochelys ternminchi*) found through the watershed of the Mississippi River, is vicious and aggressive when provoked. It has powerful jaws and sharp claws. The alligator snapper is recognized by three, distinct, keel-like lines running longitudinally the full length of the upper shell. There are also wart-like projections about the head and forelimbs. The alligator snapper is extremely long and muscular and can strike rapidly by extending the neck.

The common snapper *(Chelydra serpentina)* is smaller and similar in appearance to the alligator snapper. This species is considered by some authorities to be more vicious when provoked than the alligator snapper.

The softshell turtle may also inflict a serious wound. Contact with these turtles should be avoided or special precautions taken in handling.

Standard first aid for laceration wounds is recommended [1]. Tetanus immunization is recommended.

Alligators and Crocodiles

The American alligator has been encountered by divers but is not known to be aggressive or to cause injury. Yet the potential of injury is present, and divers should be cautious. In Central and South America, the crocodile may certainly constitute a hazard to divers, and in Africa the crocodile is responsible for many human deaths each year. The saltwater crocodile of the coast of Queensland, Australia, is very large (up to 30 feet) and reported to be a vicious aggressor.

Mammals

The common muskrat is the only warm-blooded animal that would probably attack a diver in U.S. fresh waters. It attacks only in defense, and the wound is usually minor. However, the possibility of rabies is present and serious. It is important for the diver to seek medical advice if bitten and for the animal to be captured or killed for laboratory examination. If encountered while diving, the muskrat should not be provoked. If it is provoked into attack, escape is virtually impossible.

Fishes

The only freshwater fishes of noted hazard to divers are the freshwater sharks of Lake Nicaragua in Central America and the piranha fish of the Orient and South America. In U.S. waters the only fish capable of inflicting serious injury are those of the catfish family, which are discussed in the section on venomous marine fish, and the gar. The gar fish commonly weighs in excess of 100 pounds and, if provoked by spearfishermen, has the capability of inflicting wounds with needle-sharp teeth.

The previous discussion has concentrated on the freshwater life hazards of the United States. Certainly, it is only common sense for the diver to consult with local authorities prior to commencing diving in other parts of the world.

MARINE AND FRESHWATER PLANTS

Kelps, the great brown algae of northern waters, is considered a potential hazard for divers. West Coast kelps, the bladder kelp, are large, and some grow to lengths of over 100 feet. A tough holdfast anchors the kelp to the rocky bottom and air bladders float the plant to the surface, where it spreads out to form a thick, floating canopy. The diver, in moving about underwater, may find himself under such a canopy. If he must surface under the kelp, the diver should select the least dense area of growth and extend his hands overhead to part the kelp and make an opening for his head. He can then visually determine the shortest and safest route to open water, submerge (feet first), and swim under the kelp canopy. The surfacing process can be repeated if necessary. Attempting to swim "through" the kelp on the surface usually results in severe entanglement. When swimming in or around kelp, the diver should frequently check projecting equipment to keep free of entanglement. Ribbon kelp is similar to bladder kelp, but tougher.

Surf grass or eel grass grows in the surf zone. Though possible, entanglement is not common. The surge may wash it over a diver, causing panic. However, when the surge reverses, the grass will move away and the diver may surface.

A number of freshwater plants are found in dense growth in some inland lakes. Divers can become entangled in the plants, and surfacing may be difficult. Panic is the diver's worst foe in a plant entanglement situation. In one recent incident, a Michigan diver became entangled in a weed-covered bottom and surfaced in a panicked state. He was treated for an air embolism at The University of Michigan. An entangled diver should stop, relax, and systematically untangle himself. Naturally, the buddy will be of considerable aid.

DIVING IN POLLUTED WATERS

Man has polluted his environment. As the contamination of our rivers, lakes, and oceans continues, one certainly must question the quality of the water that thousands of divers from the U.S. and Canada enter each year. Aside from the inorganic pollutants such as mercury, lead, beryllium, antimony, and cadmium, there is a more serious threat. Bacteriological pollution is a fact. Many microscopic bacteria, such as typhoid bacillus, can be easily detected by health authorities. However, many protozoans are not as easily detected.

Lamirande reports the death of a diver in Florida from a rarely diagnosed, incurable disease of the central nervous system caused by the amoeba *Naegleria gruberi* [22]. This amoeba has been found in lakes of Florida, Texas, and Virginia, as well as several foreign countries. Several deaths due to this amoeba have been recorded in the United States in recent years. The amoeba may lie dormant for many years until nutrient levels in the body of water are concentrated enough to stimulate uncontrolled development. *Naegleria gruberi* may enter the body through the nose, bore into a nasal nerve, and migrate to the brain, where they multiply by the thousands. The result is slow, agonizing death.

Though fatalities of this sort appear to be uncommon today, we cannot predict what will happen tomorrow. Toxic pollutants including organic mercurials, hydrocarbons, and some heavy metals can prove harmful to the underwater swimmer. Toxic chemical spills, solvents, herbicides, sewage, and petroleum by-products can constitute unacceptable risk for divers. Divers must use considerable discretion regarding dives in obviously polluted waters. Being aware of this hazard isn't really enough. The only true defense is to take appropriate actions to eliminate pollution or accept the fact that acceptable waters for diving (and drinking) may progressively disappear.

CONCLUSIONS

Prevention of injuries is the best policy. Through proper diving techniques, buoyancy control, environment familiarity, and common sense precaution most diving injuries can be prevented. Carelessness and improper diving techniques lead to injury. Do not handle marine organisms that you are unfamiliar with and do not take chances with those which you know can inflict injury.

Most divers are unprepared to administer proper first aid. Generally, they simply lack the proper "tools." A review of the procedures given in this paper indicates that a properly equipped tropical diver should include the following items in a personal or group kit:

Large bottle of vinegar and/or alcohol (at least one pint);

Antibacterial soap;

Tweezers/needles/surgical blade;

Constricting band;

Sterile dressings and band aids (ample supply of assorted sizes);

Chemically activated hot packs (may be of some benefit; ideally a metal container that can be used for heating water and large enough to allow immersion of an injured hand or foot, a small stove, and waterproof matches would be better);

Aspirin;

Adhesive tape;

Tourniquet;

Anesthetic and/or antihistamine cream; and

Snake bite kit suction device.

All divers are encouraged to complete a basic/advanced first aid course. Whenever diving in an unfamiliar area, the diver must consult with local divers, professional lifeguards, diving instructors or other knowledgeable authorities regarding potentially hazardous marine life and first aid for specific marine life injuries.

There is still much to be learned regarding first aid for marine life injuries. Changing trends in modern basic first aid practices raise questions regarding "acceptable" procedures for managing a marine life injury.

Some diving instructors in the United States are quick to condemn the first aid procedures specified by Australian authorities. However, North American divers do not live daily with the potential serious consequences of injuries inflicted by such animals as the sea wasp, the blue-ringed octopus, and sea snakes. We must acknowledge the opinions of those persons who deal with these animals on a routine basis. Diving instructors and divers must remain abreast of new developments in first aid. Efforts must be made to establish universally accepted procedures. In the meantime, United States divers must know what first aid practices to expect when working with divers from foreign countries.

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ACKNOWLEDGMENTS

This chapter, in part, is the result of work sponsored by the Michigan Sea Grant College Program with grants form the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and funds from the State of Michigan. It was modified from *Oceanography for Divers: Hazardous Marine Life* (MICHU-SG-86-510) published by the Michigan Sea Grant College Program.

Manuscript published: 1986
Manuscript revised: 15 June 1990

Chapter 6-3

WAVES, TIDES, AND CURRENTS

INTRODUCTION

To dive safely, the diver must have a working knowledge of waves, tides, currents, and water quality. Lack of understanding and respect for ocean currents and surf can be of serious consequence to the diver.

Unfortunately, inland divers are unable to receive proper training in ocean diving techniques during their basic courses. Safe diving in ocean currents and executing proper surf entries/exits require special instruction. Consequently, the inland diver, whether novice or experienced, must acquire special instruction upon making the first trip to the ocean. Furthermore, a diver who learns the proper techniques for diving in the currents of the Florida Keys must still acquire additional ocean training when he/she travels to the surf beaches of the Pacific, the oil rigs of the Gulf, or the wrecks off the New England coast.

This paper on the diving environment is designed to provide the diver with a general understanding of the physical characteristics common to lakes and oceans. The descriptions of diving techniques are included to give the diver a better understanding of how to safely handle himself/herself under various conditions.

These written descriptions, however, are not sufficient in themselves to prepare the inland diver for an ocean experience. The diver must acquire special instruction and dive under the supervision of an instructor or experienced ocean diver when desiring to advance his/her qualifications to include ocean diving. Proper training, common sense, good judgment, and physical fitness are prerequisites for ocean diving.

WAVES AT SEA

Waves are a series of undulations generally propagated on the water's surface by the force of the wind. Ocean waves are usually measured in terms of their length, height, and period. Wave length is the horizontal distance between successive crests, height is the vertical distance between crest and trough, and period is the time required for the movement of two successive crests (or troughs) past a given reference point (Figure 1).

Waves are moving forms, a transfer of energy from water particle to water particle, with very little mass transport of the water. The volume of water transported by the passing wave form is negligible for waves of little steepness (under normal conditions) and can be disregarded for all practical purposes. The water particles within a wave move in an orbital motion (Figure 2). The surface particles move in a circular orbit exactly equal to wave height; below the surface, the orbits become smaller and, in an ideal deepwater wave, the diameters diminish with increasing depth.

Common water waves develop under the influence of newly formed winds (Figure 3). The air pressure changes on the surface and the frictional drag of the moving air of these winds develop ripples on the water surface which evolve into waves whose dimensions tend to increase with the wind velocity, duration, and fetch (the length of the area over which the wind is blowing). Energy is transferred directly from the atmosphere to the water. The waves grow in height and steepness (height/length ratio) until, in some cases, the wave breaks at a steepness of about 1:7 to form whitecaps. In a steady wind, waves of various dimensions develop with progressively increasing heights and periods until a steady state is reached in which the sea is fully developed for the prevailing wind speed. This steady state is maintained as long as the wind remains constant. These waves, generated locally by a continuing wind, are known as sea. Although this local sea originated in a single wind system, it is a combination of many different superimposed wave trains with various heights and directions. This gives the appearance of a rapidly changing ocean surface.

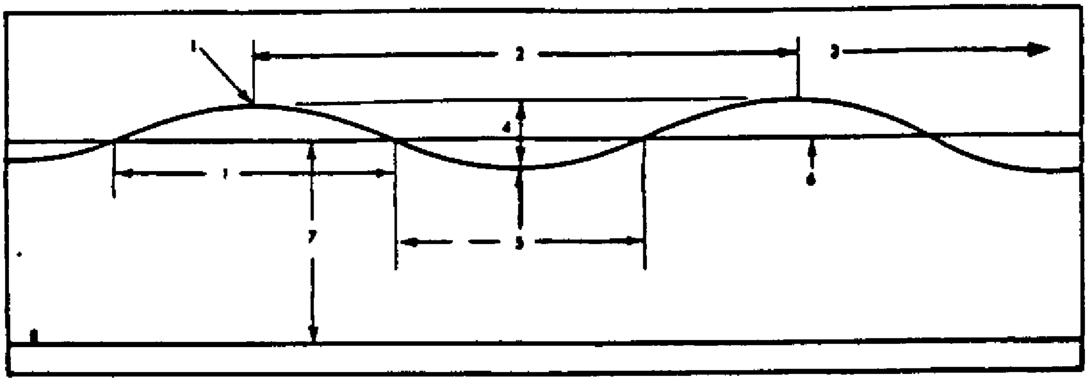


Figure 1. Wave Characteristics: (1) Wave Crest; (2) Wave Length; (3) Direction of Wave Travel; (4) Height; (5) Wave Trough; (6) Still-Water Level; (7) Depth; (8) Ocean Bottom [1]

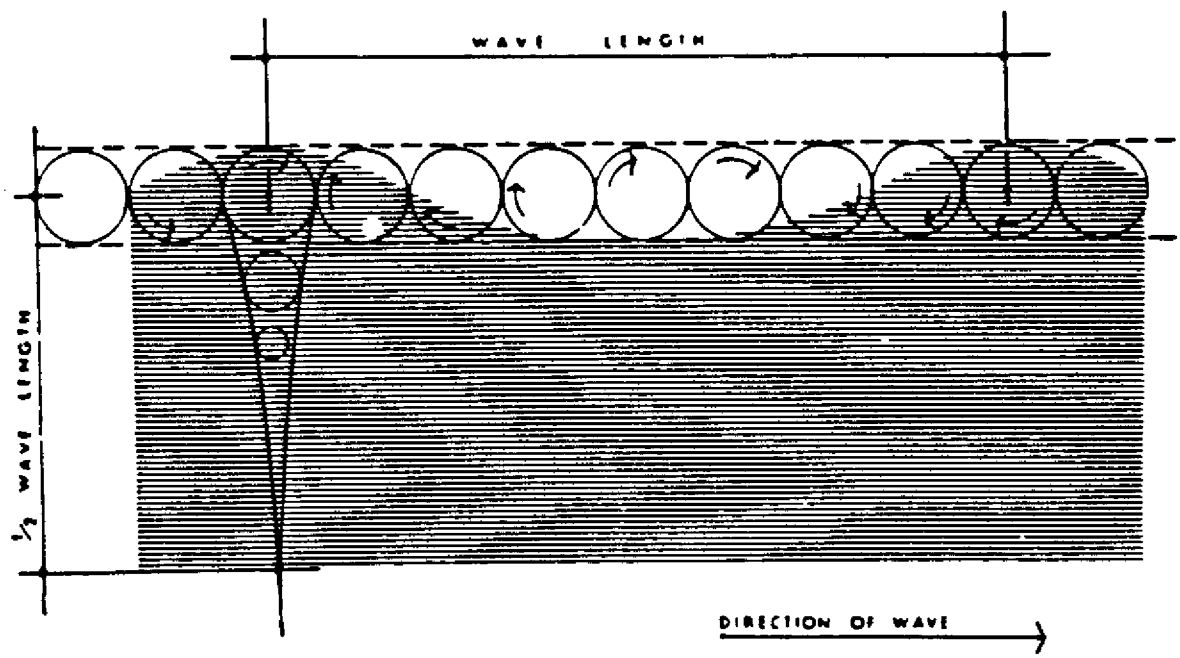


Figure 2. Cross-Section of Wave (Traveling from Left to Right): Circles Represent Water Particles in the Wave

Sea persists only in the fetch area and for the duration of the generating wind. When the wind velocity decreases or the wave leaves the fetch area, it is called a swell wave. Swell waves are characterized by long, rounded crests and decreased wave heights relative to sea waves, and they are more regular in height, period, and direction. As a swell wave progresses, in absence of a sustaining wind, its height decreases, with a consequent reduction in wave steepness. This change in wave form is known as wave decay. One cause of wave decay is a loss of energy from the wave that is brought about by internal friction, wind resistance, current action, and the effects of solid objects (ice, seaweed, land masses, etc.) in the path of the wave.

WAVES IN SHALLOW WATER

As the wave forms approach shore and move across shallow bottoms, they are reflected, diffracted, and refracted. When a wave encounters a vertical wall, such as a steep rocky cliff rising from deep water or a seawall, it is reflected back upon itself with little loss of energy (Figure 4). If the period of the approaching wave train is regular, a pattern of standing waves may be established in which the orbits of the approaching and reflected waves modify each other in such a way that there is only vertical water motion against the cliff and only horizontal motion at a distance out of one-fourth wave length. Submerged barriers, e.g., as a coral reef, will also cause reflections.

When a wave encounters an obstruction, the wave motion is diffracted around it (Figure 5). As the waves pass the obstruction, some of their energy is propagated sideways due to friction with the obstruction, and the wave crest bends into the apparently sheltered area.

As the wave train moves into shallow water, the friction on the bottom causes it to slow. Since different segments of the wave front are moving in different depths of water, the crest bend and the wave direction constantly change. This is called refraction (Figure 6). Essentially the wave crest or front parallels the contours of the bottom. A simple example of refraction is that of a set of waves approaching a straight shoreline at an angle. The part of each wave nearest shore is moving in shallower water and, consequently, is moving slower than the part in deeper water. Thus the wave fronts tend to become parallel to the shoreline and the observer on the beach will see larger waves coming directly toward him/her. On an uneven shoreline the effect of refraction is to concentrate the wave energy on points of land and disperse the wave energy in coves or embayments. Submarine depressions, i.e., canyons, also cause the waves to react in a similar fashion. The waves dissipate over the canyon and increase in intensity on the perimeter of the canyon. Any irregularities in bottom topography in shallow waters will cause refraction to some degree.

A knowledge of the behavior of waves as they enter shallow water is of considerable significance to scuba divers when planning entries from shore. By observing wave patterns and by studying the shoreline configuration and bottom topography, the diver can select the locations where wave energy and, consequently, height is least. This will aid entry and nearshore work.

SURF

As swell, the waves traverse vast expanses of ocean with little modification or loss of energy. However, as the waves enter shallow water, the motion of the water particles beneath the surface is altered. When the wave enters water of depth equal to or less than one-half the wavelength, it is said to "feel bottom." The circular orbital motion of the water particles becomes elliptical, flattening with depth. Along the bottom, the particles oscillate in a straight line parallel to the direction of wave travel.

As the wave "feels bottom," its wave length decreases and steepness increases. Furthermore, as the wave crest moves into water where the depth is about twice that of the wave height, the crest changes from rounded to a higher, more pointed mass of water. The orbital velocity of the water particles at the crest increases with increasing wave height. This sequence of changes is the prelude to the breaking of the wave. Finally, at a depth of approximately 1.3 times the wave height, when the steepest surface of the wave inclines more than 60 degrees from the horizontal, the wave becomes unstable and the top portion plunges forward. The wave has broken; this is surf

(Figure 7). This zone of "white water," where the waves finally give up their energy and where systematic water motion gives way to violent turbulence, is the surf zone. The "white water" is a mass of water with bubbles of entrapped air.

Having broken into a mass of turbulent foam, the wave continues landward under its own momentum. Finally, at the beach face, this momentum carries it into an uprush or swash. At the uppermost limit, the wave's energy has diminished. The water transported landward in the uprush must now return seaward as a backrush, or current flowing back to the sea. This seaward movement of water is generally not evident beyond the surface zone or a depth of 2-3 ft. This backrush is not to be considered as an undertow. Undertow is one of the most ubiquitous myths of the seashore. These mysterious mythical currents are said to flow seaward from the beach along the bottom and "pull swimmers under." There are currents in the surf zone and other water movements which may cause trouble for swimmers, but not as just described. Such problems will be discussed later.

Once the wave has broken, if the water deepens again, as it does where bars or reefs lie adjacent to shore, it may reorganize into a new wave with systematic orbital motion. The new wave is smaller than the original one and it will proceed into water equal to 1.3 times its height and also break. A diver may use the presence of waves breaking offshore as an indicator for the location of rocks, bars, etc. and plan his/her entry or approach to shore accordingly (Figure 8).

One characteristic of waves most evident to an observer standing on shore is the variability in the height of breakers. They generally approach in groups of three or four high waves, followed by another group of relatively small waves. This phenomena is frequently the result of the arrival of two sets of swells (from two different storms or sources), of nearly the same wave period, at the same time. When the crest of the two sets of swells coincide, they reinforce each other and produce waves higher than those of either set. When the crests of one set coincide with the troughs in the other set, a cancellation effect results in smaller waves. By studying the waves, the diver can determine the "surf beat," or frequency of the pattern (Figure 9), and time his/her entry (or exit) to coincide with the period of minimum wave height. Two groups of waves, each with a period of about 12 seconds, combine to cause an overall "surf beat" period of 2 minutes. Consequently, under such conditions, a period of minimum wave height can be expected every 2 minutes.

Currents

In and adjacent to the surf zone, currents are generated by waves approaching the bottom contours at an angle and by irregularities in the bottom. When waves approach the shore at an angle, a longshore current is generated which flows parallel to the beach within the surf zone. Longshore currents are most common along straight beaches. The speeds increase with breaker height, decreasing wave period, increasing angle of breaker line with the beach, and increasing beach slope. Speed seldom exceeds 1 knot. As previously discussed, wave fronts advancing over nonparallel bottom contours are refracted to cause convergence or divergence of the energy of the waves. Energy concentrations, in areas of convergence, form barriers to the returning backwash, which is deflected along the beach to areas of less resistance. These currents turn seaward in concentrations at locations where there are "weak points," extremely large water accumulations, gaps in the bar or reef, submarine depressions perpendicular to shore, etc. and form a rip current through the surf (Figure 10).

The large volume of returning water has a retarding effect upon the incoming waves. The waves adjacent to the rip current, having greater energy and not being retarded, advance faster and farther up the beach. This is one way to visually detect a rip current from shore. The rip may also be transporting large volumes of suspended material, creating a muddy appearance.

The knowledgeable diver will use modest rip currents to aid rapid seaward movement. An unsuspecting swimmer, when caught in a rip, should ride the current and swim to the side, not against the current. Outside the surf zone the current widens and slackens. he/she can then enter the beach at another location. The rip current dissipates a short distance from shore.

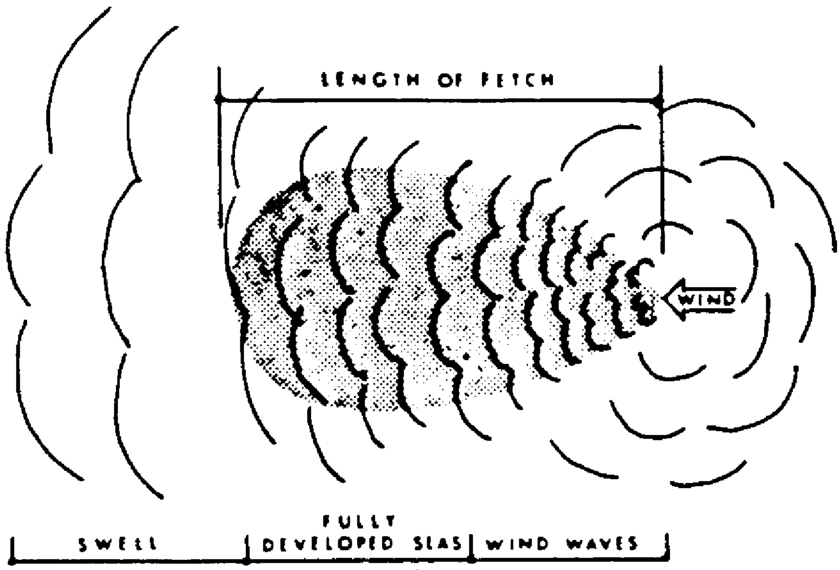


Figure 3. Diagram of Wave Development

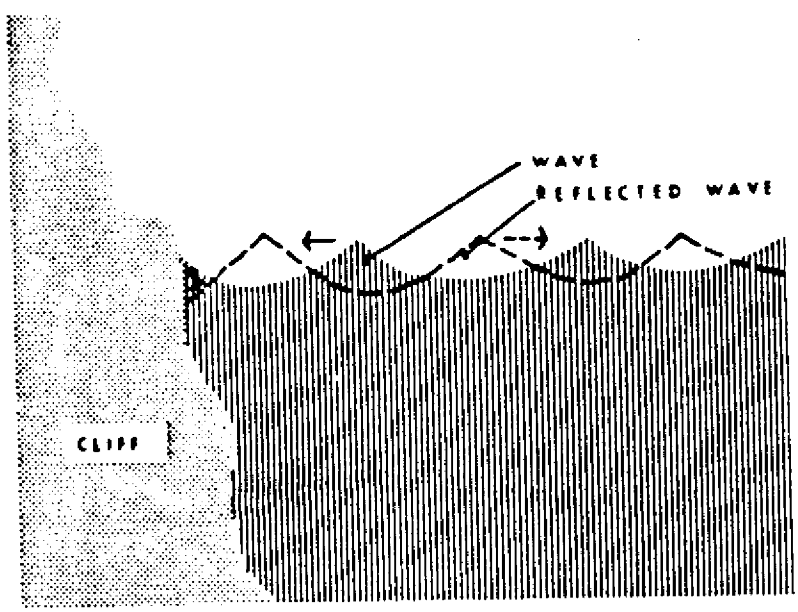


Figure 4. Wave Reflection

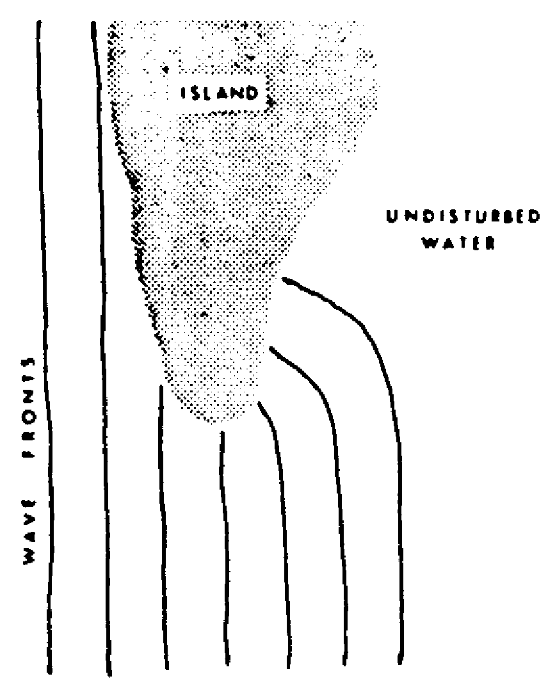


Figure 5. Wave Diffraction

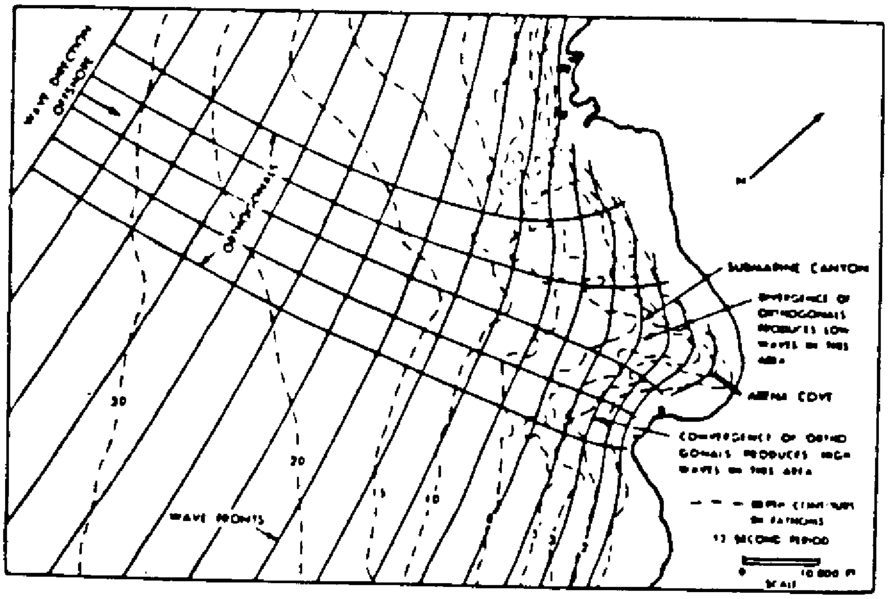


Figure 6. Wave Refraction [1]

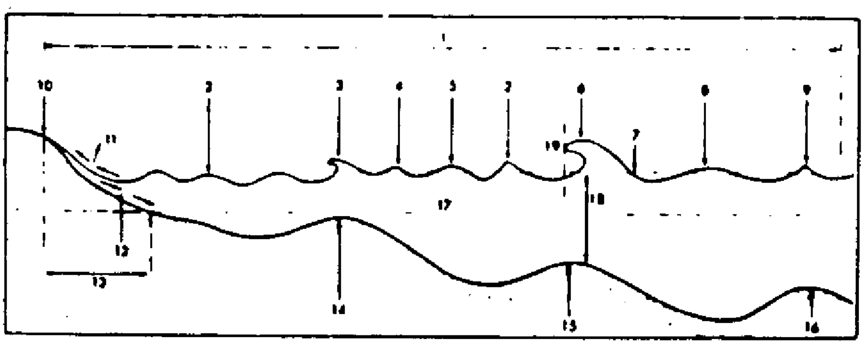


Figure 7. (1) Surf Zone; (2) Translatory Waves; (3) Inner Line of Breakers;(4) Peaked-up Wave; (5) Reformed Oscillatory Wave; (6) Outer Line of Breakers; (7) Still-Water Level; (8) Waves Flatten Again; (9) Waves Break Up but Do Not Break on This Bar at High Tide; (10) Limit of Uprush; (11) Uprush; (12) Backrush; (13) Beach Face; (14) Inner Bar, (15) Outer Bar (Inner Bar at Low Tide); (16) Deep Bar (Outer Bar at Low Tide); (17) Mean Lower Low Water (MLLW); (18) Breaker Depth, 1.3 Height; (19) Plunge Point [1]

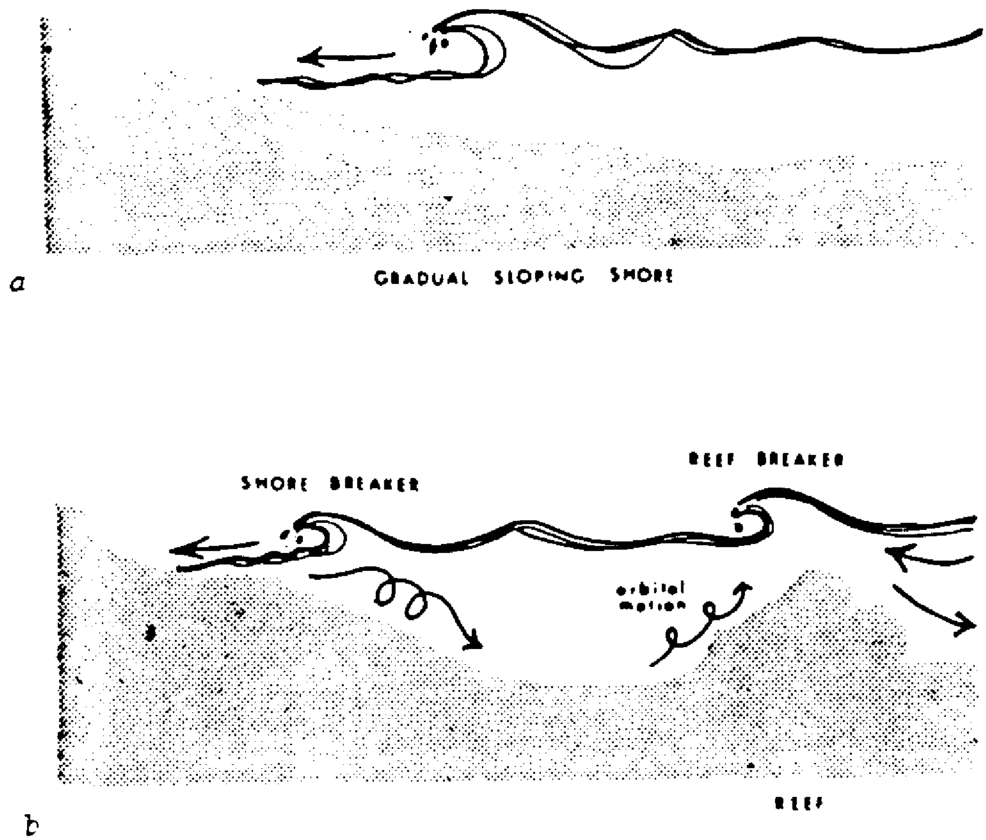


Figure 8. (a) No Bar or Reef Offshore; (b) Bar or Reef Offshore

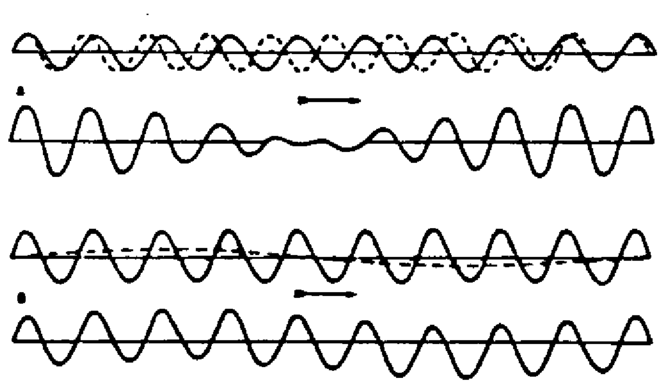


Figure 9. **Wave Interference and Surf Beat: (A) Two Waves of Equal Height and Nearly Equal Length Traveling in the Same Direction, Shown with Resulting Wave Pattern; (B) Similar Information for Short Waves and Long Swell [2]**

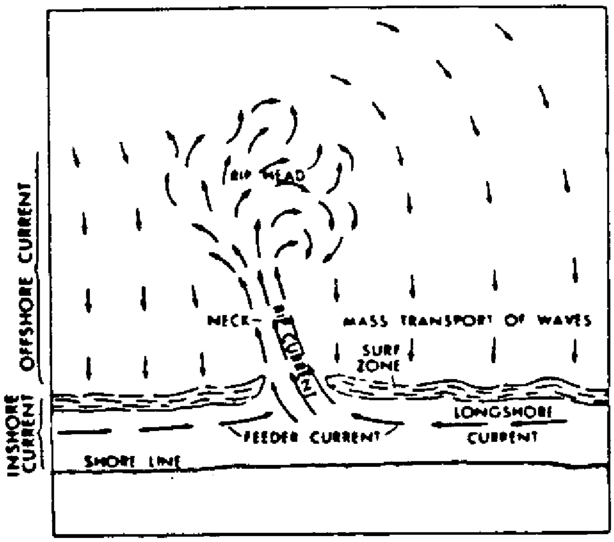


Figure 10. Nearshore Current System [1]

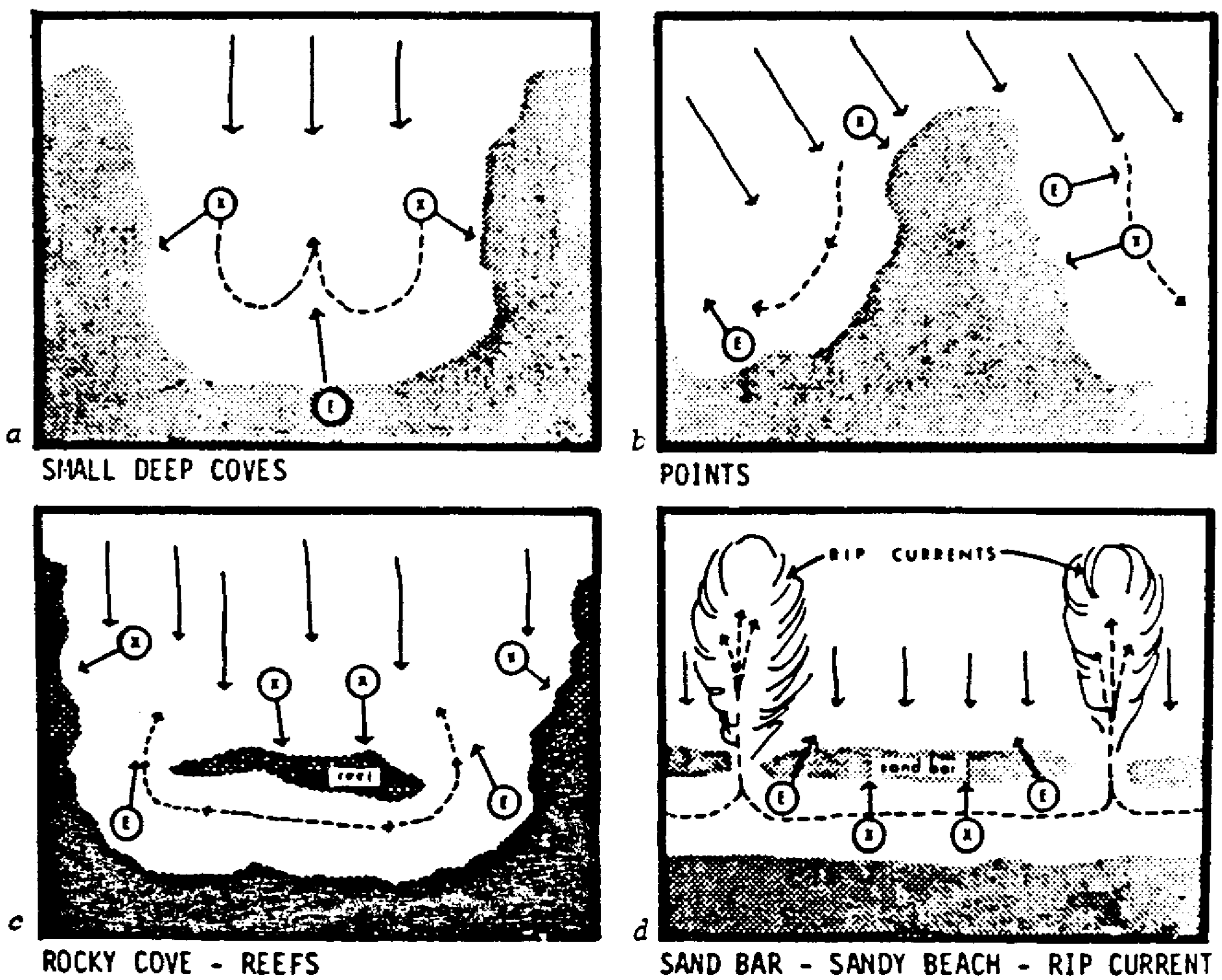
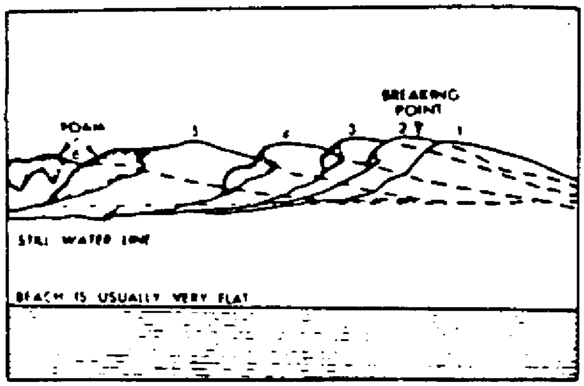
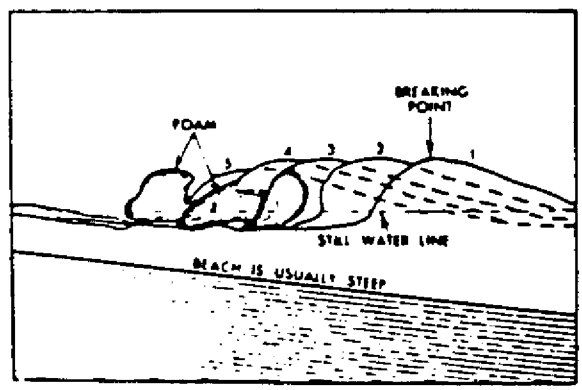


Figure 11. Shore Types and Currents: (a) Small, Deep Coves; (b) Points; (c) Rocky Cove, Reefs; (d) Sand Bar — Sandy Beach — Rip Current (E = Entry; X = Exit)



a GENERAL CHARACTER OF SPILLING BREAKERS



b GENERAL CHARACTER OF PLUNGING BREAKERS

Figure 12. Breakers: (a) Spilling; (b) Plunging [1]

Most shorelines are not straight features. Irregularities in the form of coves, bays, points, etc. affect the incoming waves, tidal movements, and the resultant current patterns. When preparing for a dive where beach entries and exits are necessary, the diver must take wave approach, shoreline configuration, and currents into account. Entries and exits should be planned to avoid high waves, as on the windward side of points, and to take maximum advantage of current movements. Avoid dives that require swimming against the current. Never undertake a dive from an ocean beach without considering these factors. Hypothetical beach configuration, wave approach, and current diagrams are included in Figure 11 to aid the diver in the concepts of planning beach-entry dives.

Sand Beach Entry

The width of surf zone and the severity of the breaking waves will be influenced significantly by the slope of the beach. On a gradually sloping beach the surf zone will be wide since the wave will break, re-form, and break again (Figure 12 a). The diver must observe the wave pattern and surf beat in order to time his/her movement into the surf zone. The best technique for entry is usually to get completely outfitted (including fins), select the best time (least wave height), and move into the zone backwards while watching the oncoming waves. As soon as the water is deep enough, the diver should start swimming. He/she must swim under the oncoming waves, not attempt to swim over them. A diver should not stand up and face an oncoming wave. If a float is used, it should be towed, not pushed into the waves.

The weight of the equipment, the shift of the normal center of gravity, the restriction of the diving suit, the cumbersome fins, and the fogginess of the mask are all factors which complicate entries through surf. A diver can compensate for the shift in center of gravity and the weight of the tank by moving with his/her knees slightly bent, feet apart, and leaning slightly forward. When moving, the diver should slide his/her feet along the bottom and not attempt to take big steps. If a diver falls or is knocked down, even in shallow water, he/she should not attempt to stand and regain his/her footing. He/she should conserve his/her energy and swim or crawl to deeper water (or back to shore).

A high surf on a steeply sloping beach is extremely dangerous for a diver in full equipment. The waves will break violently directly on the beach, with a very narrow surf zone (only a few feet wide) (Figure 12 b). A diver wearing fins may be upended by the force of the water running down the steep slope after a wave has broken. The diver must evaluate both the shoreline and the surf conditions to determine if safe entry is possible. Under severe conditions, the best judgment may be to abort the dive. To make the entry, the diver should move as close to the water's edge as possible, select the proper time (smallest wave), and move into the water and under the oncoming wave as soon as possible.

On steeply sloping beaches in Hawaii, I am told that divers sometimes elect to carry their fins through the surf instead of wearing them. This method allows rapid entry and better footing while entering the surf. Otherwise the diver may be upended by the backrush of water acting on his/her fins. Once beyond the surf zone, the diver dons his/her fins. Prior to entry, the diver using this method must inflate his/her buoyancy compensator in order to be slightly positive buoyant when he gets beyond the surf zone so he can put on his/her fins. *However, an entry without fins is not recommended.* If local conditions are such that an entry with fins is not possible, then the entry without fins must be made with considerable discretion and a great deal of caution. A fully equipped scuba diver overweighted and caught in the surf zone without fins is virtually helpless. The diver should select another entry location rather than attempt entries through surf without fins.

When exiting through surf, the diver should stop just seaward of the surf zone and evaluate wave conditions. The exit should be timed so that the diver rides the back of the last large wave of a series as far up the beach as possible. At a point where the diver can stand, he should turn his/her back toward the beach, face the oncoming waves, and move toward the beach with his/her body positioned to retain balance. If the oncoming waves are still at chest level or higher, the diver should dive head first into the wave and stand up as soon as possible when the breaking part of the wave has passed. If the wave is below chest level, the diver should simply lie on top of the wave, keep his/her feet under him/her, and ride the wave toward shore. A fatigued diver should not attempt to regain his/her footing, but ride the wave as high up the beach as possible and crawl out on his/her hands and knees. On exits through the surf, the float should be pushed in front of the diver and released if necessary to avoid injury or entanglement.

Rocky Shore Entry

When entering surf from a rocky shore, the diver should not attempt to stand or walk. A fall can be extremely hazardous. The diver should evaluate the wave conditions, select the backwash of the last large wave of a series, and crawl into the water. The backwash will generally carry the diver through the rocks. Once the diver is moving, he/she should not attempt to stop or slow down. If the diver retains a prone swimming position and faces the next oncoming wave, he/she can grasp a rock or kick to keep from being carried back toward the shore. He/she can then kick seaward after the wave passes. Floats should be towed behind the diver.

When exiting on a rocky shoreline, the diver must stop outside the surf zone and evaluate the wave conditions. Exit toward the beach is made on the backside of the last large wave of a series. As he/she loses momentum, he/she should grasp a rock or kick in order to avoid being carried seaward by backwash. The diver should maintain position, catch the next wave, and move shoreward. The diver will finally find it necessary to crawl from the water. When exiting through surf, the diver should always look back in order to avoid a surprise condition.

TIDES AND TIDAL CURRENTS

The tidal phenomenon is the periodic motion of the ocean waters in response to the variations in attractive forces of various celestial bodies, principally the moon and sun, upon different parts of the rotating earth (Figure 13). On the seacoasts this motion is evidenced by a rhythmic, vertical rise and fall of the water surface called the tide and horizontal movements of the water called tidal currents. Essentially, tides are long-period waves having a period of 12 hours and 25 minutes and a wave length equal to one-half the circumference of the earth. The tidal cycle is 24 hours and 50 minutes. The force of the earth's gravity acts approximately toward the earth's center, and tends to hold the earth in the shape of a sphere. Although the sun is larger in mass than the moon, the moon's effect on the earth is much greater because of its proximity to the earth. The moon appears to revolve about the earth, but actually the moon and earth revolve about a common center of mass (the sun). The two bodies are held together by gravitational attraction and pulled apart by an equal and opposite centrifugal force.

In this earth-moon system, the tide-producing force on the earth's hemisphere nearest the moon is in the direction of the moon's attraction (toward the moon). On the hemisphere opposite the moon, the tide-producing force is in the direction of the centrifugal force (away from the moon). The resulting effect on the oceans is that two bulges of water are formed on opposite sides of the earth's surface. The earth rotates on its axis once each day, and one can visualize that it rotates constantly inside a fluid veneer (the oceans). This concept considers the tidal "wave" as standing motionless while the ocean basin turns beneath it. Ideally, most points on the earth should experience two high tides and two low tides daily. However, due to changes in the moon's declination (position) relative to the equator, there is introduced a diurnal (daily) inequality in the pattern of the tidal forces at many places.

There are similar forces due to the sun, and the total tide- producing force is the result of both the sun and the moon, with minute effects caused by other celestial bodies. The sun tides increase or reduce the lunar tides. The two most important situations are when the earth, sun, and moon are aligned (in phase) and when the three form a right angle (out of phase). When they are in phase, the solar tide reinforces or amplifies the lunar tide to cause spring (highest) tides. Spring tides occur at new and full moon. Neap (lowest) tides occur when the sun and moon oppose each other (out of phase). The tidal range is further influenced by the intensity of the tide-producing forces (Figure 14). When the moon is in its orbit nearest the earth (at perigee), higher perigean tides occur; when the moon is farthest from the earth (at apogee), the smaller, apogean tides occur. When new or full moon and perigee coincide, the great perigean spring tides (highest tides of the year) occur. When first quarter or third quarter moon and apogee coincide, the small apogean neap tides occur. A slight delay or lag may be noted between a particular astronomical cause and the resultant tide.

Although the tide-producing forces are distributed over the earth in a regular manner, the sizes and shapes of the ocean basins and the interference of the land masses prevent the tides from assuming a simple, regular pattern. The position of the tide relative to the moon is somewhat altered by the friction of the earth as it rotates beneath the water. This friction tends to drag the tidal bulge, while the gravitational effect of the moon tends to hold the bulge beneath it. The two forces establish an equilibrium and, in consequence, a point on the earth passes beneath the moon before the corresponding high tide.

A body of water has a natural period of oscillation that depends on its dimensions. The oceans of the earth's surface appear to be comprised of a number of oscillating basins, rather than a single oscillating body. The response of the basin of water to tide-producing forces is classified as semifinals, diurnal, or mixed (Figure 15). In a semidiurnal type of tide, typical to the Atlantic coast of the United States, there are two high and two low waters each tidal day, with relatively small inequalities in the high- and low-water heights. The diurnal type of tide of the northern shore of the Gulf of Mexico has a single high and single low water each tidal day. In the mixed type of tide, the diurnal and semidiurnal oscillations are both important factors and the tide is characterized by a large inequality in high-water heights, low-water heights, or in both. Such tides are prevalent along the Pacific coast of the United States.

The tidal range will vary considerably, depending on the configuration of the shoreline, time of month, time of year, wind conditions, etc. On small oceanic islands, the range may be a foot or less. However, along the coasts of major continents, the tidal range is exaggerated at the shore. Estuaries with wide funnel- shaped openings into the ocean tend to amplify the tide range even more. The width of the tidal wave that enters the mouth of the estuary is restricted as the channel narrows; this constriction concentrates the energy and increases the height of the wave. The frictional effects of the sides and bottom of the channel tend to reduce the energy and height. The classic example of this phenomenon is the Bay of Fundy, where the tidal range exceeds 40 feet. Only a few hundred miles away, Nantucket Island has a tidal range of about 1 foot.

Tidal current, the periodic horizontal flow of water accompanying the rise and fall of the tide, is of considerable significance to the diver who must work in restricted bay-mouth areas, channels, etc. Offshore, where the direction of flow is not restricted by any barriers, the tidal current flows continuously, with the direction changing through all points of the compass during the tidal period. In rivers or straits, or where the direction of flow is more or less restricted to certain channels, the current reverses with the rise and fall of the tides. In many locations there is a definite relationship between times of current and times of high and low water. However, in some localities it is very difficult to predict this relationship. Along channels or waterways the relationship will change as the water progresses upstream.

At each reversal of current, a short period of little or no current exists, called slack water. During flow in each direction, the speed will vary from zero at the time of slack water to a maximum, called strength of flood or ebb, about midway between the slack periods. These tidal movements are represented graphically in Figure 16. The current direction or set is the direction toward which the current flows. The term "velocity" is frequently used as the equivalent of "speed" when referring to current; however, in proper terminology "velocity" implies direction as well as speed. Tidal current movement toward shore or upstream is the flood; the movement away from shore or downstream is the ebb.

Divers are encouraged to consult local tide tables, confer with local authorities, and make personal evaluations of the water movements in order to determine time of slack water and, consequently, the best time to dive. Tide tables and specific information are contained in various forms in many navigational publications. Tidal current tables, issued annually, list daily predictions of flood and ebb tides, and of the times of intervening slacks.

In some channels or straits the diver will be limited to 10-20 minutes of safe diving at time of slack water (Figure 17). Specific precautions must be taken when working in these areas. Dives must be planned and timed precisely. Scuba diving may be least desirable. Surface-supplied diving equipment, with heavy weighted shoes, may be required for the diver to work in the currents. The diver should not attempt to swim against the tidal current. If he/she is caught in a current, he/she should surface, inflate his/her buoyancy unit and swim perpendicular to the current toward shore or signal for pick up by the safety boat.

WIND CURRENTS

The stress of wind blowing across the sea causes the surface layer of water to move. This motion is transmitted to succeeding layers below the surface; however, due to internal friction within the water mass, the rate of motion generally decreases with depth. Although there are many variables, generally a steady wind for about 12 hours is required to establish such a current. A seasonal current has large changes in direction or speed due to seasonal winds.

A wind current does not flow in the direction of the wind due to the effects of the rotation of the earth, or Coriolis force. Deflection by Coriolis force is to the right in the northern hemisphere, and toward the left in the southern hemisphere. This force is greater in higher latitudes and more effective in deep water. Current direction varies from about 15 degrees relative to wind direction along shallow coastal areas to a maximum of 45 degrees relative to wind direction in deep ocean. The angle increases with depth, and at greater depths the current may flow in the opposite direction to the surface current.

The speed of the wind-derived current depends on the speed of the wind, its constancy, the length of time it blows, and other factors. In general, about 2 percent or less of the wind speed is a good average for deep water where the wind has been blowing steadily for at least 12 hours.

A number of ocean currents continue with relatively little change throughout the year. These large-scale currents are primarily the result of the interaction between the general circulation of the atmosphere and the ocean water.

The primary generating force of currents is the wind, and the chief secondary force is the density differences in the water. In addition, such factors as water depth, underwater topography, shape of the ocean basin, land configuration, and the earth's rotation affect oceanic circulation.

SEICHES

When the surface of a large, partially enclosed body of water, such as one of the Great Lakes or a bay, is disturbed, long waves may be set up which will rhythmically oscillate as they reflect off opposite ends of the basin. These waves, called seiches, have a period that depends on the size and depth of the basin. The seiche is a rather common phenomenon not frequently observed by laymen because of the very low wave height and extremely long wavelength. A seiche can be regarded as a standing wave pattern.

In the Great Lakes, seiches are induced by differential barometric pressure changes and, most frequently, winds. For example, a strong wind blowing for several hours along the axis of Lake Erie will drive the surface water toward the leeward end of the lake, raising the water surface there as much as 8.4 ft, and lowering the level at the windward end of the lake. When the wind ceases or shifts, the lake surface will start to oscillate, alternately rising and falling at each end of the lake. This oscillation, which diminishes rapidly in amplitude, has a period of 14-16 hours [3]. Lake Erie is particularly subject to seiches because the lake is shallow, nearly parallel with the prevailing winds, and has a basin of fairly regular and simple shape.

In 1954 a severe seiche in Lake Michigan, resulting from both wind and barometric pressure changes, caused an abrupt increase in water level to 10 feet above normal in the vicinity of Chicago. At least seven lives were lost [4,5].

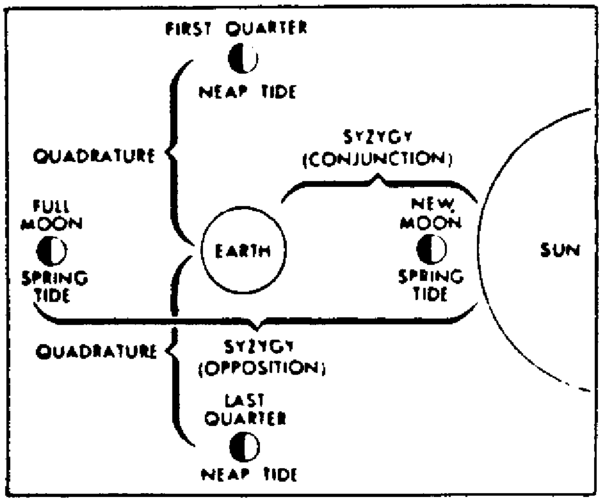


Figure 13. Tide Cycle [1]

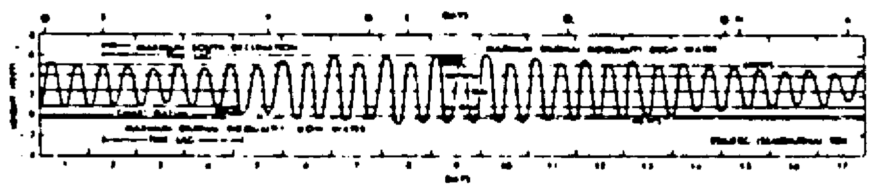


Figure 14. Typical Tide Curve [1]

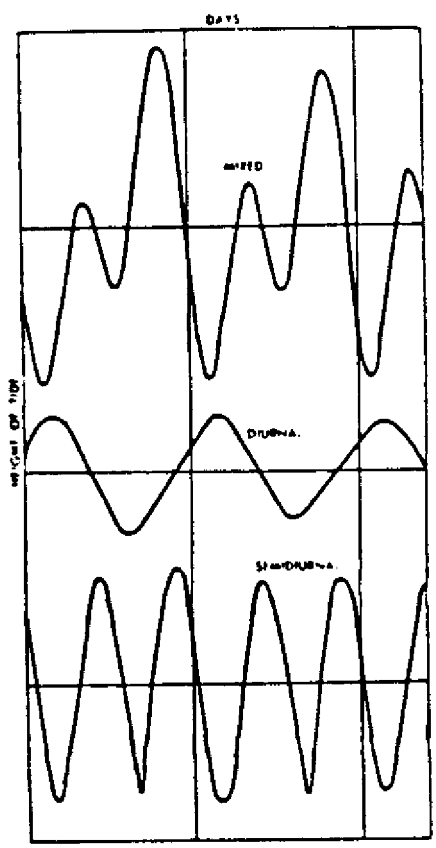


Figure 15. Types of Tide Curves [1]

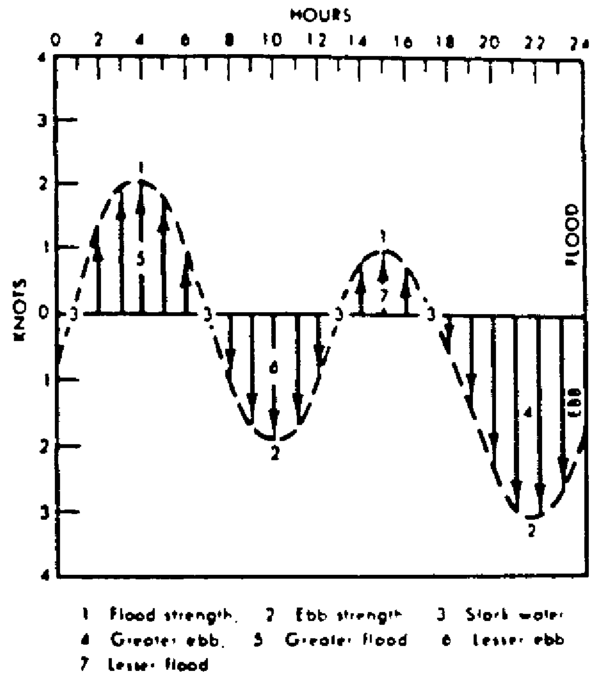


Figure 16. Tidal Current Curve [1]

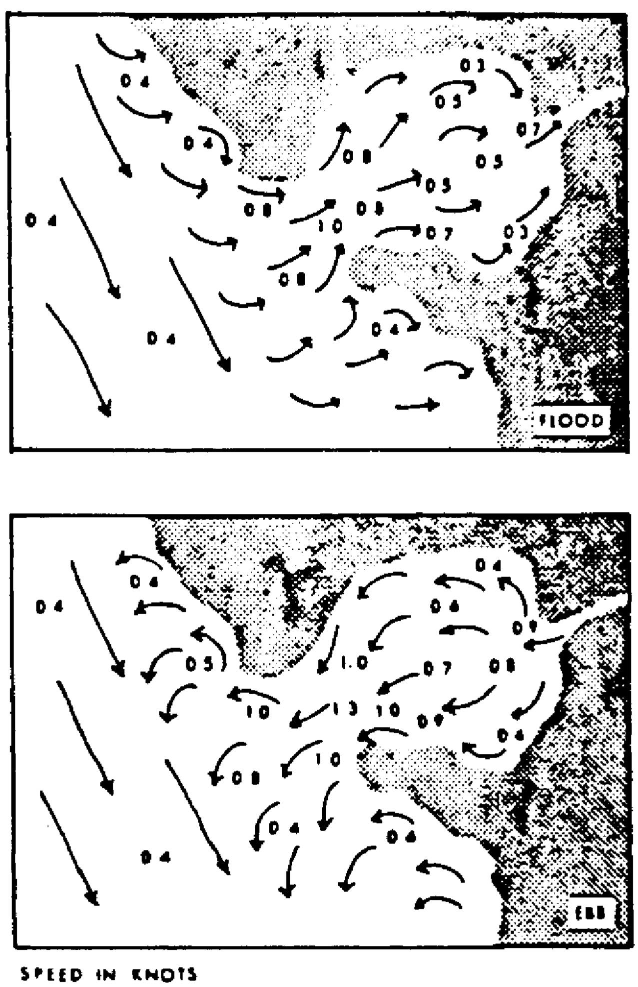


Figure 17. Flood and Ebb

In bays that open to the ocean, seiching is almost always caused by the arrival of a long-period wave train. Once the water is set in motion by the initial wave, seiching continues at the natural period for that harbor or bay. Bascom discusses the phenomenon of seiching in ocean bays [6].

DIVING IN CURRENTS

Currents are caused primarily by the influence of surface winds, changing tides, and rotation of the earth. They are essentially flowing masses of water within a body of water. Divers must always take currents into account in planning and executing a dive, particularly a scuba dive. Large ocean currents such as the Gulf Stream of the Atlantic and Japan current of the Pacific flow continuously, although there may be local variations in magnitude and location. Local wind-derived currents are common throughout the oceans and on large lakes.

The current velocity may exceed 2-3 knots. Attempts to swim against this type of current may result in severe fatigue. Sometimes in the Gulf of Mexico, as well as other portions of the ocean, there may be no noticeable current at the surface with a 1- to 2-knot current at a depth of 10-20 ft, or there may be a current at the surface and no current at 10-20 ft down. The following precautions should be observed to minimize the hazards to the diver:

* The diver should always wear a personal flotation device.
* The diver should be in good physical condition when working in currents.
* A safety line at least 200 ft long with a float should be trailed over the stern of the boat during diving operations when anchored in a current. Upon entering the water, a diver who is swept away from the boat by the current can use this line to keep from being carried far down current.
* Descent should be made down a weighted line placed at the stern, or, if unavailable, down the anchor line. Free swimming descents in currents should be avoided. If the diver stops to equalize pressure, he/she may be swept far down current. Furthermore, if a diver has to fight a current all the way to the bottom, he/she will be fatigued, a hazardous situation underwater. Ascent should also be made up a line.
* When a bottom current is encountered at the start of the dive, the diver should always swim into the current, not with it. This will facilitate easy return to the boat at the end of the dive. He/she should stay close to the bottom and use rocks if necessary to pull himself/herself along in order to avoid overexertion. If the diver wants to maintain position, he/she should grasp a rock or stop behind a rock, not attempt to swim. The same technique should be used by a fatigued diver to rest.
* A qualified assistant should stay on the boat at all times. This will facilitate rescue of a diver swept down current.

WEATHER

Weather is always a factor to consider when planning offshore diving operations in large lakes or the ocean. Divers must be familiar with local weather conditions and monitor weather forecasts. Different areas may have unique weather conditions and the diver must consult with local authorities regarding weather conditions and changes. In some areas, offshore operations from small boats are prohibited by weather and, consequently, wave conditions during certain portions of the year.

When diving offshore, abrupt wind and sea condition changes can transform a pleasant day into a nightmare. The diver should not venture too far from shore or from his/her diving craft when he/she is aware of the possibility of weather changes. High winds and rough seas can defeat even the strongest swimmer. It is therefore wise to surface periodically and evaluate the weather situation. In the Florida Keys, a squall can sometimes appear seemingly out of nowhere on an otherwise perfect day.

A squall line which appears to be some distance away should be observed for direction of movement, greater development, increased wind velocity, water spouts, etc. If the approaching storm looks severe and is approaching from open ocean, it may be wise to abort the operation and return to shore if you are working from a small boat. In the Florida Keys, however, these squalls approach quickly and are generally of short duration. If the squall overtakes the fleeing boat, navigation in poor visibility will be very hazardous.

Under these circumstances it may be wiser to anchor the boat securely and ride the storm out. If the skipper decides to anchor, he/she must face his/her boat into the oncoming waves and let out plenty of anchor line; a taut line can snap and the boat will be set adrift.

Following a heavy rain squall, there may be high winds, and the skipper must exercise caution while getting underway again. Choppy seas and murky water may make it difficult to avoid shallow reefs, floating objects, lobster trap lines, etc.

The diver must remember that a wind blowing from land to sea can be very deceiving. What may appear as calm water from shore may be a raging sea at the outer reef. Returning to shore into the waves will be difficult.

Serious storms and severe wave conditions can be expected on the Great Lakes in September, October, November, and December as a result of local weather phenomena. This period of instability relates to the energy system established when cold atmospheric air encounters the air heated by the warmer lake water. The result is sudden storms and high seas. Again the diver is encouraged to consult with local authorities and monitor weather forecasts before diving offshore. Divers are also encouraged to acquire instruction in boat handling and seamanship. Courses are available from the US Coast Guard Auxiliary, sportsman groups, etc.

CONCLUSIONS

Since the beginning of time, the waters of our planet have stimulated the imagination of man. Under these waters lies an exciting world of beauty and challenge. The underwater explorer and researcher can now, as never before, venture to greater depths and to the most remote corners of the ocean. However, he/she must be equipped with a basic working knowledge of waves, tides, and currents. When divers visit unfamiliar areas, they must consult with local divers and authorities to gain information on particular environmental conditions.

The diver must develop a "sixth sense" in the evaluation of environmental conditions in order to plan dives safely and efficiently. Most divers get into trouble at one time or another by underestimating the potential hazards associated with the underwater environment or by overestimating their physical capabilities and diving skills in coping with adverse currents, waves, etc. Good physical condition, basic knowledge, common sense, and good judgment are prerequisites for safe underwater exploration.

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Manuscript revised: 15 August 1990

NOTES:

SECTION 7

INTRODUCTION TO OPEN WATER SCUBA DIVING

CHAPTER 7-1

THE SCUBA DIVE

INTRODUCTION

The fundamentals of scuba diving theory and practices have been discussed in detail throughout this manual. Self-contained underwater breathing apparatus has been described and you have practiced skills during numerous pool sessions. You are now prepared to advance to *supervised* open water diving.

This paper is devoted to preparing you for your initial open water diving experiences. Since many topics have already been discussed in detail they will only be summarized here. Keep in mind that the initial four to five open water dives are instructor supervised training dives. Unless you immediately enroll in an advanced or specialty diving course or dive under the supervision of a resort dive guide following open water training, you will be on you own for subsequent dives.

Once you have completed open water diver training and receive a certification card you are now prepared to learn to dive. That's right — learn to dive! You now enter the most important part of diver training — the acquisition of experience. Each and every dive you make must be thoughtfully planned, well executed, and critically reviewed. Learning to dive is a continuing series of experiences progressing from simple to more complex. Initially you must limit your dives to shallow water under as near to ideal environmental conditions as possible. Once you have mastered your equipment, learned how to evaluate diving companions, and understand a given environment you may begin your progression.

Keep in mind that you must crawl before you can walk. During scuba diving training you have been learning to crawl. Most authorities suggest that it takes 10 to 15 initial diving experiences involving planning, preparation, equipment assembly, entry, and simple dive execution in order for a new diver to become relatively competent in a given environment. When you go deeper, change environments, or acquire new equipment, you literally begin a new set of learning experiences.

THE LIMITATIONS OF A SCUBA DIVER

Both you and your equipment determine the limitations of scuba diving. The physiological limitations associated with pressure changes and breathing compressed air are clearly defined elsewhere. Keep in mind that there are individuals who challenge physiological limits in any activity. Divers have reached depths in excess of 400 feet while breathing compressed air. These individuals have elected to take a considerably high risk in order to pursue a goal. These individuals are unique in their own right — physiologically and psychologically. Physiologically they can tolerate partial pressures much higher than those recognized as normal human limits of oxygen and nitrogen. Emotionally, they have conditioned themselves to achieve goals under conditions that others perceive as life-threatening and irrational. They swim on the edge!

Dive duration and, ultimately, dive depth is limited by the amount of air that can be contained in your scuba cylinder(s). Today most divers enter the water with 70 to 100 cubic feet of air contained in a single cylinder. The duration of this air supply is controlled by the individual diver's physiology, emotional status, thermal condition, and work level. Air consumption also increases with depth. Theoretically, a 40 minutes air supply at 30 feet will only be sufficient for about 20 minutes at 100 feet. Keep in mind that individual factors may change considerably between 30 and 100 feet. Also, air consumption at 100 feet in clear tropical waters may be quite different than at the same depth in the cold, dark water of the Great Lakes.

Although equipment failures are rare in modern day diving, a reasonable and prudent individual will limit dives to a depth from which they may safely ascend in the event that they lose their air supply. Emergency ascents may be made independently or with the assistance of another diver. Thus the ability of a "buddy" to assist in an emergency also becomes a limiting factor.

The national recreational diving training agencies have established *reasonable and prudent limits* for scuba diving. Based on diver physiology, equipment performance, air supply duration, emergency response capability, and a number of other factor a *maximum depth of 130 feet* has become the standard of the recreational diving community. Most agencies and instructors encourage scuba divers to not exceed 100 feet and any dive beyond 60 feet is considered as a deep dive. The standard also focuses on *no-decompression dives*. Statistically, individuals diving in excess of 80 feet and exceeding the no-decompression limits are at higher risk of decompression injury. As a beginning diver your first 10 to 15 dives should be limited to depths less than 30 feet and the next 15 dives to a maximum depth of 60 feet. One deep diving instructor told me that no more than 2% of trained recreational divers have the physical and emotional constitution to advance to diving *safely* beyond 130 feet.

DIVE TRIP PLANNING

The amount and degree of trip planning depend on the proposed dive location, distance from home, and mode of transportation. Obviously, traveling thousands of miles to dive in the tropics takes more planning and arrangements than diving at the local quarry. However, every dive trip, regardless of location, has common elements of planning.

First, select a good diving buddy and traveling companion. If you are traveling with a group try to get to know the other divers in advance. In some cases you might even get a chance to review scuba diving skills with them in a pool.

Second, the prudent diver will learn as much about the dive site as possible through discussion with other divers, attending travel lectures, reading guide books, and so on. The diver must be aware of environmental conditions and dive support facilities when selecting equipment. Ideally, the diver should review descriptions of underwater dive sites. Popular dive sites at several Caribbean Sea islands are describe in detail in diver guide books. One of the primary objectives of this pre-trip research is to eliminate as many surprises as possible.

If you are planning a dive in a locate quarry or lake ask a fellow diver to draw a sketch of the dive area and describe underwater conditions and features. Determine the best part of the quarry for diving and sketch in a proposed underwater swim path. Plan to view major features.

Determine best site entry points and find the location of the nearest telephone for use in the event of an emergency. Is there a 911 emergency response system? If diving in a remote area, where is the nearest medical facility and what is the best means of transportation to get there? Are first aid supplies available at the dive site or must you take your own?

Third, carefully select, inspect, test, and pack all necessary dive equipment. Prepare a complete check list right down to extra o-rings for scuba cylinders and silicone lubricant for the cameras. Carefully inspect and test rental equipment before you leave the dive shop. All of this must be done well in advance of your planned travel. It is generally too late to make repairs if you find that your BCD has a hole or your regulator is free-flowing the night before the dive or when you arrive at the dive site. Diving with inadequate or malfunctioning equipment could predispose you to serious injury or a fatal accident.

Finally, plan to arrive at your dive location in the best possible physical condition. Get plenty of sleep and maintain a healthy diet and life style prior to your trip or dive day. Avoid alcohol while traveling and prior to diving.

Trip planning can range from very simple to quite complex. The above is just an overview of major considerations. Through research, personal experience, and the experiences of others you will ultimately develop your own planning scheme. Keep in mind that the quality and safety of your diving experience is directly related to the degree of planning.

BUDDY SELECTION

How do you select a proper diving buddy? There is no easy answer to this question. Frankly, most divers pay little attention to training, experience, equipment, and physique when selecting a person that they may have to assist (even rescue) during a dive or rely on for similar services. In some cases, bedroom prowess takes precedent over diving expertice.

Diving buddies must be *compatible*! Ideally, they should have received training in similar courses. Even more ideally, they should have been trained by the same instructor. Even though training agencies have established strict standards for course content and skill methodology, we still find considerable variability in diving instruction. For example, just a couple of years ago I went on a diving holiday with an instructor and several of his former students. On the first dive I discovered that only myself and the dive guide were equipped with an auxiliary breathing unit (octopus). Twelve other individuals had been taught to rely on conventional buddy breathing. This is obviously not the standard of the modern diving community. Dives are encourage to read *Selecting a Scuba Diving Buddy* for detailed guidelines on buddy selection [1].

I often attempt to answer the following questions when diving with an individual with whom I am unfamiliar:

1. Is the diver certified?

2. When did this individual last dive? Where? How many dives? How experienced is this individual?

3. Does the individual have a cold or other physical ailments that might compromise the dive or my safety?

4. Is the diver properly equipped? Does the equipment appear to be well maintained?

5. How does the individual handle equipment? With reasonable care? Haphazardly? Does the individual have difficulty in assembling equipment?

6. Did I observe the individual drinking last night? Excessively? Intoxicated? Hangover?

7. Does the individual smoke?

8. Have I heard any good or *bad* comments about the individual from other guest-divers?

9. Could I rescue this individual? Could this individual rescue me?

10. Mr. Macho or Ms. Machette?

Naturally, there are many other questions that you might ask. Simple observation and casual conversation may provided the best clues. You may even make a dive with the individual and discover that he/she lacks buoyancy control skills, swims excessively fast underwater, consumes air supply quickly, has poor buddy diving technique, and so on. Consequently, you would avoid diving with them again.

What if you are paired with a stranger who does not have an auxiliary breathing unit someday? Do you simply proceed with the dive and hope that nothing adverse will happen? Do you rely on conventional buddy breathing with an individual you have never meant before? In the rare event of losing your air supply would you elect to rely totally on your emergency swimming ascent capabilities? Keep in mind that disregard for an item of equipment that is virtually mandated by modern scuba diving standards may reflect additional deficiencies in knowledge, skill, safety attitude, and so on. For example, in the group of divers mentioned above I soon concluded that general skill, experience, attitude, and drinking habits precluded most of the individuals as acceptable dive buddies.

In such cases you have several alternatives. First, you can ask the dive master for reassignment to a more acceptable buddy. Secondly, if there are no other divers available, you might arrange for you and your undesirable buddy to swim with the dive guide. In the event of an emergency, the guide would be immediately available to assist. Third, you may simple elect to not make the dive. This may seem extreme, however, you may be placed in a situation where you must make a risk-benefit assessment and simply find that the potential risk is too high.

DIVE SITE SELECTION

Select a dive site where the environmental conditions are consistent with your level of training and experience. Beginning divers have no business in swift currents, deep water, extremely limited visibility, adverse surf conditions, caves, and so on. Keep in mind previous statements regarding progressive acquisition of experience. *Do not let another individual lead you into conditions for which you are not prepared!*

I recall one situation where an individual convenienced his younger inexperienced brother to dive with him in swift river current. To my knowledge, the younger brother had only completed four open water training dives and had no current diving experience. The older brother had not made more than a dozen or so dives. The inexperience diver apparently experienced air supply depletion, surfaced, and panicked. He was apparently unable to inflate his BCD. The older brother apparently could not provide sufficient assistance in the swift current. The inexperienced diver died; the experienced diver entered psychological therapy. Neither diver had the training or experience to dive in swift water. This was an unnecessary death resulting from poor judgement.

You should be completely aware of the environment conditions to be expected at the dive site prior to arrival and select your site accordingly. If you arrive at the site and find unfavorable conditions or are unsure about your ability to dive under the conditions, *do not dive!*

EQUIPMENT SELECTION

Equipment selection has been discussed in detail in other sections of this manual. Naturally, your dive location and underwater activities will determine specific equipment requirements. However, certain items of equipment are common to most scuba diving activities. Only a list of basic required equipment with some comments is presented below:

Mask, fins, and snorkel (check straps prior to leaving; include extra straps for remote dive locations)

Environmental protection garment (range from thin wet suit in tropics to dry suit with heavy undergarments in the north; 1/4-inch neoprene wet suit is common; include boots for foot protection in tropics)

Buoyancy control device or BCD (inspect prior to trip; signal device attached; octopus attachment option; includes scuba backpack)

Regulator (includes pressure gauge, auxiliary breathing unit, BCD inflation hose, and dry suit inflation hose; inspected/serviced; extra o-ring for scuba cylinder)

Cylinder (current internal inspection and hydrostatic test; traveling divers seldom transport cylinders on air craft; more than one cylinder need for some boat trips)

Instruments (include depth indicator, dive timer, and compass; console unit including cylinder pressure gauge; batteries for electronic units replaced as needed; dive computer options; protect during transport)

Knife (compact low profile model)

Weight belt (belt only when traveling to resorts by air; small weights for adjustment; quick release buckle design)

Slates and pencils (for dive planning and records; generally carried in BCD pocket; extra small slates in dive bag)

Plastic dive tables (for dive planning; carry in BCD pocket)

Equipment bag (net bag for boat; duffel bag or suitcase for travel)

Tool kit/spare parts (as needed; personal preference; location dependent)

Be certain that all equipment is functioning properly prior to leaving home. Use checklist!

ENVIRONMENTAL ANALYSIS

Upon arrival at the dive site one of your first responsibilities is to evaluate environmental condition. Check visibility, wave conditions, current, temperature, and other factors that may influence dive quality and safety. Select a comfortable and secure staging area for shore-based operations. Determine entry and exit points as well as emergency exit points. *Keep in mind that you should refrain from diving if the environmental conditions exceed the scope of your training and experience.* Details of environmental factors in dive planning have been presented previously in this manual (Section 9).

RISK-BENEFIT ANALYSIS

Every activity that we engage in has so element of risk. Driving an automobile or crossing a street has inherent risks Today, casual relationships and dating can easily lead to fatal disease. Although most people do not formally recognize the concept of risk evaluation, reasonable and prudent individuals are continuously making risk-benefit assessments in everyday life. In diving you must assess the environment, the equipment, fellow divers and other related factors and weigh them against personal training, experience, and dive supervision. Ultimately, a diver must ask, "Are the potential benefits of this experience worth the risks that I might encountered while engaging in the activity?" and "What level of risk am I willing to accept?"

PERSONAL SPACE

Generally, a buddy team will select a location to stow and assemble their equipment whether operating from a shore base or a boat. On many boats there are seats with areas beneath for equipment. Scuba cylinders may be standing upright in a rack position in the center of the boat. This is characteristic of many smaller boats used in the Caribbean. Larger dive boats may have different arrangements. Immediately upon arrival at the boat it is desirable to "claim" a seat and cylinder. On some boats number cylinders are assigned to each diver

DIVE MASTER BRIEFING

A dive master, instructor, or dive guide is generally in charge of any organized or resort dive. At some point prior to diver deployment the person-in-charge will call for the divers to assemble and pay attention to a site and activity briefing. The briefing generally includes information on environmental conditions, diving procedures, current direction, swim direction, underwater features, return cylinder pressure, depth limit, time limit, special precautions, and so on.

During briefing you should not be assembling equipment, working out dive schedules, talking to your buddy, or day dreaming. Give the dive master your undivided attention. This is also the time to ask questions. If something is unclear, ask for a clarification. If you are unsure about boat entry/exit techniques, ask the dive master to explain.

Keep in mind that the dive is an educational experience as well as a pleasurable experience. If you do not know something, ask questions. After the formal briefing you can simply inform the dive master that this is your first boat dive and that your would like to have a certain procedure explained in more detail. Most dive masters will praise you for your honesty and be pleased to help. If the dive master appears annoyed by your questions he/she is failing to assume the responsibilities of his/her position.

FINALIZING YOUR DIVE PLAN

Once the briefing has been completed you and your buddy must review and finalize your dive plan. This includes, but is not necessarily limited to, maximum depth, maximum dive time, underwater swim path, special precautions, buddy separation procedures, who will lead the dive, and hand signals (new dive buddy). If this is a repetitive dive, both divers should compute maximum allowable dive time independently and compare results.

The following is a summary of a hypothetical dive plan:

Maximum depth is 60 feet for maximum dive time of 40 minutes;

Must be back on deck with 300 psi of air remaining;

Following entry we will descend down the anchor line to the bottom and do a brief buddy and equipment check;

We will then swim down the slope to a depth not exceeding 60 feet and swim south into the current (slight current) until the first diver's air supply reaches 1,800 psi (start with 3,000) or 18 minute have elapsed;

We will then ascend to 40 feet and swim back north along the slope (return trip with current is generally faster and you use less air at shallower depth);

Upon arrival at the anchored boat we will explore the area around the boat until the first individual's air reaches 600 psig or about 38 minutes;

Proceed to decompression bar (suspended 15 feet under boat) and stop for approximately 5 minutes;

If we get separated and do not reunite in 1 minutes, surface; and

I will lead on this dive and use this signal [give signal] if I find the sea horse.

PRE-DIVE EQUIPMENT ASSEMBLY AND BUDDY CHECK

Many instructors and agencies have a prescribe buddy check procedure and nice little memorized acronyms to assist the diver in remembering this procedure. Basically, the pre-dive buddy check begins long before the dive. You must first determine if your dive buddy is physically and emotionally qualified for the dive. Is he/she properly trained and equipped for the dive? It is too late for all of this once you are dressed and standing on the dive platform. This topic has been discussed previously.

Ideally, a buddy team should assemble their equipment together. This allows for such pre-dive considerations such as verifying air supply, security of scuba cylinder, connection of the BCD hose, and scuba/BCD operation. This way corrections may be made more easily before final dressing and deployment. Once the equipment has been donned, each diver must make a final systematic check of themselves and their buddy. Just before entering the water I do the following quick head to toe check:

Mask and snorkel in place;

Regulator on and opertaional;

BCD secure and inflator hose attached;

Scuba cylinder secure;

Octopus attached to retainer in visible, accessible position;

Pressure guage visible and cylinder pressure;

Depth indicator and timer visible;

Suit zipped and inflator hose attached (dry suit);

Weight belt on, securely positioned, and buckle visible;

Knife accessible; and

Fins secure.

THE DIVE

Each dive that you make is somewhat unique and it is difficult to describe a generic dive. Below I will develop a hypothetical dive based on the above plan.

Don equipment: You have already assembled your scuba and put on your diving suit. You and your buddy assist each other in donning scuba and proceed to the deployment area with your mask and fins in hand. You do a quick final buddy check and put on your fins and mask.

Report to Dive Master: Before deployment report diver names to the dive master who maintains a record of entry and exit times.

Entry: You make stride entry from the stern platform and snorkel to the anchor line together. At the anchor line you note environmental conditions and dive site features. The current is very slight and visibility is only about 50 feet. You can see the bottom below. The boat is anchored near the edge of a shelf in about 35 to 40 feet of water. The shelf break and slope are visible from the surface.

Descent: After a brief check of each other and an "OK" signal you and your buddy descend together. During descent you adjust buoyancy to remain neutral. Upon arrival at the bottom you take a minute or so to do a quick check of your equipment and a visual check of your buddy. You note that the anchor is secure and not damaging the surrounding coral.

Orientation: The top of the slope is visible from the anchor line. You signal your buddy to swim with you to the slope and observe a very large assembly of tube sponges at exactly 40 feet. The sponges are the most prominent feature in the area adjacent to the boat and will serve as your reference marker upon return.

Swim: You now swim down the slope to a depth of about 55 feet and begin a slow swim south into a slight current. You are very careful to maintain proper buoyancy throughout the swim. Occasionally, you stop to observe marine life. Every few minutes you check your depth gauge, cylinder pressure, and timer. At about 15 minutes dive time your buddy swims to you and points to his gauge; it reads 1800 psig.

You begin a slow ascent to 40 feet, turn and swim slowly back along the slope at 35 to 45 feet. You see the large tube sponges about 15 minutes later. As you approach the sponges you look upward and see two divers on the decompression bar under the boat. Your pressure gauge reads 1000 psig and your buddy's gauge reads 800 psig. You decide to explore for a few minutes below the boat.

Ascent: At 37 minutes you signal your buddy and you slowly ascend *together* to the decompression bar where you will remain for 5 minutes. As you near the 5 minutes mark you look toward the ladder to see if it is clear for exit. As soon as the buddy team ahead of you exits, you and your buddy swim to the ladder. Your buddy removes his fins and exits first. You remain clear in case he falls back into the water. As soon as your buddy is on deck, you remove your fins and climb the ladder. Do not loiter on the ladder or at the exit area; proceed to your seat.

Report to Dive Master: As soon as you are onboard you report both names, maximum depth, and dive time to the dive master. Some dive masters want depth and time information and others don't; they will tell you or ask for the information.

Remove, Disassemble, and Stow Equipment: You immediately proceed to your "space" and assist each other with equipment. The scuba is disassembles, all personal equipment is placed in your net bag, and the bag is stowed beneath your seat.

Record Dive Information: As soon as you have taken care of your equipment you should record all pertinent dive information on a slate.

Return to Port: During the return trip you will rewarm yourself, talk water other divers, and/or relax. Be careful with regard to sun. Thirty minutes of post-dive tropical sun exposure can do considerable damage to already over-exposed skin.

Washing and Stowing Equipment: If you are diving close to home you will simply take your equipment home to wash and dry. Procedures differ from one resort or boat to another. In most cases there will be a tank or hose for washing diving equipment. You should allow your equipment to drain and dry as much as possible. At some resorts a bin or dive locker is assigned to each diver and at others you simply hang your net bag filled with equipment on a hook. These areas are generally secured at night. However, most divers do take small valuable items such as computers back to their quarters.

Post-Dive Activity: I encourage divers to relax for a hour or so following a dive. Avoid heavy exertions such as jogging or tennis for several hours. Drink plenty of water and nonalcoholic beverages such as fruit juice. Be careful of excessive sun exposures. It is best to allow at least one hour between dives.

CRITICAL ANALYSIS

Following each dive you should critically review the dive and discuss it with your buddy.

This is especially important for beginning divers. If you had even the slightest problem, figure out why you had the problem and what you can do to avoid such problems in the future. Experience is a great teacher.

RECORDS

All divers are encourage to maintain an accurate dive log. Unfortunately, far too many do not. If you intend to participate in advanced diver training or progress to leadership positions in diving, this record becomes mandatory. Details of dive record keeping are covered in *Record-Keeping for Divers* (Section 11).

CONCLUSION

Each of your beginning dives will be unique and present different rewards, challenges, and problems. You are learning and acquiring the necessary experience to progress to more exciting diving. Observe and analyze the actions of other divers. The only way to become a good diver is to *dive!*

REFERENCE

1. Somers, L., *Selecting a Scuba Diving Buddy* (Ann Arbor: Michigan Sea Grant College Program, 1987).

Manuscript completed: 7 April 1990

CHAPTER 7-2

BOAT DIVING

GENERAL

Frequently, divers will be required to use a boat as a diving platform. Diving vessels range in size from small, inflatable rubber boats to large research vessels or charter boats. The type and magnitude of diving operation, environmental conditions, distance offshore, number of personnel, amount of support equipment, etc., will dictate the type and size of vessel. For nearshore, scuba diving in relatively calm water, a small 14 to 18 ft (4.2 to 5.4 m) outboard motorboat is commonly used. More extensive offshore diving operations must be undertaken from a larger vessel with adequate deck space and seaworthiness. The following factors must be considered:

1. Adequate size to comfortably accommodate divers, surface personnel, and equipment;
2. Sufficient stability and seaworthiness to function as a platform for diving operations;
3. Vessel well-maintained, in satisfactory operating condition, and equipped with proper safety equipment as required by state and/or federal laws (Certificate of Inspection, if applicable);
4. Large, open work/staging area;
5. Mooring capability (3- or 4-point moorings may be required for working dives from large boats);
6. Adequate protection from sun or cold;
7. Sufficient storage space to accommodate diving equipment when not in use;
8. An adequate ladder and staging area to facilitate entering and leaving the water;
9. Diving personnel and/or professional crew trained in boat handling, seamanship, etc. (licensed crew when applicable); and
10. Ship-to-shore communications (marine radio with Federal Communications Commission Station license posted; CB may be used in some small boat operations).

A satisfactory diving ladder/exit platform is an extremely important safety consideration. Most boats, unless specifically designed and equipped for diving, will not have a ladder that is safe for use by divers. Serious injuries have resulted from the use of inadequate ladders. The ladder should include the following features:

1. Solid construction;
2. Rungs wide enough to allow comfortable use with bare feet and stability with fins;
3. Hand rail extending the full length of the ladder to give the diver a hand-hold until he is completely on deck;
4. Inclinated relative to the side of the vessel; and
5. Secure enough to avoid movement when the diver is on it.

*The information contained in this paper is intended to provide divers with a general overview of boat operations. **It is not intended as an instruction manual for boating and must not be used as a guide for boat operation.** Persons intending to operate boats must receive proper instruction from authorized agencies and instructors.*

SMALL BOAT DIVING

Choice of Craft. Features to consider in selecting a small boat for diving include seaworthiness, stability, space, and carrying capacity. The boat may be of rigid construction or an inflatable design. Good quality inflatable boats are excellent diving crafts if protection from surface exposure is not required.

Propulsion. Most small boats are powered by outboard engines. The engines must be serviced and in good working order. A rigid, comprehensive service/maintenance program should be established. Engine operation must be verified prior to leaving for the dive area. Avoid outdated, poorly maintained outboards.

Be certain to secure the engine to the vessel with a safety chain. Generally, a gasoline-oil mix will be required. Use appropriate mix proportions and oil. Be certain that you have sufficient fuel for all requirements plus reserve fuel for an emergency.

A spare parts/tool kit must be included as standard boat equipment. The kit must include spare plugs, shearpins, and a starter rope plus the appropriate tools to replace them. Ideally, an engine trouble-shooting chart with correction procedures should be included in the kit. The kit should be fully waterproof and stowed in a secure location. At least one member of the dive team must know the function of the engine and how to make field repairs.

Always carry an auxiliary pair of paddles or oars; they could be your only means of propulsion in an emergency. Many divers prefer the use of twin-outboards. This means you will generally have propulsion if one engine fails. Others use a small auxiliary engine that is exclusively for emergency use.

Safety Equipment. In addition to the spare parts/tool kit standard boat equipment must include a bailing device or container, a flashlight, emergency flares, and approved lifejackets. The diver's inflatable vest is not an approved flotation unit for boating. Ideally, a rescue lifeline/float should also be available. A first aid kit is standard equipment. Ship-to-shore communications is required for all diving operations covered by federal/state occupational safety and health regulations and are recommended for all offshore diving operations. A diver's flag and adequate support must be available. All boats must be equipped with a fire extinguisher; even gasoline outboards can present a hazard if fuel is mishandled. A megaphone is useful for warning approaching boaters or recalling divers on the surface. An underwater diver recall/signalling device is also desirable.

Navigation Equipment. The amount and type of navigation equipment will depend upon the diving location, distance offshore, landmarks, and so on. Ideally, a waterproofed chart, or chart in a waterproof case, of the area should be on board. Even if you navigate by landmarks and buoys a compass must be available. Fog, forming while you are offshore, can necessitate the use of a compass for safe return to port. A sextant, pencils, and instruments should be included as required.

Knots for Line Handling and Attachment. All boat divers should be able to tie the following knots: bowline, square knot, clove hitch, two half hitches, and sheet bend. Lines must be coiled in a fashion to prevent snagging when being deployed. Coiling the anchor line into a locker or container is a good practice. The line may also be figure-eighted on the deck to minimize snagging during rapid deployment.

Preparation of Boat. Pre-launching preparation procedures will depend upon the boat itself. In general, inspect the boat to assure that no damage has occurred during transport, secure drain plugs, secure engine, ready mooring and anchor lines, and stow safety equipment. Do not bury the anchor and anchor line under diving gear. Do not load heavy equipment into the boat until it is afloat. Be certain that inflatable boats are assembled in accordance with the manufacturer's instructions.

Launching. When launching from a trailer, make sure that someone is holding onto the mooring lines while the boat is being pushed off the trailer. Be certain that the trailer is parked in a proper location so as not to interfere with the launching of other boats. Load heavy equipment while the boat is moored. Be assured that the water depth is adequate to prevent damage to the engine. Install or lower engine, connect and prime fuel system, start engine, check for cooling water coming from engine, and allow sufficient time for the engine to warm up before proceeding to sea. Be cautious to avoid engine damage in shallow water.

Handling Under Way. All boat operators, regardless of the size of the boat must be familiar with boating *rules-of-the-road*, local rules, speed regulations, and so on. Pamphlets and manuals relating to these subjects are available from the U.S. Coast Guard, state agencies such as the Department of Natural Resources, and some sheriffs'departments. A variety of boating manuals are available in book stores. Each operator should be provided with appropriate information.

Speed is one of the greatest hazards. Avoid unnecessary speed, particularly in confined water. Avoid sudden bursts of speed and tight turns under full power. The latter can cause a capsizing and, if not expected by those in the boat, can pitch people overboard. In addition, equipment may move around causing damage or injury.

The operator must be in total control of the vessel at all times. This requires, among other things, constant and uninterrupted attention to the boat and surrounding water. Always be alert for other craft or persons in the water (swimmers, waterskiers, etc.) . *Do not allow a person under the influence of alcohol or drugs or a person suffering from motion sickness to operate a boat.*

Hopefully, a diving team will not put to sea in adverse rough water conditions. However, such conditions can develop quickly and a team in a small boat can be caught out by bad weather conditions. The general rule is, "Keep the boat headed into the sea and proceed at slow speed." When it is necessary to go with the sea, allow the waves to overtake you; to travel faster than the sea means that the boat is more likely to suddenly swing off course and be hit broadside by the waves.

Watch waves approaching from the stern and control speed in order to minimize water flood over the stern. If your course is across the direction of the seas, it may be necessary to alternately almost head into the sea for some distance and then change course so that the sea is almost astern. If the distance between wave crests is large, it may be possible to run at speed along the trough and turn the bow into the crest at the last minute. In rough seas all persons in small boats must wear lifejackets, or at least the diver's inflatable vest. Ideally, all persons, both tenders/operators and divers, should wear diving suits or waterproof exposure suits, especially if the water is cold. Not only does this allow for greater thermal comfort and reduce the discomfort of wetting spray, but greatly enhances survival if the boat capsizes.

When going alongside a dock or object or picking up a diver in the water, approach against the wind or tide, whichever has the greatest effect on the boat, and on the sheltered side if possible. Use reverse gear to brake, if necessary. The idea is to come to a halt within reaching distance of the dock, object, or diver. The most common fault when going alongside or picking up is to approach too fast. Do not hurry! When moving off from alongside a pier or boat, back off first if possible.

Anchoring and Mooring. The anchor must be of adequate size for the boat. A Danforth or grapnel (wrecks/rock bottom) with approximately 12 ft (3.6 m) of chain is recommended. The heavy-duty anchor line should be at least three times the maximum water depth. Many divers secure a buoy near the upper end of the anchor line. In the event that the boat must be moved quickly (such as picking up a distressed diver), the anchor line can simply be thrown off and later retrieved. Mooring lines, twice the length of the boat, should be available at the bow and stern.

Always anchor clear of other craft, and not in an area designated as prohibited or restricted on a chart. Be sure that the anchor line is clear. Stop the boat into the wind or current and let the anchor go, allowing the boat to drop astern. Pay out plenty of line. Make sure the anchor is holding before stopping the engine.

Always make sure the anchor line is secured in the boat. When retrieving the anchor, start the engine first. The engine can be used slow ahead to assist in breaking out the anchor and while the anchor is being hauled in. Immediately prepare the anchor line so that the anchor is always ready for use. It may save you from disaster in the event of engine failure or other emergency.

The anchor line is often used as a descent-ascent line. Often this practice encourages divers to use less scope or adequate length of line for anchoring. Such practices can lead to dragging the anchor or place unusual stress on the line or boat hardware, especially in rough seas. Use of a specific weighted ascent-descent line secured to the stem is more acceptable. Some divers use a separate ascent-descent system. Once the vessel stabilizes after anchoring, a heavy weighted line with a surface float is placed directly off the stem of the vessel. The line is generally equal to the water depth so it remains taut.

The size buoy will depend upon the bottom weight; however, both should be of adequate size to allow the divers to pull down or up on the line without affecting the position of either. A short length of line generally leads from the boat to the ascent-descent line.

When the anchor line is used for descent and ascent and a current is running, a length of line is secured from the stem to the anchor line. The diver holds this line as he/she enters and pulls hand over hand to the anchor line. In all current diving a brightly colored floating line with a float or floats must be trained behind the boat. If a diver enters and is carried away by the current, he/she can grab the trail line and pull hand over hand back to the boat. These lines are 100 to 300 ft (30 to 90 m) long.

Boat Maintenance. Following a dive, completely clean and inspect the boat. When working in salt water, wash the boat down with fresh water, particularly the engine. Make minor repairs (tighten screws, hardware, etc.) and carefully/correctly stow all gear. Dry out lifejackets and other moisture absorbing equipment. Carefully inspect for damage, especially after operating in a rough sea or hitting an object. Routine professional maintenance schedules must be developed.

SAFETY PRECAUTIONS

Common sense and good judgement are the keys to diving and boating safety. Safety considerations are dictated by the personnel, environment, and type of boat. For example, John Dorr, University of Michigan, Great Lakes Research Division developed the following guidelines for small boat operations (16 to 21 ft outboards) and research diving in the Great Lakes:

1. Loads will be anticipated so as to avoid exceeding the capacity of the boat.
2. Operations will not be conducted during marginal weather conditions.
3. Boats will be anchored or moored from the bow only.
4. The anchor line will be attached to the boat and retained in a ready position.
5. In rough sea an anchor will be set in addition to securing mooring lines to fix anchorage buoys, especially for night operations.
6. Two buckets or bailing devices will be carried in the boat.
7. Emergency equipment (including flares, horn, whistle, and first aid kit) will be placed in a floatable container and secured to the boat in a manner to allow access in the event that the boat overturns.
8. Paddles will be secured to the boat.
9. Ideally, a radio telephone should be carried if the boat cannot be visually monitored from shore.
10. If extended offshore operations are anticipated, a means of receiving continuous weather advisories should be available.
11. Do not *overpower* small boats or place too heavy of a engine on the stem.
12. No more than 6 scuba will be carried at any time (4 for diving, one for standby diver, and 1 extra; assume single cylinder type).
13. Equipment will be carried for a maximum of 3 divers (2 divers and one standby diver).
14. All dives will be conducted with a minimum of 4 persons (2 divers, 1 standby diver, and 1 boat handler/tender).

15. During January to May and September to December all personnel will wear full diver type exposure suits (Great Lakes diving operations).

16. Standby equipment and the standby diver will be in a ready status (suit and buoyancy system on; scuba assembled; mask, fins, snorkel and weight belt readily accessible).

17. A strobe light will be displayed from the boat mast during night diving operations.

18. Arrangements will be made to have all dives, especially night dives, monitored by onshore personnel. Specific emergency procedures will be provided in writing in accordance with location and situation. A beachmaster should be designated.

19. A contingency plan will be established in the event that the divers are separated from the boat. This plan will be established prior to the divers leaving the boat for every dive.

20. Flare/smoke distress signals will be carried by divers, especially at night or in adverse weather.

21. Only the equipment and personnel necessary to complete the given task should be carried on the boat.

22. After each dive, the boat should return to shore to drop off unneeded equipment and samples and to exchange personnel as required.

CONCLUSION: LESSONS LEARNED

The above guidelines were developed following an incident involving the capsizing of a dive boat at night during early spring in cold Lake Michigan water. Fortunately this incident did not result in loss of life or serious injury. The boat was heavily loaded with dive equipment and equipped with a large engine. The boat was secured to a mooring buoy about 800 yards offshore when it began to take water over the stern. The boat rapidly filled and capsized. The individuals in the boat were not wearing exposure suits. However, they were able to climb onto the capsized boat and paddle it toward shore with their hands. Upon entering the broad surf zone they were thrown from the boat and swam to shore.

Meanwhile, the divers surfaced offshore. The night was dark and there was no boat in sight. They called to attract attention and waited to be picked up by the boat. Eventually they realized that something must have happened to the boat. As they began to chill, even in dry suits, they discarded their scuba and began the long swim to shore. The severely damaged boat was found the next day some distance down the beach. All dive equipment was lost.

Manuscript completed: 8 April 1990

NOTES:

CHAPTER 7-3

DIVING IN LIMITED VISIBILITY

INTRODUCTION

Most beginning scuba divers envision diving in the warm pristine waters of the Caribbean Sea where underwater visibility often exceeds 100 feet. Divers working far at sea or under the ice shelf in Antarctica boast of virtually unlimited water clarity. On the other hand, a diver may enter a zone of total darkness when diving in lakes, bays, and rivers where the suspended material in the water is so profuse that all light penetration is blocked. Great Lakes divers commonly explore shipwrecks in water where they can only see 10 to 20 feet.

Many divers relate *quality of diving experience* to water clarity and would never consider diving where the underwater visibility was less the 60 feet. Because of specific interest (i.e., shipwrecks) or geographic location, other divers seem to derive great pleasure from diving in water when you cannot see beyond an arms length. Search and rescue divers commonly conduct underwater searches by feel alone.

RISK-BENEFIT ASSESSMENT

I feel that most divers will agree that otherwise given equivalent circumstances, a dive in clear water has less potential risk than a dive in limited visibility water. The most obvious concern is with maintaining a proper buddy system. Navigation is also more difficult and many divers become easily disoriented. Consequently, they may have to make long surface swims following depletion of their air supply in order to return to the boat or designated exit point.

In some lakes, bays, and rivers the bottom is cluttered with debris from both human and natural sources. The risk of entanglement in lines and nets is often high. Many lakes were formed by the flood of large areas of land after rivers were dammed. Buildings, trees, barb wire fences, and other debris of pre-flooding remain in dark waters. Some rivers in our western states have large accumulations of submerged tumbleweed that can literally consume a diver. In ocean waters divers may encounter unseen marine life that can cause injury.

All of the above would not represent as high of risk if the diver could easily see and avoid encounter. Consequently, divers electing to dive in limited visibility must be prepared to accept a higher level of risk, take special precautions, use special equipment (in some cases), and obtain special training. For some individuals the emotional stress associated with perceived confinement, disorientation, unseen marine life, and surprise encounters place them at an exceptionally high level of risk, and limited visibility diving is definitely contraindicated.

FACTORS THAT DETERMINE UNDERWATER VISIBILITY

Pure water is transparent. The range of underwater visibility is controlled primarily by particles of organic and inorganic material suspended in the water. Fine-grained sediment particles (clay and silt) eroded from land by running water and weathering processes are carried into lakes and ocean waters where they remain suspended in the water column for days, even years. For example, clay size particles have a settling velocity of 0.00025 cm/sec in still water. This means that in the open ocean it would take approximately 50 years for the particle to settle to the bottom at a depth of 4 kilometers. What does this mean to the average diver? If a clay size particle is introduced into a calm body of water, theoretically it will settle toward the bottom at a rate of slightly over three feet in 4.56 days. A silt size particle (10 times larger) will settle 100 times faster. Vertical water movements can both slow and increase settling time.

Water clarity is often directly related to weather conditions. During the rainy season rivers and streams continuously supply lakes and bays with large quantities of sediment-laden water. However, during the dry season clearer water can be expected due to less influx of river water containing sediment. Many otherwise clear lakes and quarries will have severely limited visibility following a spring rainstorm and several days may be required for the sediment to settle and visibility improve.

The type of bottom sediment is also a principal factor influencing underwater visibility. Coarse-grain sand is heavy and settles rapidly back to the bottom when disturbed. Consequently, rock and sand bottom bodies of water often make the best diving locations. On the other hand, divers commonly disturb silty bottom sediments with their fins and raise clouds of sediment into the water column. In an otherwise clear quarry the bottom water can be reduced to zero visibility in a short time by careless and unskilled divers. In these waters divers must use great care in controlling buoyancy and swimming as far above the bottom as possible. The fins need not make contact with the sediment to disturb it; current produced by fin movement near the bottom is sufficient. Cave divers use an unorthodox high fin knee kick to minimize silting.

Thermal structure of the water column may also be a significant factor. During spring and fall months temperate zone lakes and quarries are isothermal (same temperature from top to bottom) and suspended sediments are carried throughout the water column by natural wind-induced circulation visibility is influenced throughout the water column. As the surface waters warm, the water column develops a thermal stratification and a thermocline is established. This is a narrow zone of rapid temperature change with less dense warm on top and denser cold water below. On occasion following mild rains and sediment influx, the upper layer of water have very limited visibility and the cold deep water will be clear. A diver may go from 3 feet visibility in surface water to more than 20 feet visibility after passing through the thermocline.

Plankton (tiny plants and animals) remain suspended in the water column for many days or even weeks. The quantity of plankton in the water depends on season, sunlight, nutrients, suspended sediment (blocks light penetration), water movements, and thermal structure. Phytoplankton (drifting plants) reproduce rapidly in well-mixed nutrient rich water during spring months due to increased sunlight exposure. This is the spring bloom. Zooplankton (drifting animals) reproduction soon follows due to the increased food supply. In some locations the water literally turns into a organic soup with plankton so concentrated that visibility is obscured. Prolific blooms of dinoflagellates, a minute planktonic organism that possesses characteristic of both plants and animals, causes the classic *red tides*. These organisms become so concentrated that the water appears reddish-brown. During red tides filter feeding marine organisms such as clams and mussels concentrate a toxic by-product in their flesh and are unfit for human consumption.

In some coastal ocean areas underwater visibility will change significantly with tidal movements. During flood (rising) tide clear ocean water moves into coastal embayments and during ebb (receding) tide dirty river or back bay moves seaward to obscure visibility. Wind and wave conditions also influence coastal currents and sediment erosion and transport.

DIVING TECHNIQUES

The most obvious concern in limited visibility diving is buddy separation. Consequently, dives must be planned and executed to minimize this possibility. For purposes of this discussion I will define limited visibility as a condition where the diver's lateral range of vision is less than 20 feet.

Safe and effective group diving in limited visibility is difficult if not impossible. When the visibility drops much below 20 feet, it is difficult for more than two divers to maintain effective visual contact. Further reduction in visibility to less than 10 feet can significantly compromise even two-person team operations.

Divers must maintain continuous visual contact throughout the dive. When entering areas of silt and completely obscured visibility, divers will have to establish physical contact by holding hands or using a buddy line. Special care must be exercised during descent and ascent to avoid separation. Even then emergency responses such as sharing air will be seriously compromised.

Divers who routinely operate in limited visibility must, in my opinion, be far more self-sufficient than clear water divers. Since buddy separation is more likely to occur and air sharing is extremely difficult, the use of an auxiliary scuba emergency air source is far more attractive that relying on using your buddy's octopus or safe-second.

Buddy Line

A 4- to 6-foot piece of 3/8-inch synthetic polyolefin braided or 3-strand twisted line with hand loops at each end makes an excellent buddy line. Polylefin line has the advantage in that it floats and thus reduces the possibility of snagging on bottom objects. Hand loops may be fashioned by placing an eye splice in each end of the rope. The rope may be looped into a small coil and carried in a BCD pocket when not in use. Although I personally discourage the use of longer buddy lines, two 6-foot lines can be easily joined to form a 12-foot line. Long buddy lines allow divers to separate far out of visual range and easily catch on submerged objects, especially if the rope sinks and drags along the bottom.

When using a buddy line it is best that one diver be designated as leader and the other remains at his/her side. The lead diver should not jerk and drag the other diver around the bottom nor should the divers compete for directional control.

Diver Separation

Even the best of divers sometimes become separated underwater. The pre-dive plan must include a procedure that is to be followed in the event that the divers become separated. Diver separation can be especially stressful for some individuals. Suddenly a diver may find himself/herself alone and disoriented. The diver may simply be fearful of being alone or that something has happened to his buddy.

Whenever you realize that you are separated from your buddy, simply stop swimming, take a breath, relax, and listen. You might hear nearby bubble noises. Often bottom visibility is very poor but improves significantly a few feet above the bottom. Carefully rise upward in the water column until you are several feet above the bottom and scan the surrounding area for your buddy, bubbles, or a silt trail (fin disturbed sediment). If both of you have responded properly you should see each other at this point. If there is no evidence of your buddy, you may spend a few seconds systematically searching the immediate area. I generally use a box search pattern. First, using a compass I will swim 4 or 5 kick cycles north, turn 90° and swim the same number of kicks east. This is repeated until you have completed the four sides of the box pattern.

As a general rule if you and your buddy do not reunite in one minute, both divers are to make a controlled ascent to the surface. At the surface the divers reunite, discuss ways to improve diving procedures, and may then descend and continue the dive. Hopefully, the divers will now use a buddy line or take greater care in maintaining visual contact. At this point (on the surface) some dive teams will elect to terminate the dive and return to shore (or the boat).

Let's assume that you surface and your buddy doesn't. Scan the surrounding area for bubbles. If there are two or more burst of bubbles surfacing side by side, it may be another group or divers (assuming others are operating in the area). A single burst of bubbles may be your buddy. Remain over the bubbles and await ascent. If a steady stream of bubbles (unlike breathing burst) is coming to the surface, this could be a free-flowing regulator and means your buddy is in serious trouble. You can descend along the bubble trail to investigate.

If you do not see bubbles and your buddy does not ascend to the surface, you must, unfortunately, assume the worst. Your next response will depend on the site, your personal experience, availability of other divers, and so on. If you are alone in the lake or quarry, have sufficient air, and are an experienced diver, you may elect to return to the bottom to conduct a brief systematic search. *However, in haste do not place your own life in jeopardy!*

On the other hand, you may lack the air and experience to conduct a search. In this case remain calm and take a series of compass bearings on several different shore objects. These bearings will be needed to assist search and rescue personnel in establishing the last known point of contact. Swim to shore and seek professional assistance as soon as possible.

If other divers are in the vicinity, signal for assistance. If possible, remain in the location where you surfaced. This is the best point for an organized search to begin.

In many years of diving I have seen many buddy separations. Most are the result of poor dive panning and technique. In a number of cases, once separated, an independent-minded diver has continue to swim about underwater and enjoy the dive while a concerned buddy experiences an anxiety attack on the surface.

TETHERED SCUBA DIVING

Modern tethered scuba diving techniques are virtually unknown in the recreational diving community and are in only limited use by scientific divers. Tethered scuba diving is probably one of the must under-rated and misunderstood of all modern diving techniques. Deployment of a single scuba diver is currently inconsistent with recreational training policies.

The modern tethered scuba diver is outfitted with an independent redundant breathing system, a full face mask, a safety harness, and a combination safety-communications line. This line leads to a surface tender and communications unit. Throughout the dive the diver and tender are in constant voice communication. In addition, a second tethered scuba diver remains on standby to assist if needed.

This technique has been used with great success by scientific divers operating in cold, dark waters where the underwater task can be easily accomplished by a single diver and attempting to maintain the buddy system is both inefficient and in effective. For selected diving activities deployment of a properly equipped and trained single tethered scuba diver is, in my opinion, much safer than placing two free swimming scuba divers in an environment where visual contact is limited to impossible. A detailed discussion of this diving technique is presented in *Tethered Scuba Diving* by Somers (available from the Michigan Sea Grant College Program in Ann Arbor).

SUMMARY

Diving in limited visibility is a higher risk activity than diving under otherwise similar circumstances in clear water. Divers may use special precautions and techniques to reduce bottom disturbance and maintain contact. A proper dive plan will include a specific procedure to follow in event of diver separation.

Manuscript completed: 21 February 1990

CHAPTER 7-4

UNDERWATER NAVIGATION

INTRODUCTION

Establishing and maintaining orientation underwater is essential for the safety and efficiency of any scuba diving operation. Sense of direction is easily lost underwater, especially when visibility is limited and the diver is unfamiliar with the area. Orientation begins at the surface and continues throughout the dive. Proper underwater navigation entails (1) establishing surface orientation relative to the underwater area to be explored and arriving at the bottom with a fixed reference point in mind, (2) establishing orientation on the bottom in reference to this fixed surface point and bottom features, (3) steering a reasonably accurate course on the bottom, and (4) returning to a predetermined point.

BOTTOM FEATURE NAVIGATION

The fixed reference point on the surface may a boat, shoreline feature, or man-made structure. Underwater, the reference point may be a prominent natural feature such as the channels between reefs; a man-made structure such as pipeline, cables, or an anchor; the general ripple mark trend; the bottom slope; a cliff or drop off; the current; or a combination of these factors. For example, if the ripple marks are orientated parallel to shore, the diver may determine his orientation with respect to shore by observing the ripple marks and relative depth. It should be emphasized, however, that ripple marks are not always orientated parallel to shore and that their orientation should be checked with a compass.

In clear water most divers navigate by bottom features. For example, many excellent dive sites are located on ledges or steeply sloping bottoms. The diver can simply use these natural features as a guide and swim parallel to the feature. For example, a boat may be anchored in 50 feet of water. The Dive Master may instruct the divers to swim in a given direction at a depth not to exceed 70 feet until they have consumed about one-third of their air supply. At this point they are instructed to move up slope to a depth of 50 feet and swim in the opposite direction. In most cases the divers will arrive back at the anchor point with one-third of their air supply remaining and complete the dive in the vicinity of the boat.

Many coral reef form a spur and groove topography. In such areas fingers of coral and rock separated by sand channels protrude seaward. The boat is anchored in a sand channel in order to prevent damage to coral. Upon entering the water the divers are instructed to observe the general underwater topography. The divers may descend to the anchor, take a depth reading, and swim to the coral area on either side of the sand channel. The divers can then move in either direction parallel to the coral. Eventually, the divers may elect to cross the sand channel and return to anchor depth along the opposite side of the channel.

COMPASS NAVIGATION

Self-contained divers commonly use a liquid-filled magnetic compass for underwater direction finding and navigation. Generally, the compass is part of the instrument console that is attached to the scuba regulator. However, some divers will secure the compass to their wrist or to a compass board. A diver's compass should have the following features: (1) correct dampening action, (2) liquid filled, (3) the compass rose marked in degrees, (4) lubber's line showing direction over the face, (5) a course setting line or reference markers, and (6) a movable bezel. A good compass will respond rapidly to even slight course changes and have a high degree of luminescence for use in dark water.

When using a compass, the diver will first obtain a bearing in degrees to the target relative to magnetic north. While sighting on the target, rotate movable bezel until the parallel lines on the comapss face (movable) are aligned with the

North needle. The bearings, in degrees, will be indicated at the end of the North needle. To navigate a straight line, the dive must point the the lubber line in the direction of intended travel and keep it perfectly aligned with the longitudinal axis of the body. Be certain to hold the compass level so that the needle can swing freely and not lock in place. *To maintain proper direction while swimming, the diver must keep the North needle aligned with the parallel lines on the compass face and maintain the lubber line parallel to the longitudinal axis of the body.*

If visibility and bottom characteristics permit, sight over the compass to an object or feature that lies in the path of travel. Swim toward that object and look ahead for another sight point. In my opinion it is easier to navigate using the point-to-point method than by constantly monitoring the compass. Unfortunately, on featureless bottoms and in very poor visibility the diver will have to navigate solely by compass observation.

A compass may be strapped to the diver's wrist (right for right-handed and left for left-handed persons). Metallic objects that might cause deviation should be worn on the opposite wrist. When swimming underwater, the *compass-lock* position is recommended. In this position the arm without the compass is extended straight in front of the diver, the diver bends his compass arm 90 degrees at the elbow, and then grasps the extended arm near the elbow. This places the compass directly in front of the diver's eyes and aids in keeping the diver's body on a straight line.

The two most serious mistakes when using a compass are failure to keep the lubber line parallel to the longitudinal axis of the body, and the diver looking down at the compass instead of sighting over the compass. The diver must keep his body straight and swim in a straight line if he hopes to navigate accurately.

COMPASS BOARDS

The use of a compass board will greatly improve accuracy on long underwater swims. U.S. Navy Underwater Demolition and SEAL Team swimmers generally operate well within a 1.3 percent margin of error relative to target; good wrist compass accuracy is about a 5 percent error factor. Compass boards are not generally sold in United States dive shops or used by recreational divers. However, they may be easily constructed of 1/4-inch sheet plastic (Plexiglas) with dimensions of approximately 8 x 10 in. One end may be rounded to give a more hydrodynamically efficient shape. Better quality compass boards are designed and constructed to be neutral in sea water. The compass may be mounted permanently or the board can be slotted in order to utilize the wrist strap and facilitate easy removal for conventional use. The compass is mounted at the middle of the board directly on the center line. A depth indicator, timer, and/or small waterproof light may be included in various configurations at the diver's discretion. A lanyard or snap-hook may be added to minimize the possibility of loss. Hand slots may be cut on each side to facilitate handling.

While swimming, the compass board is held firmly in both hands parallel to the intended direction of travel. The elbows are pressed against the sides of the body for stabilization and the compass board is held about one foot in front of the mask. When using a luminous dial compass at night, the compass board may have to be held closer to the face. Prior to submerging, a visual sighting on the target is made and the compass is set. Underwater the compass is observed throughout the swim. If the compass board also includes a depth indicator and timer, these instruments are scanned systematically along with the compass.

BASIC NAVIGATION

Assuming that the diver swims a straight course, he/she can return to the original point of entry by following a reciprocal course (180° opposite his original course bearing) with an accuracy of + 5 degrees.

Basic pilotage and dead reckoning navigation can be used by divers. The simplest method of navigation is pilotage. This involves establishing a position in relation to known features and plotting a course toward a destination from a known position. The diver simply determines the bearing and swims on course to a specific point or area. Dead reckoning, however, requires following a compass bearing in a specific direction and taking into account speed and time. An estimated time of arrival (ETA) may be computed.

Approximated distance or time required to swim between two points may be determined by the simple formula: Speed x time = distance. Thus, an ETA can be determined. Distance traveled underwater can be determined by time or counting the number of kicks. On the average, at normal swimming level, a diver wearing a wet suit will travel 2.5 ft/sec or 3.25 ft per kick cycle. The same diver without a wet suit will travel 3.6 ft/sec or 4 ft per kick cycle. The individual can measure his own underwater swimming rate by swimming a given course and recording the time and number of kicks. An average of several course swims should be used.

CONCLUSION

Keep in mind that every dive site has its own unique bottom characteristics. Consequently, each dive must be planned accordingly. The prudent Dive Master will use a chart or sketch or the dive site when briefing divers. Using common sense, natural features, and a compass, divers should always know their underwater position relative to their entry and exit points.

Manuscript completed: 20 February 1990

NOTES:

CHAPTER 7-5

DIVING AT NIGHT

INTRODUCTION

Scuba diving at night, especially in tropical waters, has become a popular activity at resorts and on live-aboard dive boats. These adventurous divers observe and photograph animals not normally seen during daytime dives. Also, being in the sea at night fulfills some fundamental human psychological needs for adventure and perceived risk-taking. In addition, marine biologists have discovered new assemblage of coral reef animals actively feed at night and this has opened new avenues of research.

In this paper I will briefly discuss fundamental factors that a beginning diver should consider when planning and executing a night dive. *Keep in mind that all divers are encouraged to acquire advanced and specialty course training which includes instructor supervised night dives.*

RISK-BENEFIT ASSESSMENT

I feel that most divers will agree that otherwise given equivalent circumstances, a dive during daylight hours has less potential risk than a dive at night. One obvious concern is with maintaining a proper buddy system. Although in clear water this is generally not a problem, limited visibility water may seriously reduce diver safety factors. Navigation is also more difficult and many divers become easily disoriented. Consequently, they may have to make long surface swims following depletion of their air supply in order to return to the boat or designated exit point.

In some lakes, bays, and rivers the bottom is cluttered with debris from both human and natural sources. As in limited visibility diving, the risk of entanglement in lines and nets is often high. Many lakes were formed by the flood of large areas of land after rivers were dammed. Buildings, trees, barb wire fences, and other debris of pre-flooding remain in dark waters. Some rivers in our western states have large accumulations of submerged tumbleweed that can literally consume a diver. In ocean waters divers may encounter unseen marine life that can cause injury.

Night diving in limited visibility is certainly more demanding and, in my opinion, carries a higher risk factor than diving in the same water during the day. Suspended particles in the water column reflect the beam of your underwater light in much the same fashion as automobile headlights reflect in a dense fog. In extremely poor visibility, the light becomes virtually useless.

All of the above would not represent as high of risk if the diver could easily see and avoid encounter. Consequently, divers electing to dive at night must be prepared to accept a higher level of risk, take special precautions, use special equipment (in some cases), and obtain special training. For some individuals the emotional stress associated with perceived confinement, disorientation, unseen marine life, and surprise encounters place them at an exceptionally high level of risk, and limited visibility diving is definitely contraindicated.

EQUIPMENT FOR NIGHT SCUBA DIVING

Standard scuba diving equipment is commonly used by most divers at night. Divers who routinely operate at night and in limited visibility must, in my opinion, be far more self-sufficient than daytime and clear water divers. Since buddy separation can occur more easily and air sharing is much more difficult to coordinate at night, the use of an auxiliary scuba emergency air source is far more attractive that relying on using your buddy's octopus or safe-second. A knife is, in my opinion, mandatory. Underwater lights and surface signal device are the only items that will be covered in significant detail here.

Dive Lights

What type or size light should you select for night diving? There are probably no less that 50 styles and models from which to make your selection. In selecting a light for travel diving, you must consider size, weight, application, cost, and versatility. If you intend to participate in highly specialized activities such as cave diving, the special underwater light requirements are beyond the scope of this paper.

A prudent diver will select a light which can be used year-round for many diving or non-diving applications. A good dive light will cost $40 to $100 or more. Selecting an expensive light that may only be used three or four times per year is a bit frivolous. If a light is designed to withstand the crushing pressure of 2000 feet of sea water, it should withstand normal everyday use.

Travel Dive Light. In selecting a travel light that is reasonably compact and lightweight, one will have to make some compromises. For example, I have two very bright underwater lights which are both acceptable for cave diving. One has a separate battery pack that is about 18 inches long and weighs approximately 10 pounds with charger. The other is a large hand-held diver's light that weighs approximately 5 pounds. Both of these lights are extremely bright. The larger one will illuminate a very extensive area of a reef as well as blind other divers and frighten marine life. Although nice to have, these lights are simply too large, heavy, and expensive for the average traveling diver.

Several flashlight-size models weighing 10 to 16 ounces are available. The consumer should compare beam intensity, beam angle, beam quality (i. e., even illumination versus dark zones and hot spots), burn time, recharge time, and cost). A simple comparison chart can be formulated by the prudent shopper. The shopper must be reasonable and accept the fact that he/she can not expect the same performance from a five pound light and a 10-ounce light. However, one may be pleasantly surprised by the performance of modern compact dive lights.

Battery Selection. What kind of power supply or battery is best for the traveling diver? The diver may select either a rechargeable or a disposable battery. Disposable battery lights have a lower initial cost, require limited maintenance, do not require the availability of electrical outlets for recharging, and have burn times of 3 to 10 hours. If the light is accidentally flooded with sea water, a good freshwater rinse and a new set of batteries/bulb is usually all that is needed to put it back in service, especially if it is attended to immediately.

Most compact dive lights use either AA or C batteries. Divers should always load lights with fresh batteries prior to a trip and take extras in accordance with projected use; also, include spare bulbs. It is sometimes difficult, if not impossible, to find proper batteries or bulbs in tropical cities or at resorts. From a standpoint of weight, four alkaline C batteries weigh 9 ounces and four alkaline AA size batteries weigh 3 ounces. For the average diver making only a few dives per year, disposable alkaline batteries make a lot of sense.

Rechargeable gel-cell batteries generally have a burn time of about two hours with a recharge time of up to 15 hours. They are more expensive than alkaline; however, they do pay for themselves if used with moderate frequency. They also require a periodic recharge maintenance program even when not in use.

Rechargeable ni-cad (nickel-cadium) batteries are the most expensive ones commonly used in dive lights. They generally last longer and accept more recharges that most other rechargeable types. Burn time is 1 to 2 hours with recharge requiring up to 9 or more hours. The consumer must be aware that ni-cads are manufactured in various grades and matched cells should be used in the construction of ni-cad battery packs. Be sure to avoid polarity reversal which can be caused by completely discharging the batteries; this can significantly reduce the life of a battery pack. Wattage output is relatively constant until burn time is completed, then it drops sharply. Turn the light off when the beam turns yellow.

Ni-cads will pay for themselves if used with moderate frequency. However, they do require a periodic recharge maintenance program even when not in use. Ideally, nicad batteries should be stored at a temperature of 50° to 60° F;

avoid temperatures in excess of 110° F. Improper maintenance or neglect can result in reduced life and, ultimately, destruction of the battery pack. Be certain to follow manufacturer's instructions for recharging and care.

Selecting a Light. The final selection is dependent on personal requirements. I have selected a relatatively compact light with a high intensity bulb that I can use with either alkaline disposable or ni-cad rechargeable batteries. I normally use disposable batteries and will only include rechargeable batteries and charger if I intend to use the light extensively and if I am assured of a proper power source/outlet for recharging. The beam angle is somewhat limited on these smaller lights. If I wish to illuminate a larger area, I secure two lights side-by-side using universal holders supplied by the manufacturer or by simply taping the lights together with a small homemade plastic spacer positioned between them. This does not increase the overall intensity, just the illumination area. This way I also have an extra light in case one malfunctions.

These lights are small enough to be carried in a BCD pocket, in a universal holder that can be secured to my forearm, leg, or strobe, or in a special belt pouch. I also attach a small lanyard and/or clip to the light in order to reduce the possibility of loss during entry/exit and for added convenience. Other holders and accessories are available.

The consumer can compare specifications by consulting catalogs and distributors. Talk to other divers and, if possible, examine the qualities of several different lights used by friends/other divers before making your final selection. If you wish to compare the actual illumination capabilities of several lights, take them into a large dark room. You will soon understand the differences between 8,000, 12,000, and 16,000 candle power or 7.8 and 3.7 watts.

Keep in mind that a top-of-the-line, high intensity compact light will provide only up to 7 or 8 watts of power as compared to a large cave diver's light which provide 35 to 55 watts. Also, by illuminating a low- to moderate-reflection wall surface from a distance of about 10 to 20 feet away, you will develop a better understanding of beam angle and quality. Illumination and beam angle will be less underwater than in air. More ideally, take the lights to a darkened swimming pool. Keep in mind that you need only illuminate the portion of the underwater scene which you are viewing, not the entire reef.

In addition to the various factors discussed above, consider grip, buoyancy, corrosion-resistant construction, ease of O-ring examination, bulb availability/cost, accessories, and warranty. Depth could also be a factor; however, most manufacturers claim operation depths between 300 and 2000 feet, well beyond the range of ordinary scuba diving.

As with any item of diving equipment, the prudent diver will carefully compare diving lights and select a model that best fits his/her needs and pocketbook. Look for a light that can be used for other recreational and everyday activities. You can carry a good dive light in the glove compartment of your car or keep it in your night stand 365 days per year for use as an emergency light. You will generally invest more than $40 in a good light.

Maintenance. By using reasonable care in handling the light and maintaining it in accord with the manufacturer's recommendations, it should provide you with years of satisfactory service. Be sure to include spare bulbs and batteries in your spare parts kit. Always read the manufacturer's instruction manual supplied with the light completely and assemble necessary tools, parts, replacement batteries and bulbs, and special instructions in your travel repair kit.

The primary cause of light flooding is an improperly seated o-ring. If possible determine if the o-ring is making a solid contact between the two sealing surfaces prior to each dive. Many underwater lights are designed and manufactured with clear plastic that allow the o-ring to be inspected. Through the clear plastic the o-ring should appear as a solid black line. The o-ring should be periodically removed, gently cleaned, lightly coated with silicone grease, and carefully replaced. Be certain that there is not sand, towel fibers, or other foreign matter on the o-ring. A tiny cloth fiber can wick large amounts of water into the housing under pressure.

Following each dive your light should be rinsed in fresh water, dried, and stowed where it will not be damaged by scuba cylinders and weight belts. Ideally, you should disassemble the light and inspect for moisture. Even a small amount of water can cause serious damage to batteries and internal components within a few hours. Corrosion of batteries in a partially flooded light produces a gas build up and a highly acidic solution. Take great care in opening a light if you suspect that water has entered the light. It may literally explode and spray you with an acid solution that can damage clothing and skin. If this solution enters the eyes, serious injury and vision impairment may occur.

If you discover that your light has flooded during the dive, immediately turn the light off. As soon as you return to the boat, carefully open and drain the light. Avoid contact with the water drained from the light. *Do not reseal the case!* Disassemble the light as soon as possible and rinse all components with liberal amounts of fresh water. Dry the components completely. Properly dispose of damaged batteries. Replace damaged parts as required. The light may then be reassembled and tested. If damage is significant or the will not operate properly, promptly return to factory for repair.

Keep in mind that all dive lights have an air tight seal which restricts the venting of hydrogen gas produced by the batteries. This gas could cause the light housing to explode. However, most lights manufactured in the United States and some imports contain a hydrogen catalyst. This catalyst may be located on the battery pack (rechargeable units), on/behind the circuit board, or on the reflector assembly. *If a light is flooded, this catalyst must be replaced before resealing.*

Nicad batteries require special care. New battery packs do not generally reach full capacity until they have been recharged 20 to 30 times; 2 or 3 charges will bring them to near full capacity. Following several months of storage, the battery pack may have to be recharged to reach full capacity. Keep in mind that if nicad batteries are discharged to the same point many times in a row, they will develop a "memory" and reduce the light's burn time. This memory can be erased by several training cycles of running the beam down to a yellow glow and then recharging. If the nicad batteries have not been used for many months, recharge before switching the light on.

Signal and Tracking Lights

Very few scientific and recreational scuba divers carry flares or signal devices for use at the surface. They rely on the beam of their primary light. Today open water night divers are encouraged to carry a compact backup or secondary light for emergency use.

Backup Lights. I normally carry a penlight key chain size light with a lithium battery for emergency use underwater and on land. These small lights provide only enough illumination to read instruments and see very small areas of a underwater seascape. They make excellent backup or emergency lights for use underwater or on land, but, they are generally inadequate for illuminating a large enough area for comfortable and pleasurable night diving. Improved reflectors, gas-filled bulbs (i.e., krypton and halogen), and more powerful, long-life batteries (i.e., nicad, gel-cell, alkaline, and lithium) have enabled manufacturers to produce compact underwater lights of relative high intensity.

Chemical Light Tubes. Most guides require night scuba divers to attach a "glow" light to their scuba valve or regulator first-stage or other visible location. In the event of light failure, the diver's location can still be determined by the highly visible glow light. The light tube contains two separated chemicals. When the tube is bent, one chemical discharges and mixes with the other resulting in a soft green glowing light emission that lasts for several hours. Although green is the most common color, other colors are available. By using different colors on divers, underwater identification is simplified.

Glow light may also be attached to small, stable surface floats towed by the divers. This enables surface personnel to track dive teams. Furthermore, by using different colors specific dive teams can be identified.

Strobe Lights. A compact, high-intensity strobe light may be carried for emergency signaling on the surface. These lights may be seen for several miles, especially from the air. A flashing light at sea is also more likely to attract the attention of persons on shore. Divers operating at night in areas of high current are encouraged to consider special signaling devices. These strobes are compact enough to conveniently carry in a BCD pocket.

Military Distress Flares. Military divers and surface swimmers often carry a combination day-night distress flare. One end contains a dense orange or red smoke for day time signaling; the other has a red flare. The flare is activated by means of a pull ring. After the ring has been pulled the flare must be held at arm's length at an angle of 45° down wind from the diver. If the flare does not ignite immediately, waving it will generally cause ignition after a few seconds. The flare will not ignite if pulled underwater. Do not look directly into the flare because it will destroy night vision for a short time. Although an excellent safety item, these flares are expensive and not generally available to recreational and scientific divers.

Environmental Protection Garment

Divers are encouraged to wear complete environmental protection at night regardless of the water temperature. I personally wear a full-length 1/8-inch neoprene jump suit for tropical diving. In some locations thousands of tiny jellyfish congregate near the surface at night. Either a thin neoprene or lycra hood and gloves are advisable.

NIGHT DIVE

In planning and executing a night dive one considers all of the factors associated with daytime dives. Since dive planning and basic diving procedures have been discussed in detail in other sections of this manual, I will only address the added requirements for night diving here.

Personnel Considerations

It is somewhat difficult to conduct a guided group dive at night except under the most ideal conditions. In the Caribbean Sea some organizations will have a guide lead small groups on underwater tours and a safety diver will generally swim at the rear. In some cases buddy teams simply orient on the team in front of them and hope that that team is following the guide.

I feel that it is important to place a beginning night diver with an experienced night diver, especially for their first few underwater excursions at night. This will do the most to reduce anxiety and improve safety.

It is very important to maintain a proper surface crew during night operations. *The vessel must never be left unattended!* The boat operator must be prepared to pick up distressed divers at any time. Ideally, a surface rescue swimmer should be available to assist divers in the water. Many larger dive boats will maintain a small inflatable boat and operator on standby whenever divers are in the water.

Dive Site Selection

Most dive sites frequented in daylight hours will be acceptable for night operations. However, the prudent diver will use greater care in avoiding locations with strong surface currents, rugged shore line entry requirements, high surf, and night boat traffic. Furthermore, operations should be suspended when surface conditions such as fog, rain, or snow may hinder the diver's return to the staging area or vessel.

Dive sites with distinct topographic features such as slopes, ledges, sand channels, and so on, are more acceptable because they provide the diver with natural navigation features. *Ideally, divers should be familiar with shore (and/or surface conditions) and underwater features. The prudent diver will select a location that he/she has dived during the day. I consider this to be a fundamental safety rule for night diving.*

Defining Dive Parameter

The dive area boundaries must be well defined. Divers should be restricted to a specific radius of operation. The exact radius depends on the experience level of the divers, the site, environmental conditions, nature of operation, and so on. If the dive site is well selected and the vessel is properly anchored, prudent divers will operate within a radius of 100 yards or less.

Also, divers must strictly observe depth and time limitations. Avoid decompression dives if at all possible. Since most dive instruments are not illuminated throughout the dive, some divers become careless in instrument monitoring. Take special care! *Furthermore, prudent Dive Masters will generally designate a specific time for dive termination. This means that all divers must be on board and accounted for at that time.* Stories of dive vessels pulling anchor and returning to shore only to find that some one is missing are not without foundation.

The Night Dive

Every dive site is unique. Consequently, it is difficult to establish specific procedures to address the requirements of all geographic areas and water conditions. Also, divers participate in various geographic specific activities such as photography, collecting lobsters, and collecting shells. Most simply go sightseeing. Night diving interest has increased significantly for divers vacationing in tropics over the last decade. The following is a more or less generic approach to night diving that is slightly biased toward tropical oceans.

Departure. I prefer to leave shore for the dive site at a time that will assure arrival at the site and anchoring well before dark. In some clear tropical locations it is beneficial for the divers to make a short snorkel swim before dark to view the orientation underwater features. This could be significant in navigating and maintaining orientation at night.

Anchoring. Ideally, the vessel should be anchored in a sand channel or flat area adjacent to a reef or major bottom feature. Avoid anchoring the boat on delicate reefs or in a position so that it will swing over a reef. Beginning night divers need an opportunity to adjust buoyancy and equipment before venturing about. They generally descend to the bottom as part of this adjustment procedure.

Be certain that the anchor is secure, or if you are using a permanent mooring the line is secured to the anchor unit. Ideally, a crew member or guide dive team should be deployed to inspect and secure the anchor prior to deployment of other divers. I recall one dark moonless night off the coast of Jamaica when I was diving with a group of beginning divers. My team deployed and descended first. When we returned to the anchor line we found that the boat was gone. The shackle securing the anchor to the permanent mooring block had broken. The boat had rapidly drifted several hundred yards down current where a second team deployed sometime later. One individual stayed in the boat but was unaware of continued drifting. My team surface to find that there was no boat in sight, and we had surface current, wind, and waves. Fortunately, whistles and light signals eventually attracted attention on shore and a boat was sent to investigate.

Rigging the Vessel. The exact procedure for preparing the vessel will depend on the type of vessel and the environmental conditions. If there is any hint of current, a floating *trail line* with a light marker at the end should be deployed. This is a line 100 to 200 feet in length with a series of small floats. If a diver is carried away from the boat by current, he/she can pull hand-over-hand back to the boat.

A distinct surface light should be placed at a high point on the mast or other elevated feature in a position so that it is visible from any position in the water. This is to guide divers who might surface away from the vessel. Large boats are often visible because of deck lighting.

Some divers will use the anchor line of descent and others will deploy a special weighted descent-ascent line at the entry-exit point. I prefer the latter. Ideally, a light should be fixed to the line in mid-water and on the line weight which is usually several feet off the bottom. A similar light arrangement may be used on an anchor line. Some divers use chemical glow lights and others use flashing strobes. Still others prefer a standard underwater hand light. Regardless of the type used, it should have 360° visibility.

Briefing. Divers should be briefed well in advance of deployment. Ideally, the briefing should take place before darkness so that the divers can get some visualization of underwater features. In calm, clear water reef areas will tend to appear dark and sand areas light. The briefing should include a sketch of the underwater area and a recommended course to follow. It is essential that the Dive Master define depth and time limits and verify that all divers have had sufficient surface intervals following prior dives. Avoid mandatory decompression dives.

The Dive Master must also identify specific characteristics of the site, currents, and potential hazards. Also, the Dive Master must designate special procedures to be followed in the event of light failure, diver separation, and need for assistance at the surface. Other briefing factors specific to the site, vessel, and activity must be addressed. Dive teams must be allowed sufficient time after the briefing to discuss individual dive plans and ask questions. *The Dive Master shall designate a specific time which all divers must be back on deck for post-dive roll call. It is each diver's responsibility to adhere to this requirement.*

Equipment Preparation. Individual divers may prepare their equipment either before or after the briefing. Ideally, lights have been assembled and inspected prior to departure. Scuba assembly and pre-dive inspection is best accomplished in daylight. Attempting to do this in darkness and by hand light is difficult and may increase the likelihood of mistakes. Special care must be take by diver and Dive Master to assure that the diver enters with complete and properly assembled equipment. For example, many divers are careless with their safe-seconds (octopus regulators). They may be caught under straps, in a BCD pocket, or dangling behind the diver. In the event that the unit is needed, in an emergency, locating it can be quite difficult in daylight and next to impossible at night.

Safety Boat Deployment. When diving from a large vessel it is desirable to deploy a small pickup boat. In the event that a diver is injured or surfaces far from the vessel, he/she can be more easily retrieved using the small boat. Generally, a response team remains on standby on the large vessel and scans the ocean surface for signals. In some cases the safety boat will be used to follow a group of divers. The divers may be tracked by the glow of their underwater lights or by a small lighted surface float towed by one of the divers.

Diver Deployment. Ideally, divers should be deployed *before* darkness. As the sun sinks below the horizon there is unique underwater twilight that fades rapidly to darkness. I encourage beginning night divers to enter the water early in this twilight period. In the tropics the last of the day time feeder (fish) are moving into the security of the reef for night. For a few moments there is a unique serenity. As darkness falls the night feeders emerge. In this twilight a diver can observe surrounding features, establish orientation, and adjust to the dimming light.

Underwater Swimming. Swimming underwater at night is much like swimming in the day time. Your range of vision is generally limited to that of your light. You are aware of those around you from the glow of the hand lights and chemical lights. *When approaching your buddy or other divers be certain to never shine your light in their eyes!*

Some nights in shallow, clear tropical water you can turn out your light and actually swim by moonlight. As your eyes adjust, bottom featur become quite distinguishable. The movement of your fins leaves a trail of tiny sparkles — the cold light emitted by stimulation of bioluminescent plankton.

Night divers must have exceptional buoyancy control. Without visual references beginning divers tend to lose track of their position in the water column and must make a special effort to properly adjust buoyancy. Also, divers must take care when kicking close to the reef or bottom in order to avoid damage to marine life or injury to themselves.

More attention must be given to navigation at night if you expect to exit at a predetermined location. Observing ripple marks, current direction, feature trends, and moonlight as well as your compass is necessary throughout the dive. Monitor your instruments at frequent intervals. Plan to be back at the boat with plenty of air remaining and well before the designated termination time. Spend the last few moments exploring the area in the immediate vicinity of the boat and at your ascent control stop.

Light Signals. Divers may use normal hand signals that are illuminated by the lights. The light itself can be used to signal. To signal a diver that is ahead of you look for the point where his/her light is shining and cross the light beam with yours. For example, swinging the light back and forth on the horizontal plane designates an emergency need and that you wish your buddy to immediately come to your assistance. If you only wish to attract a diver's attention, sweep the light beam up and down in a vertical motion. The "OK" signal is transmitted by making a slow circle with your light. This can be either a question or an answer. If your buddy signals "OK", respond with the same signal if you are "OK".

Light Failure. If your primary light fails during the dive, secure it and activate your backup light. Stay close to your buddy and rely on his/her light for viewing underwater scenery. Your backup light is generally only satisfactory for viewing small areas and instruments. Some Dive Masters require that the buddy team immediately return to the boat if one primary light fails. This is discretionary based on diver experience level, environmental conditions, and backup lights. Many divers now carry compact backup lights that have higher light output than primary lights used several years ago. Divers must observe policies established by the Dive Master.

Diver Separation. If separated, look for your buddy's light or chemical light. You may have to turn your light off for a few seconds. If a short visual search is unsuccessful, make a controlled ascent to the surface, inflate your BCD, and wait for your buddy. Scan your light below the surface and occasionally across to surface so that your buddy can find you. If diving with a group, you and your buddy can scan the area from the surface for lights and surface swim to a position over the group to descend and reunite. Dive Masters are encouraged to review diver separation procedures in the pre-dive briefing.

Emergency Assistance. In the event that a diver is injured, caught in a current, fatigued, or distressed at the surface some distance from the dive vessel, a small boat should be available for emergency deployment. In some cases where a small boat is not available, a rescue swimmer may have to be deployed or the dive boat moved. This can be very complicated if the injury is serious or if there are a number of divers in the water.

Divers may attract attention of the Dive Master or other persons by waving and/or flashing their dive lights and blowing their whistles. Ideally, each diver should be equipped with a strobe light to use as an emergency signal. Prior to the dive the Dive Master should identify signal methods.

Marine Life Hazards. The fear of an adverse marine life encounter is probably the most stressful aspect of night diving for some individuals. In fact, this fear can be so significant that some individuals should be discouraged from diving at night. For the most part such fears are without foundation. There are few, if any, actual documented reports of shark attacks on divers at night. In reality, a surface swimmer is probably at much greater risk than a scuba diver.

Most marine life injuries result from careless encounter with coral or sea urchins. Jellyfish stings are also common. However, at one time or another all night divers have a serious flash of anxiety when they think they see a large form move in the water outside of the range of their light beam.

Returning to Vessel. You should return to the immediate vicinity of your vessel well before the designated dive termination time. Ideally, the vessel will be anchored in relatively shallow water so that the dive may be completed at the 10 to 30 foot ascent control stop while casually viewing the underwater scene. In some cases a decompression bar will be suspended below the boat or the divers will simply stop on the ascent line.

Once you have completed your stop requirements ascend slowly to the dive platform or ladder and immediately leave the water. Do not swim casually about the exit area since other divers may be waiting for you to leave the water before they ascend. One of the most unpleasant aspects of a tropical night dive may be encountered during surfacing and exiting the water. In some locations thousands of tiny jellyfish congregate just below or at the surface at night. The stings are annoying but not generally painfully uncomfortable. The Dive Master will generally inform you if this encounter is likely to occur and advise you on exiting procedures. Once on the boat report to the Dive Master and remove and stow your equipment.

Roll Call. One procedure that is often neglected by Dive Masters is post-dive roll call. Too often I have heard a Dive Master say, "Is everyone on board?" Dive boats have returned to shore only to find that a quiet team of divers is missing.

Shore-Based Dives. Shore-based dives are conducted using basically the same procedures as stated above, except the dive is staged from a well-selected location on a beach or from a pier or dock. The staging area should be established well before dark. This location is marked with some sort of light or lights. Ideally, one light is located near the water and another farther up the beach slope. Aligning the two lights enables surface swimmers to return to shore on a straight course. In some cases permanent lights such as street and building lights may be used. However, do not rely on house lights that might be turned off during your dive. *Be careful with regard to the position and type of shore light that you use to assure that it cannot be mistaken for a navigation light by boaters.*

SUMMARY

Karl Huggins, co-inventor of the EDGE, once said, "If you dive at night take a light because it is dark!" Words of wisdom. Night diving can be a very pleasurable and rewarding experience. However, by comparison, diving in restricted visibility, both surface and underwater, is potentially more hazardous that diving during daylight hours. Many of the same procedures associated with limited visibility diving in daytime also apply to night diving.

Night dives must be well planned and properly supervised. Special attention is given to beginning divers to assure that they enter the water under optimum conditions, establish orientation, and navigate properly. Buoyancy control is very important. Divers are encouraged to carry a backup light and display a chemical glow light. Although the basic principle of buddy diving apply, a higher degree of self-sufficiency is desirable in night divers.

Manuscript completed: 28 February 1990

NOTES:

CHAPTER 7-6

RECORD-KEEPING FOR DIVERS

The diver's log book is a permanent record of training, experience, and qualifications. A record of diving experience is essential for advancement in research diver classification at various universities and governmental agencies. Diving instructor applicants are required to provide a record of a minimum number of dives or hours underwater in order to qualify for acceptance into instructor training programs. Employed divers are required by both management and occupational safety and health regulatory agencies to maintain an accurate record of all dives.

Unfortunately, no standardized procedures or format for diver records exist at present in the civilian diving community. This is left to the discretion of the individual company, school, or agency. Most often the diver's individual log book is a matter of personal preference. Several excellent formats most commonly used are listed below:

1. Cumulative record sheets on which each dive is entered on a separate line are used most commonly. Vertical column headings generally include date, location, depth, time, environmental conditions, and buddy. These sheets may be simple loose-leaf notebook pages or bound into a convenient small booklet form. Many universities use this format to facilitate submission of monthly records.

2. Several diving log books are available to recreational divers that use a separate page for each dive entry. Some books provide headings and spaces for a fairly complete record of the dive. In addition, space is provided for remarks and observations.

3. Research divers often combine the diving record with a comprehensive field observation or data book. These books are generally relatively large bound notebooks with more than 200 pages. A standard dive record format may be designed and placed on a rubber stamp. The scientist simply stamps the page at the beginning or end of each dive and enters the appropriate dive data. This is most convenient for researchers since a record of observations or experiments may require only half of a page on one dive and 4 or 5 pages for another dive.

4. Some divers simply keep a diary-type record in a small notebook. There are no special forms or format. This is the least expensive method of recording dives; however, it is the most difficult for others to review in terms of qualification advancement, employment records, or evaluation of experience.

Before one can design the "ideal" diver's record book, one must first determine what information must be included in the record, how this information may later be used, and who will use it. In general, employers, health and safety officials, and diving coordinators agree that the diver should record the following data for each underwater or pressure exposure:

Date and time;
Geographical location;
Name of buddy, tender, supervisor, dive master and other persons directly associated with the dive;
Depth of dive;
Bottom time, decompression schedule (if required), and total dive time;
Environmental conditions (sea state, underwater visibility, water temperature, atmospheric temperature and conditions, and current);
Type of equipment used;
Brief description of work performed or dive activity;
Unusual conditions and/or observations made during the dive;
Description of injuries (if any); and
In the case of a working dive, the employer should be designated.

The above data should be recorded in a hardbound book and, in the case of working dives, each dive must be verified by the supervisor or an employer representative. The recreational divers may not wish to go to such a comprehensive procedure for each dive. However, the above procedure has many excellent points.

Why use a hardbound record book instead of loose-leaf fillers in a ring binder? It seems that the loose-leaf method is more flexible, less expensive, and easier to use. True! However, the working diver's log book is a legal record of his/her activity in the event of a future court case that involved something that occurred during that dive or as a result of the work or observation accomplished on that dive. The hard bound book is more likely to be recognized as a legal document whereas the loose-leaf sheets from a notebook may or may not be considered acceptable. This is an especially important factor for recreational diving instructors and dive masters.

The "ideal" diver's record book should include much more than an entry for each individual dive. The most important additional data includes:

Records of periodic medical examinations;
Records of training in diving and all activities such as first aid, CPR, boating, etc., that relate to diving;
Records of diving-related employment;
Annual dive summaries or requalification designations;
Record of personal equipment including serial numbers or identification markings;
Record of equipment malfunctions/problems;
Records of equipment maintenance and inspection; and
Notes on special related activities.

The first entries in a diver's log book should be the pretraining medical examination results and a verified record of completion of training. Some agencies prefer to include a cumulative training, experience, and qualification summary page. Instructors and supervisors can enter brief notations verifying special training or advancement.

The diver can briefly summarize each year of diving experience. For example, the diver may enter the following summary, "1989 dive summary: 56 scuba dives, depth 20 to 110 fsw including 6 dives over 80 feet, 37.8 hours total cumulative dive time; 14 surf entries southern in California, 10 boat ocean dives in Caribbean."

The diver's log sheets may be reviewed and this entry verified by the agency diving officer, dive club safety officer, or other "official" persons. Divers not involved with agencies or clubs simply make the entry and personally attest to its accuracy. This is much simpler for persons reviewing the book than attempting to count or read each individual dive log sheet. In this fashion, several years of diving experience and training can be recorded on a single sheet for "quick-look" review.

Some diver record books include special sheets for periodic depth gauge calibration data, flotation unit (BCD) inspection, regulator inspection, and cylinder inspection. These records are vital to diving safety.

A cumulative medical record sheet should include entries of periodic medical examination (signed by a physician), illness or injury related to diving, and medical information that should be known by persons who might be treating a diving accident victim. The diver or his buddy should give the diver's log book to the attending physician if it contains this information.

How is the information in a log book used? For a commercial or scientific diver this data becomes vital for qualification or classification advancement. In research diving it is a common practice to limit the depth and/or environmental condition exposure for a diver until he has acquired sufficient experience and proficiency to advance to the next level. The diving supervisor, project director, and/or division representative must neither force nor permit a diver to exceed his level of qualification. In many cases the diver's log book is consulted as a verification of the diver's qualification before assigning work tasks.

As previously stated, candidates for scuba instructor certification must provide the course or institute director with a complete record of diving experience. In order to qualify for certification the individual must have logged a given number of dives and/or hours underwater using scuba. In past years this requirement has often been waived since many recreational divers have not maintained records of their experience. In other cases, especially with loose-leaf log book binders, it is probable that records have been falsified. In reality, hardbound record books should be considered mandatory if an individual anticipates eventually qualifying for scuba diving instructor certification.

In recreational diving as well as commercial and research diving there are now many levels of training or advancement following entry level certification. These may include advanced open water, medic firs aid, rescue, dive master, assistant instructor, and instructor certifications for recreational scuba divers. In addition, a number of specialty certifications such as cave diving, ice diving, and underwater photography are available. Various prerequisites in terms of training and experience are necessary for acceptance into these courses. The log book is the diver's only record of experience.

In commercial diving, qualification advancement is based on field experience, diving proficiency, and technical proficiency. The diver must maintain and verify a specified number of dives or exposures each year in order to maintain a given qualification rating. These various ratings include tender/trainee, tender, diver/tender, air diver, rack/console operator, mixed gas diver, saturation diver, lead diver, air diving supervisor, and mixed gas diving supervisor. Advancement and designation depend upon number of field days diving and tending, specific number of dives (with minimum depth and bottom time requirements) at each designation, and technical training. The diver's record book with employer verification is his only personal record of experience. This record is vital to his advancement, work assignment, and pay-grade designation.

What about the *average* recreational diver who never intends to work underwater, take an advanced course, or become an instructor? Why should this individual maintain a log book? At the completion of basic training the diver generally receives a plastic certification card. This card simply indicates that the individual completed a training course in accord with a given minimum standard of knowledge and skill performance. Realistically, this card does little more than identify that the individual is qualified to scuba dive in a swimming pool and that he has participated in a few supervised open water dives. Certainly, it does not indicate a level of proficiency in open water diving since many authorities recognize that it takes at least 10 to 12 open water diving exposures to gain acceptable proficiency for even shallow open water scuba diving.

The card generally does not indicate environmental condition exposure or training. A diver trained to dive in a calm, small, shallow quarry in the Midwest receives the same plastic card as a diver trained to dive under rigorous surf and ocean conditions of northern California. What happens when a diver travels from the Midwest to northern California? How does the charter boat operator, the dive master, or the buddy determine the diver's qualifications?

The log book is, in my opinion, the only cumulative record that the diver can use to verify experience and qualification. I feel that it is quite appropriate for a charter boat operator, a dive master, or a buddy to ask to see some sort of verification of experience that indicates that a diver is qualified to participate in a given diving activity. This is very little to ask considering that these parties may be ***held legally responsible*** if something were to happen to the diver. To be even more basic, the diving buddy may have to depend on that stranger to save his/her life. Again, the diver's log book is his only record of training and experience.

Scores of diver's logbooks are available from instruction agencies and diving equipment supply stores. Some universities now maintain records on computers. In such cases divers complete a special single page form for each dive and submit it to the Diving Office. Divers are encouraged to select their personal record-keeping system to meet present and anticipated future requirements.

The diver's log book is not a private or confidential document. As evident in the above discussion a number of persons including advanced course instructors, dive masters, instructor training directors, employers, charter boat operators, court officials, safety inspectors, supervisors, project directors, and diving buddies will at sometime or another review the content. The entries must be neat, complete, and factual.

Manuscript completed: 1986
Manuscript revised: 3 January 1990

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CHAPTER 7-7

VOLUNTARY REQUALIFICATION

INTRODUCTION

Unlike military and scientific divers, most recreational scuba divers are not subject to periodic requalification (or recertification) requirement. Some diving clubs and at least one certifying agency have developed requalification procedures. However, most recreational divers and agencies *aggressively oppose mandatory requalification*. This is understandable from a viewpoint of economics, freedom, and so forth. However, in a physical activity such as scuba diving, a knowledgeable and reasonable individual should impose personal voluntary requalification requirements.

DIVING ACTIVITY

To be considered for qualified diver status one must simply *dive*. I suggest that a diver must make at least 15 dives per year to be considered an active diver. Furthermore, no more than two dives on any given day should count toward this 15 dive minimum, and a diver should have at least one diving day in any three month period. In other words, one Caribbean diving trip involving 15 dives over a 5 day period is insufficient for retaining a qualified diver status.

I am aware that environmental restraints such as extremely cold weather and ice cover may prohibit strict adherence to this type of schedule. And I am not encouraging persons to participate in adverse weather and under ice diving unless they have the specific training and personal desire to do so. However, I am encouraging active spring, summer, and fall diving under appropriate conditions and midwinter diving vacations in warmer climates. Also, many ice bound northern divers can find exciting and interesting dive sites during most winter months in states south of the Ohio River without necessarily traveling to Florida or the Caribbean. Some of these sites are accessible on three-day weekends. Some northern dive tour guides sponsor excellent long weekend trips to Florida dive sites. These trips often include specialty training in activities such as current diving and cavern diving.

MEDICAL EXAMINATION

Commercial, military, and scientific/academic divers are required to pass annual medical examinations. Recreational divers should develop a self-imposed periodical medical examination program. Although a complete medical examination similar to that used for working divers is desirable, the recreational diver is encouraged to develop a personalized examination protocol with his/her personal physician. The examinations can be at one to five year intervals depending upon age, medical problems, physical condition and so on. An annual chest x-ray, for example, may or may not be required by your physician. Special attention to one's medical fitness is a matter of common sense, especially in the over thirty years old age group. However, even teenagers can develop medical problems that are inconsistent with safe diving. Needless to say, the examining physician must be familiar with the unique physiological aspects of diving.

PHYSICAL FITNESS PROGRAM

As previously stated, scuba diving in itself is not an adequate physical fitness development or maintenance activity for the average participant. Diving must be supplemented with a regular physical exercise routine. A fitness program must be designed to meet the individual's needs and motivations. Any form of aggressive exercise on a regular basis should prove beneficial. Endurance-oriented weight training, swimming, jogging, cycling, cross-country skiing, hiking, underwater hockey and so on will contribute to a high level of general fitness for the seasonal diver. Although some authorities advocate simply swimming with fins as the best form of physical conditioning for divers, I feel that this activity offers limited advantages to the average participant. Naturally, a routine pre-dive season schedule of swimming pool workouts with fins will be beneficial for leg muscle development. However, from a cardiovascular conditioning standpoint other, more physically demanding activities should be considered.

Diet or weight control is an extremely important consideration, especially during periods of relative inactivity. In some individuals eating habits can lead to very rapid weight gain. Generally speaking, it is easier to gain weight than lose weight, especially for the less active, over 25 age group. Obesity may have some limited benefits for staying warm in cold water. However, excessive body fat is contraindicated from a standpoint of general condition and decompression sickness susceptibility. Fitness and physical conditioning is an "individual thing." The benefits for the scuba diver are obvious. Being able to demonstrate to yourself that you are physically fit is a part of your voluntary requalification program.

I feel that all divers should be capable of swimming at least 400 yards and be in reasonable physical condition. The 12- Minute Swimming Test (*The Aerobics Way* by Kenneth H. Cooper) is an excellent self-evaluation mechanism. The test can be self- administered in a swimming pool. A diver should fall in Category III (Fair) or better. This means that a male between 20 and 29 years old must swim 500 yards in 12 minutes; a female, 400 yards. If you are unable to complete at least a 400 yard swim and/or perform poorly on the fitness test, the development of a personal training program to improve your fitness and performance is absolutely necessary. *Please do not attempt a maximal effort activity "unless you are under 35 years of age, are already conditioned, OR have progressed through at least the first 6 weeks of one of the (conditioning) programs."* All divers are encouraged to acquire a copy of *The Aerobics Way* or an equivalent personal training guide.

OFF-SEASON SKILL MAINTENANCE AND OTHER ACTIVITIES

Scuba diving in a swimming pool is not an unacceptable activity. During winter or off-season months divers are encouraged to practice skills at least once per month in a swimming pool. This is an excellent opportunity to review all aspects of basic skill training and lifesaving with your diving buddy and to assess the skill of anticipated new diving buddies. Skills such as buddy breathing, which are not commonly practiced during open water diving, should be given special attention. This is also an opportunity to learn to safely and properly use new equipment such as variable-volume suits and buoyancy systems.

Diving clubs often promote special training, skill contests, underwater hockey (for fitness and fun), and so on. Skin and scuba diving in a swimming pool need not be considered an undesirable or boring activity. Arrangements for special group pool sessions must be made well in advance. Often, skin and scuba diving will not be permitted during general recreational swimming periods. Special attention must be given to equipment maintenance since chemically purified pool water can be just as harmful to your equipment as sea water. Also, special precautions must be observed in order to prevent unnecessary damage to the pool facility itself.

In addition to a skill maintenance program, divers should use off season months to research prospective dive locations through literature, correspond with other divers, and so on. Summer diving activities can be planned and scheduled, rooms reserved, boats chartered, etc. Research/planning should include determination of emergency facilities and procedures. Preliminary planning is a key to safe, pleasurable diving. A proper and safe diving attitude is just as important as skill and fitness.

EQUIPMENT MAINTENANCE

Diving is an equipment oriented activity. Few activities require that an individual use an umbilical-supplied or self-contained life support system to maintain normal life function in an otherwise nonlife supporting environment for human beings. Malfunction of equipment underwater can lead to a life-threatening situation. The diver is equipped with both primary and, in some cases, emergency equipment that must be maintained in proper operating condition at all times.

Periodic requalification for safe diving not only includes the diver, but also the diver's equipment. Although routine equipment maintenance procedures are required for each dive, the following special periodic and/or annual procedures must be considered:

Annual inspection of regulator(s) and submersible pressure gauge by qualified person. This inspection may also include lubrication/replacement of rubber parts, adjustments, and replacement of other worn/damaged parts. Annual inspection and maintenance also includes the "octopus" and pressure gauges! Many repair facilities now have performance analysis equipment. Maintain in your logbook a record of inspection/repair date, person (and facility), and work required and file the repair receipt. This is useful for future resale, trade-in, or warranty service requirements. Note: If a malfunction is suspected, have the regulator serviced immediately. Do not delay until "annual" inspection time. Even if a regulator is not used during the preceding 12 months, it must be inspected and properly maintained prior to use for diving.

Annual scuba cylinder inspection. All scuba cylinders are to be internally and externally inspected on an annual basis for corrosion, contamination, and damage. An inspection decal is placed on the cylinder indicating the date and facility (inspector). Every five years, or more often if internal corrosion/external damage is evident, the cylinder must be hydrostatically tested. This test date is stamped into the cylinder metal. Remember that the annual inspection should also include inspection (and repair, if necessary) of the cylinder valve including placement of cylinder to valve o-ring. Record all inspection/repair information in logbook and file receipts. Remember to inspect and repair (if necessary) backpack cylinder clamps and the harness/quick-release mechanisms.

Annual depth gauge evaluation. Depth gauge error can be caused by repeated use, abuse (even minor), and deterioration with age. Although few repair facilities are equipped to perform an "accurate" depth gauge analysis, the diver should make an effort to find an appropriate facility. Shallow, in-water evaluations can be made by the diver using an accurately measured line or chain. Record test results in your logbook and secure a "correction" tab to depth gauge side or strap.

Buoyancy compensator test. The buoyancy compensator must be routinely inspected prior to and following each dive. However, periodic maintenance must include:

a. Flushing/disinfecting interior,
b. Lubrication of CO_2 inflation system,
c. Verification of CO_2 inflation function by activating a CO_2 cylinder every 6 months, 30 dives, or if malfunction is suspected,
d. Professional inspection/repair of air inflation system,
e. Inflation (hold for 4 hours without significant gas loss) and leak test (in water),
f. Harness inspection and repair, and
g. Verification of over-pressure valve function.

Inspect and sharpen knife. A *dull* knife may prove useless in an emergency. Also, a damaged knife sheath may result in loss of a valuable knife.

Weight belt release. The weight belt release must be inspected to ensure that it will not accidentally release during normal use, but properly release in an emergency.

The six items of equipment listed above are all important to the diver's safety. However, every item of equipment used by the diver must be in excellent operating condition at all times. For example, variable-volume dry suits require special maintenance procedures for valves, zippers, and seals. Consult diving manuals and manufacturer instruction materials for maintenance information on specific items of equipment. Your life or that of your buddy may well depend on your equipment maintenance program.

CONTINUING EDUCATION

All divers should be trained in first aid, cardiopulmonary resuscitation, and lifesaving. This is an excellent off season activity to complement year around diving. Colleges, diving stores/schools, and recreation departments conduct a variety of specialty programs during the winter months including seminars or classes on such topics as underwater photography, underwater physiology and ice diving. Excellent underwater photography courses at Caribbean diving resorts permit the diver to combine a continuing educational experience with a winter diving vacation. This is a wise investment for the developing photographer.

Specialty training in activities such as wreck diving, search and recovery diving, advanced diving, current diving and so on also represent an excellent way to remain active during the diving season. The diver should take advantage of every possible opportunity for special environmental training. For example, any Midwest diver traveling to the west coast should make arrangements to train in beach (surf entry), kelp, and offshore boat diving. Information regarding instruction in vacation areas can be acquired through national instruction agencies and dive shops/tour guides in the area you intend to visit.

For avid recreational divers with extra money, several commercial diving schools offer excellent training in surface- supplied diving, bell-saturation diving, diving emergency medical techniques, and so on. The cost may exceed $2,000 plus living expenses and course durations may exceed 4 months. This is vocational education. Entry requirements are high and in some cases only a relatively small percentage of applicants are actually accepted. However, even if you do not choose to seek employment in the offshore diving industry, the training and experience gained through a commercial diving education is exciting and unique. Remember, successful completion of a commercial diving course does not guarantee a career in commercial diving. However, if you can afford this type of training, the experience will be worth it. Any person considering a commercial diving vocation or enrolling in commercial diving school should read Nic Zinkowski's *Commercial Oil-Field Diving* and write to several schools for literature.

Some universities offer special short courses, workshops, and clinics in hyperbaric chamber operation, surface-supplied diving, fish identification, ecology, general oceanography, marine biology, and research diving. Although these courses do not provide occupational level skill, they do give the diver an insight into a variety of diving activities at a nominal cost.

Finally, many divers will find considerable personal satisfaction, challenge, and employment opportunity as a scuba diving instructor. These individuals are encouraged to first seek training in advance diving, divemaster, and assistant instructor courses. Before attending an instructor training/certification course, the assistant instructor should assist an instructor in several basic scuba diving courses and develop a self-preparation program.

DIVE CLUB

Dive clubs vary in popularity and amount of benefit to the member from one geographic location to another. Often they are more social club oriented rather than diving oriented. However, the club does afford the opportunity for people with a common interest to share experiences and activities. The active dive club can have pool practice sessions, sponsor both weekend and vacation diving expeditions; sponsor CPR, first aid and lifesaving courses; sponsor fitness programs; research diving sites; and conduct numerous other activities. The key word is *involvement*!

CONCLUSION

Diving knowledge, procedures and equipment is progressively changing. Students trained 5 years ago may not be familiar with new buoyancy systems, multilevel diving, dive computers, new logbooks, improved first aid techniques, etc., that are commonly taught in current courses.

Diver trainees must absorb a considerable amount of knowledge and learn relatively complicated skills in a very short period of time. Unfortunately, modern trends in diver education have significantly reduced course durations. If you do not continue your diver education and do not dive on a regular basis, your skills and knowledge will deteriorates considerably within a short time.

Can you requalify? Every safe diver must know his or her personal limitations. Through remaining active in diving and voluntary requalification you can be a better and safer diver.

Manuscript Completed: 1986
Manuscript Revised: 3 January 1990

SECTION 8

DIVING IN TROPICAL OCEANS

CHAPTER 8-1

OUTFITTING THE TROPICAL DIVER

INTRODUCTION

The selection of diving equipment is a personal thing for most divers. When I say personal, I mean that every diver has his/her own ideas about brands, models, and styles. Unfortunately, there are very few, if any, objective consumer guides on diving equipment selection. If one reads the equipment reports in one national diving magazine, one gets the idea that every piece of diving equipment that has ever been manufactured is highly satisfactory. This leaves both the novice and experienced diver at the biased mercy of instructors, dive shop employees, and friends. Thus, the objective selection of proper equipment can be a difficult task. I can't solve that problem in this publication. However, I can offer a few suggestions based on personal experience. Keep in mind that my suggestions relate only to the diver planning to travel to *tropical diving* locations.

First, let's select the equipment that the average diver will need for a tropical diving adventure:

* Mask, fins, snorkel, and boots
* Buoyancy control device (BCD)
* Regulator with pressure gauge and alternate air source
* Weight belt (weights are provided by most resort dive operators; remote-area divers may need to include weights)
* Environmental protection garment
* Compact diver's knife
* Depth gauge, dive timer/watch, and compass and/or dive computer
* Waterproof decompression tables and slate/pencil
* Lightweight gloves
* Compact underwater light
* Compact tool/spare parts kit
* Travel bag and net bag

In the following discussion I will address the selection of certain items of diving equipment such as environmental protection suits, buoyancy control device, underwater lights, and knives in considerable detail — items which, in my opinion, may be selected on a different basis for tropical diving than temperate/polar region diving.

BASIC EQUIPMENT

Fins, masks, snorkels, gloves, and weight belts are generally among the first to be purchased by a diver. Divers can select from literally hundreds of models and colors. As with all diving equipment, I recommend that the traveling tropical diver carefully select mask, fins, and snorkels that meet the highest standard of construction, performance, and durability.

Many northern divers wear extra large fins for diving in a dry suit, but occasionally, an individual will find that these fins are a bit oversized for tropical diving in a thin wet suit and may wish to invest in a second pair.

Large gum rubber fins can be very heavy compared to ones constructed of lightweight rubber and thermoplastic compounds. For example, a pair of my old fins weighs 7.5 pounds compared to 4.75 pounds for a newer model. That means that I now have 2.75 pounds less luggage weight. Some divers, finding that the buoyancy characteristics of the lighter weight fin combined with the buoyancy of neoprene boots make their feet float and kicking awkward, use small ankle weights to adjust for this problem. However, if you select lighter fins to decrease the weight of your luggage and have to add ankle weights, you really haven't gained any advantage. Also, some divers who do an extensive amount of surface swimming/skin diving find the buoyant fins to be more awkward. If you do plan to select new fins for your tropical holiday, be certain to swim with them before you leave for your remote tropical dive site.

Carefully inspect your fin straps and buckles before departure. It is wise to include an extra fin strap.

Traveling tropical divers may spend hours surface swimming and breath-hold diving when vacationing in the tropics. These divers should consider a high-quality comfortable low-volume mask. Many divers require a mask with prescription lenses. Persons with serious vision problems may wish to include a spare mask in their kit, while some divers will simply rely on their contact lenses as a backup. I always pack a spare pair of glasses for use in the event that mine are broken or lost. In an emergency these spare glasses can be used for diving by removing the temples and wedging the glasses into a nonprescription mask. A spare prescription mask should be considered when diving in very remote and underdeveloped areas.

Many northern divers do very little surface swimming with a snorkel at home. During a tropical vacation, however, they may spend hours snorkeling. Some divers discover too late that their snorkel mouthpiece is very uncomfortable for extensive use and mouth and gum irritation can seriously affect your scuba diving comfort and pleasure. Carefully select a snorkel that is comfortable and test it during long surface swims before you depart for the tropics. Keep in mind that even a minor mouth injury could develop infection and ruin a tropical diving trip.

Most dive resorts and marine laboratories provide lead weights. However, most require divers to furnish their own belts. I have selected a nylon mesh pocket-style weight belt for my travels which facilitates rapid adjustment of weight by simply placing two- or three-pound weights in the pockets and zipping the top closed. I find this belt to be more comfortable than conventional belts with slip-on lead weights. Some divers, especially those wearing nylon body suits or diving without a suit, prefer foamed-neoprene pocket-style weight belts for added comfort.

ENVIRONMENTAL PROTECTION

Most divers associate cold stress and hypothermia with polar or temperate region waters and fail to recognize that significant *thermal drain* can be associated with diving in the tropics. Silent or symptomless hypothermia can result from long term, slow cooling of the body submerged in water at a temperature greater than 80° F (26.7° C) [1]. Field experience has shown that some tropical divers were reluctant to continue diving after several days of exposure to these higher water temperatures.

In the presence of symptomless mild hypothermia there is obstruction of memory processing, interference with performance of previously learned tasks, slowed reasoning and decision making, and extreme fatigue [7]. Symptomless hypothermia can be a hazard for any tropical diver [1, 3].

The prudent diver will take as much care in selecting a thermal protection garment and maintaining proper thermal balance for tropical diving as he/she will for diving in colder regions. A good thermal protection garment will greatly reduce the possibly adverse consequences of symptomless hypothermia, protect the diver from marine life hazards and sun, reduce air consumption (thus, increase dive time) and significantly improve the quality of the diving experience.

For tropical ocean diving, winter or summer, I have selected a *1/8-inch (3 mm) foamed neoprene full-length, one-piece wet suit* [4]. The suit is thick enough to provide adequate thermal protection for the tropics, yet thin enough to allow for maximum freedom of movement. The new high quality foam neoprene materials with nylon bonded to exterior and interior surfaces provide excellent flexibility and comfort for extended wear both in and out of the water. Buoyancy problems due to neoprene compression are minimal.

In addition to thermal protection, this jumpsuit provides excellent protection from injury that might result from contact with marine coelenterates and bottom materials. Knee patches are recommended, especially for underwater photographers. This full length suit also provides excellent protection from the sun while snorkeling and during surface activities associated with dive preparation and completion.

To extend the thermal range of the lightweight jumpsuit, the diver may add a 1/8-

inch (3 mm) *hooded vest* or a 1/8-inch (3 mm) foamed neoprene hood can greatly improve thermal comfort. The head is one of the most significant heat loss areas of the body [3].

The 1/8-inch (3 mm) neoprene jumpsuit is also excellent for use during confined water diver training and for aquatic recreation activities in cooler climates. It provides significant thermal protection and body comfort for surfing, boardsailing, rafting, kayaking, water skiing, and other aquatic sports. In colder weather it can be used as an undergarment for boating and fishing. The waterproof vapor barrier undergarment principle is quite valid for increasing thermal protection for persons participating in more sedentary activities. In the event that a fisherman or boater falls into cold water, survival time is increased significantly. Soft interior linings such as lycra velour make the suit relatively comfortable for reasonably long periods of surface wear. Periodic laundering in accord with manufacturer's recommendations will keep the suit clean and odor free.

Some divers prefer a two-piece lightweight wet suit instead on the one-piece jumpsuit model. The two-piece model provides the diver with the option of wearing only the top or over-the-shoulder style bottoms for warmer water diving.

The *full-length nylon (lycra) body suit* has gained considerable popularity among tropical divers. These thin nylon suits are available in numerous colors and color combinations and are considered to be quite fashionable. They offer excellent protection from the sun for skin divers and reasonably good protection from encounters with marine coelenterates. However, these suits have only limited, if any, thermal protection qualities. In the past many tropical divers have used denim jeans and cotton sweat shirts for environmental protection. Such garments tend to fit loosely and absorb a considerable amount of water. Their increased drag and resistance to movement may be a significant factor in increasing diver fatigue.

More recently several manufacturers have marketed a 3-ply special fabric suit that is waterproof, windproof, and breathable. Promotional materials indicate that body suits constructed of this fabric offers as much protection from heat loss as a 1/8-inch foamed neoprene suit. At the time of this writing I am unaware of any unbiased scientific evidence to support this claim.

An alternative to the nylon body suit is a *1 millimeter neoprene suit* with nylon bonded to both sides of the neoprene. This suit should provide the flexibility and freedom of movement of a lycra body suit with a level of thermal protection.

In some tropical waters vast numbers of jellyfish and other stinging planktonic hydrozoans may be encountered in the water column near the surface, especially at night. Full body protection is very desirable. Some divers have found that a thin polypropylene or nylon balaclava (more commonly used for cold-weather skiing and hiking) provides excellent protection to the head, neck, and face. The addition of thin, tight-fitting gloves tucked under the sleeves of the wet suit and high-topped neoprene boots provides the diver with nearly complete protection from these stinging organisms.

Dive operators on Bonaire are now promoting a "no gloves" diving policy. They feel that persons wearing gloves are more likely to touch and damage delicate corals. I concur with their observations and support this policy. The diver must learn proper buoyancy control and movement underwater to avoid accidental contact with delicate marine life.

Most scuba divers wear *foamed neoprene boots* for foot comfort and protection. Otherwise, loose fitting fins can cause serious abrasive and blister-producing injuries. Sturdy, lightweight hard-sole neoprene boots are desirable to protect the feet when walking on boat decks, docks, beaches and coral debris as well as for use with fins. Some divers prefer low-cut slip-on boots for the tropics, whereas others use a high-top zippered model. Be certain that the low-cut boot is high enough to prevent chaffing of the foot by the fin strap or foot pocket. Keep in mind that foamed-neoprene boots are uncomfortable and, possibly dangerous, for running, extensive walking, moving about on jagged, pitted, carbonate beach rock or for extensive wading in shallow water.

For years U.S. Navy scuba divers have used a high-topped athletic-type shoe to protect their feet and ankles when working around sharp objects in shallow water or on beaches. These shoes were constructed of a canvas upper attached to a rubber sole. Swim fins could be worn over the shoe, when necessary. This shoe was commonly called a *coral shoe*. It has never achieved popularity, or even recognition, among civilian sport divers. The shoes have to be periodically replaced due to deterioration as a result of repeated exposures to sea water. The shoes are less comfortable than foamed-neoprene boots for extended swims with fins. In addition, most high-topped athletic shoes available to civilians are too bulky for use with fins.

Divers with special requirements for wading in shallow water and walking/running on beaches in conjunction with underwater or surface swimming with fins may find the Maine Hiking Shoe (L. L. Bean, Inc., Freeport, Maine 04033) or an equivalent useful. These lightweight shoes are constructed of 9.7 ounce army duck uppers with a cushioned inner sole and vulcanized crepe rubber outer sole. They are designed for hiking and wading and may be worn with appropriately sized fins. The diver may wish to experiment with various quick-drying synthetic socks and different lacing patterns for added comfort depending on swimming and walking/running requirements. Fully laced, these shoes provide reasonably good support. For swimming, partial lacing allows for more comfortable ankle flexibility. This type of shoe is an excellent addition to a tropical diver's kit.

Many divers prefer to wear some form of hand protection for tropical diving. A variety of cloth or vinyl gloves are available. The gloves should fit tightly, have some stretch, be easy to put on, and be thin enough so that you can easily handle small objects and camera controls.

BUOYANCY CONTROL DEVICE

The 1980's has certainly been the decade of the BCD (buoyancy control device). They come in all sizes, shapes and colors. You can buy a jacket , collar, or back mount buoyancy compensator. It is said that more than 80% of the divers use the jacket BCD today. Most students currently use the jacket BCD throughout training and are familiar with the major advantages afforded by it. As with any item of equipment, the diver should use that with which he/she is familiar and comfortable. *The important consideration is that the diver uses a buoyancy unit for both skin and scuba diving.*

I own and use both jacket and collar BCDs. When it comes to tropical diving I will use either style, depending on the location and activity. Why would I even consider the old fashion collar BCD. At the risk of being considered a diving dinosaur who is out-of-touch with modern times, I will give my reasons.

First of all, I seldom use the BCD to compensate for negative buoyancy on tropical dives, especially with my 1/8-inch (3 mm) suit. I do quite nicely by selecting the right amount of weight for my belt and by breathing properly. Therefore, the need for a large jacket BCD is less in average tropical diving. Secondly, and subjectively, I feel that I experience less drag with my compact collar BCD than I do with most of the larger cylinder-mounted, jacket models.

However, in 1989-90 several manufacturers are offering a very compact, low-profile jacket BCD with a soft backpack. Although reports from divers in the field are limited at this time, these BCDs appear to be an excellent choice for tropical divers. One company markets the new BCD especially for the traveling diver and includes a small stuff bag.

Third, I find the collar to be far more comfortable and acceptable for snorkeling. The jacket BCDs can be bulky and cumbersome, especially if the scuba backpack is attached. And, if used for surface flotation, many jacket BCDs have a tendency to push the diver into a face down position when the scuba cylinder is not in position.

Since my BCD is often used without scuba I have equipped it with a CO_2 inflation device which, in the event of an emergency, becomes an extremely important consideration. Let me assure you that oral inflation of a BCD under severe stress is seldom successful. The availability of the CO_2 inflation system an important factor for scuba dives, as well as skin dives.

The CO_2 inflation system has become one of the most scorned and misunderstood items of equipment in modern scuba diving. Some consider it to be a remnant of the era of diving dinosaurs. Most modern BCDs are sold without a CO_2 inflator. Some BCDs are designed to accept CO_2 as an accessory items; others lack adaptive fittings. A review of the use and rejection of CO_2 inflation systems in modern scuba diving was published by Orr [2].

Keep in mind that the above discussion may only be academic at this time in diving history. Very few manufactures and instructors endorse the use of a CO2 inflator in 1989. And, it appears that more and more BCDs will be designed without this system in the next decade.

Fourth, when diving from small boats in the ocean I often wear my BCD during the boat trip because many, if not most, small Bahamian and Caribbean dive boats are not equipped with emergency personal flotation equipment. On more than one occasion I have found great psychological comfort in knowing that I had my flotation gear on me instead of the scuba cylinder since there were no life-jackets on the boat and the sea condition and boat handling was going from bad to worst.

Fifth, if I am forced to make a long survival swim or surface rescue in the ocean, I consider discarding my scuba. And, I want the BCD on me, not the scuba. Most divers find it hard to visualize a situation where such drastic measures might be necessary. True, this isn't an everyday occurrence, but I can assure you that it has happened. In all fairness, the scuba cylinder may also be released from a jacket-type BCD and the BCD retained by the diver if such an emergency were to occur.

A word of caution! Standard scuba backpacks are becoming increasingly rare items at dive resorts. In the summer of 1988 I had to use a rented jacket BCD on several occasions because no standard backpacks were available. In the event that you do elect to use a collar BCD for scuba diving, also include a compact scuba backpack in you diving outfit. Unfortunately, these old-style backpacks are becoming increasingly rare in dive stores.

So, based on these reasons and my personal comfort, I still continue to use the collar BCD for tropical diving. I do not expect all readers to discard their jacket BCDs and buy a collar BCD. In fact the previous paragraphs may be only an academic exercise at this point in time. However, I include the above explanation of my selection process to demonstrate how one might analyze their personal needs more objectively. Divers often equip themselves on a basis of marketing and trends rather that objective analysis of need and performance. For additional information on BCDs consult "Buoyancy and the Scuba Diver" [5].

Keep in mind that if you elect to use a collar BCD for scuba diving on a tropical holiday, you may very well be the only person doing so. Furthermore, very few dive shops even sell them anymore and salespersons will no doubt attempt to discourage you from buying one. Collar BCDs usually cost less than one-half the price of other styles. You must be prepared to, in some cases, defend your choice. Some divers, dive guides, and instructors may even scorn you.

Some prudent divers elect to include a compact collar BCD for skin diving and a compact, low-profile (single bladder) jacket BCD for scuba diving in their tropical dive kit. This may very well be the most appropriate consideration.

I also use the combination alternative breathing second stage regulator/BCD inflator in order to reduce the number of regulator hoses from four to three.

INSTRUMENTATION AND DATA RECORDING

The vacationing tropical diver and researcher may make two or more multilevel dives per day for five or six consecutive days. It is imperative for that diver to have a good dive timer, an accurate depth gauge, a means of determining appropriate dive schedules, and a documentation system. *Keep in mind that multi-day repetitive diving may increase your risk of decompression sickness. Use common sense and good judgment. Many instructors recommend a limit of three dives per day and encourage taking a midweek break.*

The needs of the average diver can be served quite nicely by a modestly priced digital dive timer, a depth gauge, a plastic dive table, and a small plastic slate with pencils. The diver must simply remember to activate the dive timer (or use one that automatically activates) and set the maximum depth indicator on his/her gauge before descent. Dives should be planned to not exceed the no-decompression limit for the maximum dive depth. The dive plan and a record of repetitive dive information is recorded on the plastic slate.

A diver must know his/her nitrogen status throughout the dive and diving day. The need for proper monitoring and documentation can not be overemphasized. I personally use a combination digital/analog diver's watch which is easier to read under lower light conditions and allows for timing two events at a time. I also have an automatic activation time/depth gauge combination console. This provides for accurate dive timing in the event that I forget to set my watch. The analog depth gauge is also fitted with a maximum depth indicator so that I can easily determine the maximum depth attained during the dive. The plastic tables and slate/pencil are carried in the BCD pocket.

Diver computers are increasing in popularity every year. We are entering the age of electronic diving. The unit that I use provides a continuous status display of current depth, maximum depth, and no-decompression dive time remaining. The no-decompression and decompression status is updated every three seconds based on current depth, bottom time, and previous theoretical nitrogen absorption-elimination factors.

The modern vacationing diver wants to get every minute of diving possible during any diving day. This diver will often purchase a dive computer that sells for $300 to $600 in order to extend his/her diving range. These devices add a new dimension to an individual's diving activities. By continuously updating the diver's nitrogen status, the diver may take advantage of multilevel diving capabilities to increase underwater time and range. For example, if the maximum dive depth is established at 100 feet, the diver properly using standard decompression tables will enjoy a bottom time of about 20 minutes. However, using a dive computer the diver may stay at 100 feet for only a few minutes if desired and then ascend to a shallower depth range for the remainder of the dive. This diver may enjoy an hour or more underwater without a decompression requirement.

All divers must remember that any mechanical/electronic device is subject to failure or malfunction. Most frequently these failures are a result of human error, carelessness, or physical abuse. A microprocessor will fail if the battery compartment floods because the diver did not clean the O-ring or properly close the compartment. A careless diver may accidentally turn the device off while putting it on or taking it off. Consequently, all dive information from previous dives is lost.

In the case of data loss, the diver must wait at least 18 hours for nitrogen levels to be reduced to the point where the device can again be properly and safely used for its intended purpose. In theory, the diver should not return to diving until the "model" that the microprocessor is based on allows for all nitrogen to clear from the body. Consequently, the user of a unit where all tissues are used to compute repetitive dive gas uptake should not dive until the slowest tissue has theoretically cleared. In some units this is 48 hours or more. As a safeguard, the prudent diver will carefully monitor his/her dive computer throughout the dive and always maintain a no-decompression status. If the device malfunctions during a dive, the diver can ascend to a shallow depth and complete a long safety decompression stop.

When using a decompression microprocessor, many divers also wear a backup timer/depth gauge, carry a set of decompression tables in their BCD pocket, and document all dives on a slate or in a notebook throughout the day. It is not that they do not trust the dive computers, but simply wish to protect themselves from personal errors and carelessness.

I certainly encourage accurate documentation of all dives and the use of backup instruments. However, if your microprocessor *crashes* you are basically finished for the day, if not longer. You simply cannot mix tables and computers at this time! However, some of the new computers of 1989-90 are program with the same decompression model as some dive tables. Read the manufacturer's instruction manuals carefully to determine if there is now a table backup procedure for your computer. However, be careful!

Another safety alternative to protect a diver in the event of data recording equipment malfunction is the proper use of buddy diving procedures. I prefer to dive with a given individual throughout the day, both of us diving approximately the same profile or schedule. That individual must also be equipped with a timing/depth determination capability or a microprocessor. Although our dive profiles will not be exactly the same, they will be close enough so that either of us may *conservatively* use the others dive data for determining no-decompression time and calculating repetitive dive schedules.

In the case of dive computer users, keep in mind that the buddy team must have dived the same dives and essentially the same profiles throughout the day. In the event that one diver's unit crashes, a relatively conservative safe ascent may be made following the buddy's unit. However, I discourage subsequent repetitive diving on the single unit.

I encourage each diver to be equipped with a dive computer and discourage the use of one dive computer for more than one diver. Furthermore, ideally each buddy diver should be equipped with units using the same decompression model. Keep in mind that there are several different decompression models being programmed into various units today.

Divers must keep in mind that there is no such thing as a perfect decompression model, table, or device. Under the right physiological conditions or with the right combination of dive exposures, a diver can *bend* when using any of the existing decompression models, tables, or devices. There are a dozen or so decompression tables and devices based on different models available today and you can "bend" on any of them if you push them too far. ***Deep, multilevel, repetitive dives and multi-day dive trips are not without increased risk of decompression injury!***

REGULATORS

The selection of a regulator is a matter of the diver's personal preference. However, if a diver intends to travel extensively, the following should be considered:

* The most important consideration is to select a top quality regulator that meets a high standard of performance. Regulators are improving each year as designers and engineers find ways to improve air flow characteristic.

* Select a regulator that has an established reputation for sustained performance and durability. Field repairs are often haphazard and undependable. At some resorts, and especially at more remote locations in the tropics, qualified repair persons or parts may not be available.

* Some newly released high-performance regulators require adjustments and parts replacements to correct minor malfunctions soon after release. I seldom travel with a new regulator. I either select a "proven" regulator or, if I select a new one, I like to have about 10 to 20 hours of local/pool diving with it prior to major trips.

* Keep in mind that regulators should be inspected annually. Many traveling divers only use their regulator once or twice each year. They equate maintenance requirements with usage and often ignore the annual inspection policy. Usage in itself is not the only factor that leads to regulator problems. An infrequently used regulator may be more subject to deterioration of rubber parts or performance degradation than one that is used on a regular basis, especially if it is improperly stored.

* Have your regulator inspected at least one month prior to you trip. This inspection must also include your pressure gauge and octopus (or combination octopus/BCD inflator). Many divers ignore these combination units since they are attached to their BCDs. Always test your regulator following annual maintenance. Use the regulator two or three times before the trip, even if only in a pool. This way you can identify any problems and have them corrected before you depart.

* Many traveling divers select a regulator that is lightweight and compact, but it

meets high standards of performance and other criteria for regulator selection.

Most modern divers prefer to use an instrument console attached to their regulator. These consoles include expensive, shock-sensitive instruments. Special care must be observed in handling and transporting digital timers, analog depth gauges, pressure gauges, and decompression microprocessors. Damage to any one of these instruments could lead to serious consequences for the diver, i.e., decompression sickness or accidental air supply depletion.

Divers commonly pack their regulators and consoles in a duffel bag along with the rest of their equipment. Some place them in special regulator bags. Keep in mind that a regulator bag may or may not provide protection, depending upon its design and location in the larger duffel bag. Even if the regulator is carefully wrapped in a wet suit it may still be subjected to considerable shock during baggage handling.

I usually pack my regulator in a equipment bag using my wet suit as a protective container. However, I do remove my depth gauge/timer and dive computer and pack them in my carry-on. One manufacturer markets a high-pressure quick-connect fitting to facilitate removal/replacement of the complete console.

UNDERWATER LIGHTS

Diving at night is a very popular activity on tropical vacation. Some dive resorts/charter boats provide underwater lights for an additional charge. However, most divers travel with their own lights. Actually, any seasoned adventure traveler, diver or not, will include some sort of hand-held light on his/her list of basic necessities. Power failures are not uncommon and at some back-country lodges power is supplied by on-site generators that are turned off at night.

I recall one night on the island of Granaha off the coast of Honduras. I was staying at a quaint lodge surrounded by dense tropical flora. Without warning the lights went out at about 8 PM. Under the jungle flora canopy it was like being deep inside a cave. That night I realized the value of carrying a small, key chain-style penlight. I now seldom leave my room at night when staying at remote lodges without a light. In addition, the small light is very useful for that midnight trip to the bathroom, especially if you are a bit queasy about stepping on little things moving across the dark floor. During one such trip in a Florida Key's cottage I did encounter a scorpion.

What type or size light should you select? There are probably no less that 50 styles and models from which to make your selection. In selecting a light for tropical diving, consider brightness, beam characteristics, size, weight, application, cost, and versatility.

A prudent diver will select a light which can be used year around for many diving or non-diving applications. A good dive light will cost $40 to $100 or more. Selecting an expensive light that may only be used three or four times per year is a bit frivolous. If a light is designed to withstand the crushing pressure of 2000 feet of sea water, it should withstand normal everyday use.

In selecting a travel light that is reasonably compact and lightweight, one will have to make some compromises. For example, I have two very bright underwater lights which are both acceptable for cave diving. One has a separate battery pack that is about 18 inches long and weighs approximately 10 pounds with charger. The other is a large hand-held diver's light that weighs approximately 5 pounds. Both of these lights are extremely bright. The larger one will illuminate a very extensive area of a reef as well as blind other divers and frighten marine life. Although nice to have, these lights are simply too large, heavy, and expensive for the average traveling diver.

On the other hand, small waterproof penlights or key chain lights provide only enough light to read instruments and illuminate very small areas of a underwater seascape. They make excellent backup or emergency lights for use underwater or on land, but, they are generally inadequate for illuminating a large enough area for comfortable and pleasurable night diving.

Improved reflectors, gas-filled bulbs (i.e., krypton and halogen), and more powerful, long-life batteries (i.e., nicad, gel-cell, alkaline, and lithium) have enabled manufacturers to produce compact underwater lights of relative high intensity. Several flashlight-size models weighing 10 to 16 ounces are available. The consumer should compare beam intensity, beam angle, beam quality (i. e., even illumination versus dark zones and hot spots), burn time, recharge time, and cost). A simple comparison chart can be formulated by the prudent shopper. The shopper must be reasonable and accept the fact that he/she can not expect the same performance from a five pound light and a 10-ounce light. However, one may be pleasantly surprised by the performance of modern compact dive lights.

What kind of power supply or battery is best for the traveling diver? The diver may select either a rechargeable or a disposable battery. Disposable battery lights have a lower initial cost, require limited maintenance, do not require the availability of electrical outlets for recharging, and have burn times of 3 to 10 hours. If the light is accidentally flooded with sea water, a good freshwater rinse and a new set of batteries/bulb is usually all that is needed to put it back in service, especially if attended to immediately.

Most compact dive lights use either AA or C batteries. Divers should always load lights with fresh batteries prior to a trip and take extras in accord with projected use; also, include spare bulbs. It is sometimes difficult, if not impossible, to find proper batteries or bulbs in tropical cities or at resorts. From a standpoint of weight, four alkaline C batteries weigh 9 ounces and four alkaline AA size batteries weigh 3 ounces. For the average diver making only a few dives per year, disposable alkaline batteries make a lot of sense.

Rechargeable nicad and gel-cell batteries generally have a burn time of about one to two hours with a recharge time of up to 15 hours. They are more expensive than alkaline, however they do pay for themselves if used with moderate frequency. They also require a periodic recharge maintenance program even when not in use. Improper maintenance or neglect can result in reduced life and, ultimately, destruction of the battery pack.

The final selection is dependent on personal requirements. I have selected a compact light with a high intensity bulb that I can used with either 4 C-cell alkaline disposable or nicad rechargeable batteries. I normally use disposable batteries and will only include rechargeable batteries and charger if I intend to use the light extensively and if I am assured of a proper power source/outlet for recharging. This light has a relatively narrow beam however I a found it to be very satisfactory for most tropical night dives. If I anticipate extensive night diving, I will often pack a spare light for my trip. I also use the light as a general flashlight on land year around. In addition, I generally carry a key chain light with a lithium battery for emergency use underwater and on land.

These lights are small enough to be carried in a BCD pocket, in a universal holder that can be secured to my forearm, leg, or strobe, or in a special belt pouch. I also attach a small lanyard and/or clip to the light in order to reduce the possibility of loss during entry/exit and for added convenience. Other holders and accessories are available.

In addition to the various factors discussed above, consider grip, buoyancy, corrosion-resistant construction, ease of O-ring examination, bulb availability/cost, accessories, and warranty. Depth could also be a factor, however, most manufacturers claim operation depths between 300 and 2000 feet, well beyond the range of ordinary scuba diving.

As with any item of diving equipment, the prudent diver will carefully compare diving lights and select a model that best fits his/her needs and pocketbook. Look for a light that can be used for other recreational and everyday activities. You can carry a good dive light in the glove compartment of your car or keep it in your night stand 365 days per year for use as an emergency light. You will generally invest more than $40 in a good light. By using reasonable care in handling the light and maintaining it in accord with the manufacturer's recommendations, it should provide you with years of satisfactory service. Be sure to include spare bulbs and batteries in your spare parts kit.

KNIVES

If one were to consider all of the dive knives that are available from diving equipment manufacturers plus those included in survivalist catalogs/stores, the scuba diver has well in excess of 100 models and designs from which to select. Often an individual will select a knife on a basis of aesthetics, status symbolism, or notoriety with little regard for utilitarian purpose. This often results in the selection of a knife that is large, heavy, equipped with special survivalist-combat features, and expensive. In other words, a "RAMBO" knife.

Many tropical divers do not even carry a knife. Is a knife really necessary for diving in clear water? I do not personally recall any entanglement emergency while recreational diving in clear, tropical waters. However, the possibility can not be disregarded and since carrying a knife is an accepted safety practice for scuba divers, I do include one in my kit.

The average tropical scuba diver needs a *compact, sharp knife* capable of cutting fish line and net in order to resolve an entanglement situation. Many northern divers carry large knives that are easier to handle with gloved hands. Large knives are cumbersome, heavy, increase resistance for underwater swimming, and often must be worn in less desirable locations on the body. Inexpensive models are often difficult to sharpen, do not retain an edge, and may prove to be ineffective as a cutting tool.

Traveling scuba divers are encouraged to consider the following when selecting a knife for routine diving:

* Do I have any special requirements other than safety and management of a potential entanglement situation? If so, would a special purpose tool better serve my needs for those specific and occasional tasks?

* If safety is the primary requirement, a compact, sharp knife is considered to be satisfactory by most divers. A blade length of about 3 to 4 inches is satisfactory.

* Is the knife constructed of a stainless steel alloy that is characterized for optimum sharpness and edge retention?

* Is the handle designed so that I can comfortably, securely, and safely handle the knife with a bare or gloved hand? Be certain to handle the knife with a gloved hand before final selection.

* Is the knife designed with a line cutter? This is one of the most important features of a diver's knife.

* Can I draw the knife with one hand? Either hand? A gloved hand? This is a function of both knife/sheath design and location worn.

* Is the knife-sheath system designed and constructed in a fashion that will prevent accidental loss of the knife in any position?

* Is the sheath designed and constructed so as to minimize the possibility of accidental injury to myself when wearing or drawing the knife?

* Could I comfortably carry this knife at various places on my body such as arm, lower leg, BCD, etc?

* Will the knife-sheath system interfere with swimming and underwater movement in any way? If so, consider another model.

Daggers, stilettos, and double-edged knives offer little or no advantages to the diver and may, in fact, have some disadvantages from a standpoint of routine cutting and handling safety. They are advantageous for fighting and killing if you are into that sort of thing.

A good knife also has many other recreational and everyday applications. Consider a model that would be acceptable for other recreational or work use. I selected a model that comes with both a leather (or nylon) belt sheath and a plastic underwater sheath. A universal design nylon belt sheath may be purchased for almost any model knife at many military specialty or surplus stores.

For additional information on selection, maintenance, and safety, consult "The Diver's Knife" [6], manufacturers' catalogs, and the instruction booklet included with your knife.

EQUIPMENT BAGS

What type of dive bag should you buy? Dive bags, in fact, all types of bags, have become fashionable in the 1980's. Scores of dive equipment and duffel bags of varying sizes, colors, and materials are available at prices ranging from $20 to over $100. Many have several inside or outside zipper pockets. Nearly all of these bags display diving *symbols* such as flags or manufacturer's names/logos.

The dive equipment carrying bag must be sturdy, large enough for all of your diving equipment *plus* items that you might acquire during your travels and *discrete*. Keep in mind that logos and diver status symbols *advertise* the contents of your bag and used diving equipment *sells easy* in most tropical dive resort areas, especially in developing countries. If your well-marked bag does smake it onto the plane in your home town, the possibility of it making the transfer in a certain southern departure city is rated at only fair; and if you have to transfer planes in a certain major Caribbean airport, you should consider filling out the insurance forms before you leave home.

Your dive bag really doesn't have to be a *bag* at all. Sturdy, lightweight suit cases can be excellent shipping containers for diving equipment. You can use either hard-sided or soft-sided luggage. A visit to a local "secondhand" shop may turn up an excellent dive equipment shipping container for $3 to $10. Check with friends and relatives; thousands of excellent pieces of luggage can be found rotting in attics and garages!

Persons traveling to Central America and other politically sensitive areas should avoid carrying diving equipment in any type of military-style duffel bags or containers. Avoid olive-drab color and, especially, camouflage pattern materials. Some divers have found that metal ammunition boxes make excellent protective containers for cameras, regulators, and other fragile items. Definitely *do not use* such containers for travel to sensitive areas, regardless of color.

I always use a *net bag* for carrying my dive equipment to the boat and stowing equipment at a resort or on a boat. I never carry my dive equipment to the boat in my duffel bag. Most bags get wet and very smelly in the tropics. The net bag is marvelous!

I pack my depth gauge/timer, dive computer, and prescription mask in my carry-on bag. This reduces the possibility of loss or damage in transit.

I also pack my running shoes, extra clothing, snacks, drink mix, water bottle, suntan lotion, and other items in my dive bag. By also carrying clothing in my carry-on bag, I can often eliminate a separate (third) suit case.

SPARE PARTS/TOOL KIT

Most dive resorts now have excellent dive shops stocked with all of those extras such as fin and mask straps, neoprene cement, dust caps, and the like. However, I still carry a small tool/spare parts kit. I include the following:

First stage port plug (to use in the event that one component fails and must be removed)

Allen wrench for inserting port plugs

Small adjustable wrench for tightening regulator hoses

Extra CO_2 cartridge (if your BCD is so equipped)

Small container of neoprene cement

Spare bulbs for underwater light and extra batteries for non-rechargeable models

Extra fin and mask strap

I generally leave the extra mask, knives, assorted straps, screwdrivers, wrench sets, regulators, snorkels and the like at home. Persons with serious vision problems may wish to carry a spare mask. Naturally, additional spares will be require when diving in very remote and undeveloped areas. Consult you tour director, resort representative, or marine laboratory diving officer regarding the availability of diving supplies.

WEIGHT CONSIDERATIONS

Weight may or may not be a consideration. Most major air lines that service the Caribbean now have a check-through luggage limit of two pieces, not to exceed a given size, although the weight allowance may be as high as 70 pounds each. *However, always check your airline ticket for exact allowances and be especially careful if your travel involves a small airline!* Have your travel agent provide you with "printed" information regarding the luggage allowances for all segments of your trip. A major airline might observe the two-piece rule whereas a smaller carrier that flies to more remote locations will observe the 44 pound total for overseas travel. The charges for additional weight can be significant; one time I paid $50 overweight charges to get diving and camera equipment to Belize.

How much does your diving equipment weigh? In order to develop a better understanding of my dive travel requirements, I weighed each item in my dive kit. The following weights (in pounds) are approximate and the weight of your equipment may vary with different makes and sizes:

Snorkel	.25
Compact BCD with AIR II	2.25
Knife	.35
Weight belt (no weights)	.60
Mask	.75
Dive computer	1.75
Fins	3.50
Regulator with console	5.50
Net bag	.65
1/8-inch foamed-neoprene suit	3.75
Boots	1.00
Compact underwater lights	1.20
Parts and spares kit	2.30
Gloves	.20
Equipment bag or suit case	3.00
TOTAL	25.05 pounds

Keep in mind that some items were selected for their specific lightweight/compact characteristics and that standard equipment could weigh somewhat more. I generally carry my mask, dive computer, and depth gauge in my carry-on bag (2.75 pounds). In the event that I am on flights limited to 44 pounds, this leaves an allowance of 21.7 pounds for clothing and other personal items in checked luggage. You might be inclined to pay the extra few bucks! True, don't be so conservative that you reduce the quality of your vacation. However, I do watch the weight since I generally have to carry my luggage for long distances in airports and at some resorts. Even if you have a $10 tip in your pocket, you may not find a skycap. I also travel with a compact but very sturdy folding luggage cart which has saved my back many times.

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ACKNOWLEDGMENTS

This publication is the result of work sponsored by the Michigan Sea Grant College Program with grants form the National Sea Grant College Program, National Oceanic and Atmospheric Administration,US Department of Commerce, and funds from the State of Michigan.

Manuscript revised: 4 November 1989
19 November 1989
14 January 1990
20 June 1990

NOTES:

CHAPTER 8-2

HEALTH CONSIDERATIONS FOR THE TROPICAL TRAVELER AND DIVER

INTRODUCTION

Knowledgeable divers traveling to tropical regions can take "common sense" precautions against disease and injury if they are aware of prevalent diseases and specific environmental hazards in the areas to which they intend to travel, and take into account their own personal physical condition and limitations. With the advent of modern transportation, professional guides services, and growing interest dive adventure travel experiences, exploration of exotic geographic regions is well within the attainment of divers of all ages. By using reasonable personal safety precautions and accepting the leadership of the professional guides, risk of injury and illness is minimal.

Naturally, adventure experiences such as scuba diving require special skill training, prior to or as part of the experience, and special attention to physical condition. Dive travel counselors can provide valuable assistance in selecting experiences consistent with individual skill and physical condition.

Much of the information on disease, immunizations, and traveler's medical problems was obtained from a course study guide and lecture notes supplied by Dr. Davis for his program, *The Medicine of Sport Scuba Diving*, conducted in Bonaire, Netherlands Antilles, February 5-12, 1983.

TRAVEL PREPARATION

Assessment of Personal Health

Resort diving has become somewhat common and non-stressful. Most divers traveling to tropical resorts in the Caribbean and Bahamas pay little or no attention to their medical status prior to departure. However, if you have not been physically active or have not participated in scuba diving for several years, start your adventure travel and diving preparations with a complete examination by your family physician, especially if you are over the age of 40. Be certain to explain the nature of your anticipated dive adventure experience to your physician. Although the practice of requiring medical examinations for dive travel is not common, increasing emphasis on legal liability problems has caused some organizations may require a certificate of health signed by your physician. This is especially true if you are traveling to remote areas or diving under very rigorous environmental conditions.

It is also a good idea to have your dentist check your teeth and complete any dental work several weeks prior to your departure. During a two-week trip, even a minor toothache can be very annoying if the nearest dentist is several hundred miles away.

The prudent traveler with pre-existing medical problems will carry a medical history summary, EKG report (if indicated), and sufficient prescription medications for the duration of the trip. It is a good idea to always include health information and required medications in your carry-on luggage. If you have special dietary or medication requirements consult with your travel adviser/organization well in advance of departure.

Ask your physician if there are any special precautions that he or she would advise in your case for dealing with such conditions as oppressive heat, vigorous physical activity, or unusual diet. Ask your physician if there are any additional medications that that he/she might prescribe for common or special problems (such as colds, minor infections, constipation, diarrhea, etc.) which you might experience during your more exotic travels. If you must or choose to include narcotic drugs in your travel kit, request your physician to prepare a brief statement outlining your need or justification for such medications and carry these drugs in a container bearing the pharmacy label to eliminate some potentially serious problems with customs officials both at home and abroad.

Glasses and Contact Lens

A large percentage of today's adult population wears glasses or contact lens. Even if you don't need prescription lens, you will have to carefully select high quality sunglasses for your adventure travel, especially tropical and sea adventures. Eye fatigue and injury from sun glare can be very painful if not temporarily disabling. Inexpensive and even some very expensive "fashion" sunglasses are completely inadequate for protection from tropical sun. Be certain that the lens filter out most, if not all, of the ultraviolet and infrared radiation.

The convenience and popularity of contact lens has revolutionized vision care in recent years, especially with the advent of extended wear contacts. However, keep in mind that routine contact lens care may be much more difficult for the adventure traveler/diver, especially if special sterile solutions and electric equipment is required. Naturally, the amount and type of care will depend on the individual and the lens. The sensitive individual should keep in mind that intense tropical sun glare from water and white sand beaches can cause unusual eye irritation if you remove your sunglasses even for a short period of time. More than one person has experienced the "gritty" feeling of sunburn before they realized what was happening to their eyes. This could be an very serious problem for a person with contact lens.

Discuss your travel and environmental conditions with your optometrist at least two months prior to your trip. Some optometrists recommend that contact lens wearers include a good pair of prescription sunglasses for special environmental conditions and travel to remote areas. Since the replacement of contact lens or glasses (prescription or nonprescription) may be difficult, if not impossible, take spares!

Personal First Aid Training

Whether you spend your holiday diving at Bonaire, climbing Kilimanjaro, or basking in the sun beside your backyard pool, you should be trained in basic first aid and cardiopulmonary resuscitation. Even if you never have to use this training during your adventure travel experience, you may later save the life of a loved one in a household or backyard accident. Everyone must be prepared to deal with an emergency any place, any time!

In adventure/dive travel, guides and sponsoring organizations will take special precautions to prevent injury to clients. In the event of injury, the guides generally have specialized training in advanced first aid, rescue, and evacuation. However, the serious and prudent adventurer who frequently travels to exotic and remote areas is advised to acquire advanced and/or wilderness first aid training and should possibly consider some level of emergency medical/paramedical training.

Immunizations

At the present time, vaccinations are not required for direct travel from the United States to most countries, with the exception of some locations in Africa, Asia, and South America (French Guiana.) However, many countries require specific vaccinations for "stopover" travelers arriving for endemic areas. No vaccinations are required for travelers returning to the United States. *All travelers are advised to request specific information regarding diseases and immunizations from their physician, the U.S. Department of Health and Human Services, or the governmental office issuing the visa, and especially when traveling to African and Asian countries.*

Smallpox vaccinations are no longer required (World Health Assembly, May 1980) and **cholera** vaccination is required by only a few countries. **Yellow fever** vaccination is recommended for travel to infected areas, generally African and Central/South American countries. Many countries require yellow fever vaccination certificate for passing through (or staying more than two weeks) when coming from infected areas. Countries have the right to place travelers without proof of vaccination under two weeks' surveillance.

DISEASE AND INJURY

General

With a limited knowledge of diseases and common sense precautions, the adventure traveler can enjoy a pleasant, healthy experience. However, in the event that you do become unexplainably ill during your travel, consult your guides or the resort management (or vessel captain) immediately. Generally, they will be able to refer you to an English speaking physician. In remote areas, the guide may be able to acquire medical consultations by radio and, if necessary, arrange for air evacuation.

In the event of serious illness or injury, you may wish to consider air evacuation to the United States. Local hospitals and physicians can often assist in such arrangements. Keep in mind that medical care standards in some countries are considerably below those in the United States.

Also, illness or accidents while traveling in foreign countries can be expensive. When paying for medical treatment personal checks or credit cards may be rejected by foreign hospitals. Many physicians require payments in cash and hospitals commonly ask for cash deposits. And if you can't pay your bill, hospitals may withhold your passport until you can pay. Also, keep in mind that medical flight services can be very expensive and that advanced payment is often required.

Some health insurance policies do not cover foreign hospitalization or medical flight services. Most insurance companies that do pay these costs will require an itemized statement printed in English. Such statements may only be available by special request. It might be wise to discuss your coverage and any special considerations for foreign health care with your insurance agent.

Because of modern air travel and disease incubation time, a traveler may return home well before detectable signs and symptoms appear. In the event that you become unexplainably ill following a trip, be certain to inform your physician of your recent travel history.

Non-Quarantinable Diseases

Sleeping sickness is of limited risk to the U.S. traveler. Insect carriers are found in tropical Africa and Central America. Use of insect repellent and long clothing is wise.

Dengue fever is endemic to most tropical areas including Asia, the South Pacific, Central/South America, and the Caribbean. The disease was epidemic in Cuba (June 1981) with 61,000 cases in Havana including 31 deaths. There is no licensed vaccine. Use mosquito repellent and long clothing.

Malaria is also endemic to many tropical areas. In 1975, 430 Americans returned to the U.S. with malaria and 12 died. Caribbean countries of high risk include Honduras, Roatan, Haiti, Dominican Republic, and Trinidad. No malaria is reported on other Caribbean Islands. All travelers to malaria areas should have a prophylactic drug regardless of how short the visit. Chloroquine phosphate (500 mg.) once a week starting one week prior to arrival and continuing for six weeks after leaving the area is considered effective for most parts of the world. A few countries have Chlorquine-resistant strains of Falciparum Malaria (certain areas of Asia, South America, Panama, and New Guinea.) Consult your physician and/or public health authorities for information. Malaria is carried by the Anopheles mosquito.

Rabies risk is high in most tropical areas. The high frequency of stray dogs and cats in most underdeveloped tropical countries warrants special precautions such as carrying a stick while jogging. Areas reported to be rabies free include Aruba, Bonaire, Curacao, Bahamas, Barbados, Guadeloupe, Jamaica, Martinique, Virgin Islands, American Samoa, Australia, Figi, and Guam.

Typhoid fever vaccination is not recommended for travel to good hotels and cities. However, if traveling in rural areas and small towns of Asia, Africa, and Central/South America where poor food and water sanitation might be encountered, vaccination is recommended.

Viral hepatitis (type A) is no longer considered to be any greater risk for travelers abroad than in U.S. when travel is through urban areas or resorts using good hotels and simple precautions. No immunaglobin is recommended unless travel is off the beaten path in underdeveloped countries.

Giardiasis occurs world-wide and is prevalent in tropical countries in stool of man and, possibly, animals. It is a very common cause of severe diarrhea, increased gas, loss of appetite, abdominal cramps and bloating in travelers in the tropics. It is a major health problem in developing countries and some authorities suggest that 10-15% of individuals who camp in the Rocky Mountains contract giardiasis. The most common source is contaminated water. Disease symptoms may occur within a few days to a few weeks after exposure. Travelers must take precaution to insure uncontaminated water source or boil/treat water.

Shigellosis (bacillary dysentery) characterized by fever, nausea, vomiting, cramps and, in severe cases, bloody mucus stools, is endemic to tropical areas through fecal contamination of food or water. In Mexico, salsa or hot sauces is an excellent culture medium and should be avoided.

Travelers Diarrhea

Diarrhea is the most common affliction of the American traveler. Generally, the local populace is immune to the micro- organisms that cause diarrhea in visitors. Drinking water contamination is probably the most common source of diarrhea causing organisms. If possible, determine if the tap water is safe to drink. Resort operators will sometimes post signs and provide special bottled water if the local tap water is unsafe.

However, if you are unsure, do not drink the water unless you treat or boil it. Water may be treated with two to four drops of household bleach or 0.5 ml. tincture of iodine per liter. Let stand for 20 minutes before drinking. Water treatment tablets are available at drug and camping supply stores. However, be certain to check expiration date and do not use tablets from containers that have been opened for a long time. An ounce size dropper bottle of bleach is inexpensive and will treat a considerable amount of water. Fruit juice mix can be used to mask the chlorine taste.

Some travelers prefer to carry a small hot plate or electric coffee pot (with electrical adapters) for boiling water. Several "filter-type" water purifiers are available; however, be certain that they will remove such microorganisms as *Escherichia coli* and *Giardia lamblia*. Many inexpensive units will not! NOTE: Chemical disinfectants such as iodine or chlorine are not considered as reliable as heat in killing *Giardia*.

Remember that contaminated water can be encountered in many ways. Ice from contaminated water is also contaminated. The exterior of cans and bottles cooled in contaminated water and ice will also be contaminated. Rinsing a toothbrush with contaminated tap water is an excellent source of microorganisms. Water from a tap that is too hot to comfortably touch is considered safe.

Bottled carbonated beverages and alcoholic beverages are safe but avoid uncarbonated bottled beverages. Foods recently cooked and served hot or chilled are usually safe. Perishable or cooked foods that have been left at room temperature for serving may be unsafe. Raw fruits that you peel yourself are usually safe; however, raw, leafy vegetables are often not.

Three high risk foods are rare meats, fish, and raw shellfish. Avoid rare beef in developing areas of the world. trichinella, salmonella, and beef and pork tapeworm are the risk. Raw or undercooked freshwater fish can transmit liver flukes and fish tapeworm. Creamy deserts and rich sauces left unrefrigerated can be culture media for undesirable organisms. Mexican salsa should be avoided.

How can you tell if a restaurant is a safe place to eat? There is no sure method; however, for food safety, go to the rest-room. If you find a toilet with no or poor hand-washing facilities, (lacking soap, running water or disposable towels) expect trouble! If the public rest-room is poor, you can be assured that the one the food handlers use is far worse. Food handlers who lack proper facilities are likely to contaminate food with feces from their hands. General cleanliness and common sense are your best guide. Some of the cleanest and safest restaurants in the world are outside the U.S. If you don't believe this, check the rest-room in a southern truck-stop sometime. Don't become so compulsive that you miss the world's great culinary delights in fear of a bout of diarrhea.

Some traveler and physicians prescribe prophylactic use of antibiotics as a protection against enterotoxigenic *Escherichia coli* (a major cause of traveler's diarrhea) while other authorities highly discourage drug prophylaxis. Destruction of normal intestinal flora by some antibiotics may be undesirable. And, the use of drugs may develop a false sense of security.

Lomotil and other antimotility drugs are commonly acquired from physicians and widely used by travelers who contract diarrheal diseases. On the other hand, the use of such drugs to treat (stop) diarrhea is discouraged by many authorities. Intestinal motility is a normal process. Diarrhea is an exaggerated form of the cleansing process to rid the gastrointestinal tract of offending microorganisms and their toxins. Pepto-Bismol in large doses has been shown to be beneficial in one study; Kaopectate showed no difference between placebo and drug. Large doses of Pepto-Bismol (240 ml. per day) for prevention are inconvenient.

Oral fluid replacement is now recognized as one of the most important factors in treating diarrheal diseases. The principle losses in diarrhea are water, potassium, bicarbonate, sodium, and chloride In serious cases I.V. replacement is required. However, in most cases encountered by otherwise healthy travelers, the vital substances can be absorbed from the GI tract if provided in a solution containing glucose. The following is a *home formula* for oral glucose electrolyte treatment of acute diarrhea (prepared in two separate glasses):

1. 8 oz. orange, apple or other juice rich in potassium, 1/2 teaspoon honey or corn syrup, and a pinch of table salt

2. 8 oz. carbonated or boiled water with 1/4 teaspoon baking soda (sodium bicarbonate)

Trauma

One of the greatest risks to the traveler is injury sustained in motor vehicle accidents. Motor bikes are rented on many islands and often these vehicles are in poor repair. Furthermore, many travelers are inexperienced with motor bikes. These factors combined with poor road conditions, unfamiliar hazards, unfamiliar driving laws and customs can all lead to serious accidents. Although statistics are unavailable, I suspect that more Caribbean scuba divers are seriously injured in motor bike and vehicle accidents on island roads each year than are injured by hazardous marine life in 10 to 20 years. Keep in mind that emergency medical and surgical care is not available on many islands where dive resorts are located.

INSECTS

Insects can provide the tropical traveler with one of their greatest survival challenges. Of the thousands of insect species, mosquitoes and gnats almost constantly plague the traveler in some areas. The insects are common to moist habitats. Several serious diseases are transmitted by mosquitoes.

All tropical travelers are encouraged to consult with a physician to determine if their travels will take them to into malaria risk areas and, if so, begin an antimalaria medication program. The entire Indo-Pacific and some parts of Central America (including the western Caribbean) should be regarded as malaria areas. To consider malaria as a disease of the past which is no longer a problem is dangerous and incorrect. Ignorance, apathy, and presence of resistant strains makes malaria a common, serious, and potentially fatal disease that affect an estimated 150 million people each year.

No-see-ums (punkies or sand flies) are minute, almost microscopic gnats of the family Ceratopogonidae. The are so small (0.02 to 0.2 inches) that you may not even know that you are being bit. The females of some species are bloodsuckers. There bites cause itching and welts; secondary infections can result from scratching. Persistent, nonbiting species can be just as annoying by crawling into eyes, ears, and nose.

In areas infested with mosquitoes and gants, the traveler may wish to wear long pants and a long sleeve shirt. This is still not considered to be a complete protection, and potent insect repellent should also be included in your travel kit. The most effective repellents apparently are those that contain more than 90% *deet* (N, N-diethyl-meta- toluamide) as the active ingredient. However, some authorities indicate that high deet-containing insect repellents may be hazardous to health, especially if used excessively or improperly. Be certain to read instructions and precautions. Avoid direct inhalation of aerosol sprays.

An alternative insect repellent that is gaining considerable popularity is a 50/50 solution of Avon Skin-So-Soft bath oil and water. This solution appears to effectively deter no-see-ums, mosquitoes, and black flies. It has a pleasant smell and costs less than commercial insect repellents.

Insects can bite through loosely woven fabrics. These fabrics may be impregnated with insect repellent. Keep in mind that some fabrics may be discolored or damaged by chemical substances. Applying repellent to socks and lower legs will provide added protection when wearing long pants.

For sleeping, some people will include a large panel of mosquito net in their travel kit. Select a net that is large enough to suspended over a double bed and be tucked under the edge of the mattress without touching any part of your body. The net should be fine enough to keep out no-see-ums while allowing air to pass freely. Inexpensive nets are often too coarse. String ties may be fixed to the net so that it can be suspended from a rope.

Avoid scratching insect bites since this can lead to secondary infection. Rubbing alcohol, calamine lotion, hydrocortisone cream, and other commercial preparations may be of some aid in relieving the itch.

OTHER PERSONAL HEALTH PROBLEMS

Sunburn

Sun protection is extremely important in the tropics. Many northerners go to the tropics each year to seek golden brown sun tans, and many of these tropical travels send uncomfortable hours suffering from sunburn. The risks of sun exposure and subsequent skin cancer has made the headlines in past years. Each individual must understand they be accepting considerable risk during excessive exposure to sun.

Sunburn has ruined many diving holidays. Snorkelers must take special precaution to protect their back and legs during hours of surface swimming. Severe and potentially disabling sunburn can occur in a few hours. Divers are encouraged to wear full length protective garments. Although some sun than lotions are apparently not washed off during swimming, the user is cautioned to check their condition frequently and reapply lotion as necessary.

During travel to and from dive sites divers are encourage to wear protective garments, hats, and sunglasses. Liberal use of lotions with a high protection factor through out the day is also encouraged.

Menstrual Problems

About 80% of women who travel or work in the tropics have problems with their periods. Some women will miss periods for up to six months when they first arrive in the tropics [3]. Keep in mind that your period may be erratic and more severe than at home, especially when you first arrive. If possible, take enough tampons to last the entire journey and take special precaution to prevent contamination of the tampon. Some physicians advise the use of brands fitted with applicators in order to reduce the risk of infections caused by contamination inducted during handling and insertion. Washing hands with soap and water before inserting the tampon will also reduce risk.

Under more primitive living conditions some women have been known lose their tampons to rats, apparently for use as nest lining. Also, customs officials have been known to rip open packages believing that they are a good hiding place for drugs.

Vaginal Infections

Several women have indicated that they experienced increased susceptibility to yeast and other types of vaginal infections when traveling and living in the tropics. If you are susceptible to these problems or have questions, consult your personal physician before your travels. Also, there is no substitute for sound personal hygiene practices.

Venereal Disease

Tropical travelers will often encounters opportunities for sexual involvement. Keep in mind that venereal disease is nearly epidemic throughout the world. Unfortunately, prostitution (both male and female) is high in some tropical countries. I recall on situation in which a few days after leaving one tropical port 70 of 118 men on a research vessel were diagnosed with venereal disease. Now, the threat of AIDS makes sexual encounter a high risk activity in anybody's book. A recent report indicated that six percent of the total population of one Caribbean country is infected with AIDS. For the tropical traveler *abstention* is absolutely the only reasonable and prudent alternative!

PERSONAL MEDICAL KIT

On organized adventure/dive travel expeditions and at most dive resorts, the guides/managers will generally have a reasonably well-stocked medical or first aid kit. However, at some Caribbean diving resorts and in some countries it is difficult, if not impossible, to obtain such common items as band-aids and aspirin.

It is always advisable to take a personal medical kit which contains your individual medications and a reasonable supply of emergency items. Limit your personal kit to the essentials. Keep the following in mind when assembling the kit: 1) don't take too much; 2) use caution in selecting and carrying narcotics because you may have trouble with custom officials; 3) carry medicines in unbreakable containers; 4) include specific written instructions for prescription medications including dosage and contraindications; and 5) don't "play doctor" for yourself or others when symptoms indicate that professional medical treatment is needed.

Keep in mind that cuts, abrasions, muscle aches, diarrhea and sunburns are probably the most common ailments associated with adventure travel. Band-aids and aspirin are generally among the most used items. A list of first aid and medical items was developed based on my personal experiences and discussions with physicians knowledgeable in scuba diving and the recommendations of various authors. It contains items *to be considered* and you certainly do not have to include all of them in your kit. This list may be found at the end of this text.

The exact composition and medication quantity of your personal medical kit will depend on geographic location, pre- existing medical problems, environmental conditions, activities, travel organization, your physician's advice, etc. Some of the items listed may be used interchangeably.

Please keep in mind that any prescription medications must be used with special care and only with the advice of your personal physician. Ask your physician for specific instructions, dosage, and contraindications. Some physicians may discourage the use of specific medications or recommend more appropriate substitutes to meet your personal needs. Respect their opinion! However, be certain that your physician understands that you will be traveling in a relatively remote area where routine medical services and medications may be some distance (and time) away. For example, if you are subject to occasional urinary tract infection, it may be desirable for you to include an appropriate medication in your personal kit. Do not attempt to "treat" other persons with or share prescription medications without specific advice of a physician. ***DO NOT CONTINUE TO SCUBA DIVE IF YOU MUST TAKE NARCOTIC-TYPE DRUGS TO TREAT SPECIFIC INJURIES/DISORDERS!***

Is all of this really necessary? Hopefully, you will never have to open your medical kit during your adventure/dive travel experience. Probably, the only thing you will really need is insect repellent and suntan lotion. However, there are times when you might sell your soul for the decongestant nasal spray that you left at home so you can equalize pressure. After a few trips and assorted minor injuries or illnesses, you will no doubt find yourself carrying a more and more complete personal medical kit. It took a motor bike accident on San Salvador to convince me.

Your medical kit should be carefully packaged in a compact, organized fashion. Several mountaineering supply firms and many outdoor equipment stores sell specially designed pouches and compartmented travel kits for toilet articles. Heavy-duty zip- lock plastic bags are excellent for protection and organization. A large plastic bag or other waterproof container to protect your kit in hot, humid climates or while rafting is advisable. Infrequently used and moisture sensitive items may be heat-sealed in a plastic Seal-a-Meal pouch for added protection. For traveling in extremely humid areas I also take the time to heat seal medications in unit dose packets.

DRINKING AND DIVING

Liberal consumption of alcoholic beverages seems to be one of the traveling divers favorite past times. Some divers hardly have their scuba off before they have a bottle of beer in their hand. Many divers spend approximately two hours underwater each day and ten hours drinking at the bar or on the beach. I have read dive boat tour advertisements that state, *"complimentary beer and wine on tap."* I have listened to a noted dive tour organizer talk about successful efforts to arrange Caribbean diving holidays which includes all transportation, three dives daily, room, tips, taxes, transfers, parties, T-shirt, and all meals and beverages (which specifically includes an open bar policy) [4].

Of even greater concern is the serious promotion of the party atmosphere and the often less than serious promotion of the safe diving aspects of dive travel. Many divers have told me that they drink far more on diving vacations than they do at home. A diver who was making about four dives per day and experienced a mild case of bends was considered as a mild drinker when he consumed only 5 to 6 beers in the evening and went diving at 6 AM. At many, if not most, dive resort restaurants one must specifically request water; far too often the divers will order beer or a rum drink with the noon meal.

It is not my responsibility or purpose to attempt to eliminate consumption of alcoholic beverages or, as some would say, the fun, from diving holidays. I enjoy a drink, in fact several of them, just as much as the next person. However, there is a time and a place for everything. **The diver who chooses to accept the adverse consequences of mixing alcohol and diving is assuming a significant risk!**

Physiological and Psychological Aspects of Alcohol Consumption

The late Dr. Charlie Brown classified alcohol as "the grand champ of the downers" [2]. What happens to the body and mind when one consumes alcohol? Alcohol is a depressant drug which slows the activity of the brain and central nervous system. Any drinking causes some temporary effects on the body. Sustained and heavy drinking can result in serious problems.

Alcohol enters the bloodstream through the stomach wall and the small intestine, and requires no digestion. A low level of alcohol, such as sipping one drink, has a mild tranquilizing effect on most people. It may act as a temporary stimulant when one is first starting to drink. This results in increased heart rate and skin temperature. After a drink or two, as the alcohol numbs the brain and central nervous system cells, loss of muscle control, slurring of speech, and poor coordination result. Impaired judgment and loss of inhibition, along with exaggerated feelings of anger, fear, and anxiety also occur.

Pre-dive Drinking

The physiological and emotional adversities associated with consumption of alcohol immediately before and between dives are obvious. A couple of quick beers between dives can contribute significantly to increasing the diver's cooling rate, reducing muscle control and coordination, impairing the diver's ability to make proper judgments, promoting "risk taking" and triggering fear/anxiety responses (or panic).

Consuming a tropical punch containing 4 to 5 ounces of rum before a dive can place the diver in a state of being legally drunk underwater (.1% blood alcohol). Would a diver ever drink this much before a dive? In some cases, yes! Most people associate the "quenching of thirst" with the consumption of beverages. If a good rum punch is available, few divers stop at one! Studies of automobile accidents suggest that this level of blood alcohol increases the likelihood of an accident 7 times; a blood alcohol content of .15% increases the rate 23 times [2]. Furthermore, pre-dive consumption of alcohol causes skin vasodilation (blood vessel expansion) and increases the nitrogen uptake in subcutaneous (under skin) fat.

Post-dive Drinking

The post-dive drink favors rapid release of this nitrogen into general circulation, which, in turn, favors the development of decompression sickness. Alcohol also reduces surface tension thus favoring conditions for bubble formation and growth. Finally, it increases blood plasma fat, which favors fat emboli and blood clotting, both important in the pathogenesis (development) of decompression sickness [2]. These factors all theoretically support the premise that alcohol may increase the risk of decompression sickness, although, further research will be required to determine relationships.

Exercise followed by consumption of alcohol can be particularly dangerous, since this combination can cause significant decrease in blood-glucose levels. Low blood glucose leads to general physical weakness and mental confusion as well as interfering with body temperature maintenance [1].

Dehydration

Alcohol is a relatively potent diuretic and tends to increase the flow of urine. It suppresses the release of a hormone that normally retains body fluids. As a result your body loses important fluids and you become dehydrated. The problem of dehydration and fluid loss is further complicated by the fact that our bodies often do not adjust to the tropical climate until several days after arrival. Under normal conditions, our thirst mechanism warns us when we need liqui, but for some reason, this mechanism often does not work during the first few days following arrival in the tropics. Even though perspiring increases we do not tend to drink sufficient and proper fluids required to replace those lost and thus acclimate to the tropics. Prudent divers (travelers) will *force* themselves to drink enough water and fruit juices to maintain a urine output of at least two pints of reasonably clear urine per day. As stated in one British guidebook, "A few dark-colored drops and a puff of steam are not enough" [3].

Diuresis is also triggered by the consumption of beverages such as tea, coffee, and carbonated drinks that contain caffeine. Most people drink large quantities of coffee in the morning after consuming large quantities of alcohol the night before. This only complicates the situation physiologically. Additionally, chilling (losing heat to the surrounding water), negative pressure breathing, and submergence itself all tend to increase diuresis. It is a well established medical fact that dehydration results in blood thickening and reduced circulatory efficiency. Reduced circulatory efficiency may in turn modify the normal nitrogen absorption/elimination functions and contribute to the formation of extravascular bubbles, i.e., decompression sickness.

Dehydration may be the most significant single physiological factor that leads to degradation of diver performance and increased susceptibility to decompression sickness in tropical diving! So, when you wake up in the morning the next time you are at a dive resort, remember *"If you can't spit, don't dive!"*

Assumption of Risk

All evidence suggests that drinking and diving are not compatible activities. Alcohol is frequently associated with drownings. An analysis of drownings in the United states and Australia indicates that about 50% of the adult victims have elevated blood alcohol levels [1]. Unfortunately, similar blood studies are not available for those persons who experienced fatal diving accidents. The individual who does drink before and after diving is probably at a *significantly higher risk* of accident and/or decompression sickness than those who abstain. Can you drink and dive in moderation? How much can you safely drink in a diving situation? How long should you abstain from drinking before diving? Will a beer between dives really do any harm?

I can't answer these questions! There are simply too many variables. Keep in mind that physiologically you are not always the same person. A level of consumption normally tolerated can produce serious and adverse consequences if you are dehydrated, fatigued, or otherwise physiologically compromised. All of these factors can easily be associated with tropical vacation diving. Some authorities suggest that an individual refrain from drinking alcoholic beverages for at least 6 to 12 hours prior to diving, while others suggest that abstention for 36 to 48 hours is more desirable.

All divers and dive resort operators should re-evaluate their position on alcohol and diving. In my opinion, promotion of alcohol consumption through parties and games in a diving environment is a questionable practice. The advisability of an open bar policy on dive boats and at dive resorts is also subject to serious reconsideration. The practice of serving complimentary alcoholic beverages between and following dives is questionable.

Ultimately, as an adult each diver is responsible for his or her personal health and safety. The boat and resort operators are only responding to client and social pressures. Our society is a drinking society, and there is big money in satisfying the customer. But availability of alcoholic beverages does not mean that the diver has to drink. It is all a matter of *risk/benefit*. If you are going to drink and dive you must be willing to *accept the risk and the consequences*. Did you pay $100 to $200 per day for a vacation to drink *OR* dive? Both! If that is what you wish, then so be it. However, sue yourself, not a dive boat or resort operator or your instructor if you find yourself confined to a wheelchair.

I know that divers will continue to drink. If a dive resort did not serve alcoholic beverages or a dive boat operator prohibited the possession/use of alcohol, it would probably be out of business within a few months. Just keep it all in proper perspective. As far as the dive operators are concerned, I suggest that making water and fruit juice readily and attractively available would be a significant contribution to diving safety that could pay long-term dividends from both a legal and moral standpoint.

DEALING WITH JET LAG

It would be remiss to not mention "jet lag" in a discussion of traveler's health problems. Some people respond differently than others, however, nearly everyone suffers some adverse consequence of major daily schedule time changes. While you are traveling, you can reduce the effects of jet lag by eating lightly on the plane, avoiding alcoholic and sweetened beverages, wearing loose-fitting clothing, and walking around the aircraft occasionally. I often use a sleep aid and sleep during much of the journey. Some travelers find that a three hour or more "nap" upon arrival will lessen the effects of significant schedule changes. I personally attempt to move into the new schedule immediately and go to bed at the appropriate time, local time.

PUTTING IT ALL TOGETHER

You would be surprised at the number of adventure/dive travelers that plan everything down to the last detail, except what is best for their own physical well-being. Health and safety is an acquired attitude. You can enjoy *high adventure* in remote, exotic areas without unnecessary personal risk. Planning, common sense, good judgment, proper equipment, education, and leadership allows you to unlock the door to high adventure dive travel. You learn through your own experience and the experience of others. Go for it!

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PERSONAL MEDICAL AND FIRST AID SUPPLIES FOR TROPICAL TRAVELERS AND DIVERS

Antibacterial-antiseptic germicide skin and wound cleanser (surgical scrubs and povidone-iodine solutions are non-prescription products available in bulk liquid form; some products are available in individual swab sticks or prep pads sealed pockets; 70% isopropyl alcohol is useful as a "cold" sterilization solution and may be used on skin or wound, however, it can cause discomfort in an open wound.)

Topical antibacterial ointment (an ointment consisting of bacitracin-neomycin-polymyxin is helpful in reducing the possibility of infection in minor burns, cuts, and abrasions; appears to also relieve irritation resulting from coelenterate stings.)

Topical anesthetic-antiseptic lotions, cream, or spray for sunburn (temporary relief from sunburn discomfort, insect bites, and itching; trade names such as solarcaine contain benzocaine; a Johnson and Johnson product called Clinicaine also contains Lidocaine Hydochloride, 2.1% and is recommended for immediate applications to coelenterate stings and is carried in your dive bag for immediate availability).

Petroleum jelly (excellent for chapped lips and skin; many uses).

Vinegar (8 ounce bottle for dive bag to immediately apply to coelenterate stings; substitute for Lidocaine Hydrochloride solution).

Steroid cream (1/2% Hydrocortisone cream is useful for relief from skin irritation, itching, and rashes due to insect bites, contact with poisonous plants, heat, and coelenterate stings).

Band-aids and adhesive pads (assorted sizes).

Sterile gauze pads (4 x 4 inch).

Adhesive tape (2 inch athletic type; for taping sprains and securing dressings).

Elastic bandage (3 inches x 6 feet; for wrapping sprained ankles and knees; general purpose nonsterile bandage).

Laxative (constipation often develops as a result of change in diet and routine; many prefer a tablet or liquid laxative that works in six to 10 hours; laxative suppositories are excellent for prompt relief).

Decongestant (long-acting decongestants such as Afrin nasal spray and Sudafed tablets are popular among scuba divers; be certain to test decongestant before using for diving to insure that it is long-acting and that it doesn't cause unacceptable drowsiness, dizziness, or nervousness; individual tolerance and reaction varies).

Anti-nausea and motion sickness medication (test for adverse reaction before travel and use while scuba diving).

Pain relief tablets (5 grain aspirins or 200 mg isuprofen USP tablets are commonly used for pain relief and as an anti- inflammatory; Percogesic tablets provide pain, fever, and muscle spasm relief; for travel to remote areas where professional help is unavailable, consult your physician about the use of a more powerful pain reliever such as Tylenol with codeine).

Antacid tablets (for indigestion and heartburn).

Throat lozenges (for sore throat and cough).

Eye drops (such as Tetrahydrozoline or equivalent for relief from minor eye irritation caused by sun glare, wind, colds, dust, water, contact lenses and eye strain).

Neosporin ophthalmic drops or ointment (for eye infections).

Antibiotic capsules or tablets (for infections; prescription required; physician instructions).

Oil of clove (small bottle for toothaches).

Benadryl capsules, 25 or 50 mg (now available as a non- prescription sleeping tablet under trade names such as Sleepinal; an antihistamine used as a sleep-aid and for severe allergic reactions to mosquito and other insect bites; individual tolerance and reaction varies; can cause depression-type "hangover").

Sleeping aid (a mild sleeping aid such as Halcion 0.25 mg is excellent for inducing sleep during long overseas flights and dealing with jet-lag situations overseas; short half-life with minimal after affects).

Cortisporin ear drops (or equivalent for persons with a history of external ear infections; prescription required).

Ear rinse (Domeboro or equivalent for scuba divers with a history of ear infections; used as a preventive).

Insect repellent (a must if your adventure involves travel to the tropics; consider brands containing high percentage of the active ingredient "deet" or N, N-diethyl-metatoluanude for long lasting effectiveness; 90% or more "deet").

Sun protection lotion (a necessity in the tropics and at high altitude; consider high sun protection factor (SPF); SPF 15 to 25 for nearly total block; individual skin characteristics, pre- travel tanning, geographic location, and anticipated sun exposure as guide; persons with northern tans will burn in the tropics; special coatings for lips and noses).

Scissors and straight forceps (cutting tape and bandages; removing stingers and splinters).

Moleskin or molefoam (for blisters and prevention).

Cotton swabs (in sterile pack; for cleansing wounds, etc.).

Butterfly bandages or steri-strip skin closures (for sealing wounds; obtain instruction on what type of wound you should attempt to close, wound cleansing, and use; be careful; potential infections).

Body punch or ERG mix (several packets; for treatment of dehydration and first aid for decompression sickness).

Thermometer (useful to know core temperature when consulting with physician by telephone or radio).

Syringe (50 cc size for initial irrigation of serious wounds; caution: carrying a syringe may not be appropriate in some countries where customs officials might suspect you of drug use or trafficking).

Manuscript revised: 10 November 1989
Manuscript revised: 17 June 1990

CHAPTER 8-3

DIVE TRAVEL IN THE TROPICS

INTRODUCTION

Dive travel is big business! Each year thousands of divers from all parts of the United States travel to the clear, warm tropical waters of the Bahamas, Caribbean, and South Pacific. According to the "1987 Skin Diver Subscriber Survey," each respondent made an average of 2.5 trips per year outside of the continental United States during the previous three year period. Overseas travel accounted for 60.6% of all dive travel vacations. This represents an increase of more than 25% since the 1981 survey. It appears that nearly 97% of the divers who traveled outside of the continental United States went to tropical countries; mostly in the Bahamas and Caribbean. Subjectively, it is reasonable to conclude that tropical diving and travel has increased and will probably continue to do so throughout the rest of this decade.

Technically, the tropics extend 23.5° north and south of the equator. However, for purposes of this booklet I have extended the discussion to included diving in warm and exotic geographic locations that may lie outside the geographic tropical zone. For example, about 75% of the active American divers make at least one domestic dive trip each year and subtropical Florida appears to be to most popular vacation state for traveling divers. An increasing number of divers are extending their overseas travels beyond the Bahamas and Caribbean to include the Hawaiian Islands, Philippines, Mediterranean, and Red Sea.

Dive trips range from casual domestic resort vacations to exotic shark dives off the Great Barrier Reef of Australia. Some divers seek the comfort of a plush resort with air conditioned rooms and king size beds. Others travel to more primitive locations such as the Solomon Islands or Central America to live on small boats or in jungle huts and where antimalaria pills are a must. Diving may be simple and casual or extremely demanding both physically and emotionally. Some divers feed the yellowtails in Bonaire while others seek the thrill of facing the great white shark on Danger Reef, Australia.

Dive travel is one of the most important sources of income in the diving industry. Many recreational divers living in northern states never go diving in their home area. Northern diving businesses and instructors derive a considerable amount of their income from the traveling diver. Most northern diving businesses could probably not survive on training divers and selling diving equipment for northern diving alone.

The information contained in this chapter is based on research and personal experiences, including many personal mistakes and numerous enjoyable and adventurous dive trips. It is addressed primarily to the beginning diver with limited tropical travel experience. Important considerations regarding selection of the appropriate resort shopping, personal health, insurance, travel wardrobe, and general travel tips will assist the diver in trip planning. The knowledgeable traveler who carefully plans a trip and selects the appropriate equipment and clothing will enjoy many adventurous and pleasurable experiences. An individual who haphazardly selects a dive resort/boat and pays little attention to the details of preparation and travel will have an experience. Keep in mind that it is the *quality of experience* that counts.

THE COST OF TROPICAL DIVING

Each diving enthusiast responding to the aforementioned survey spent an average of $1,598 per year on dive trips. If this figure is projected to the total estimated circulation of *Skin Diver Magazine*, this amounts to more than $300 million spent on dive travel in one year. With increase cost of transportation and lodging, these figure have no doubt increased during the past two years. Exotic dive trips can cost in excess of $7,000.

Let's examine the actual cost of one diver's Caribbean diving trips in order to gain insight into what the diver gets for his/her investment. The average cost for each of two trips was $1,205.57. This figure represents trips that middle to low price range for tropical dive travel. It includes all expenses accrued from the time the diver left home in the Midwest until return (airfare, ground transportation, lodging, meals, diving, tips, and miscellaneous). The diver averaged 14 dives per trip with a total of 14.6 hours underwater. Consequently, each dive cost $86.11 or each hour spent underwater cost $82.57.

By the spring of 1988 the cost of a similar trip had increased to $1,753.60. On this trip the diver completed a total of 16 dives (14.48 hours underwater) at a cost of $109.60 per dive or $2.02 per minute under water (trip cost exclusive of equipment).

Let's assume that the diver used in the above example confined his/her diving activities to only tropical diving trips. The approximate retail value of a complete tropical diving outfit is $1550. If this equipment were to have a useful life of seven years, the per year cost of equipping oneself for tropical scuba diving is $221.43. However, it is reasonable to consider that the average diver will spend up to $50 per year for a good regulator maintenance program, strap replacements, and so on. This brings the equipment cost for tropical diving to $271.43 per year. If the diver makes one 14-dive trip per year, the per dive equipment cost is $19.39; or $9.69 per dive for a 2-trip year.

Now, let's assume that the diver can only make one trip per year. Considering the cost of an economy trip and diving equipment investment, the total *per dive cost* is $128.99. Assuming an average dive time of 50 minutes, the per minute cost of tropical diving can be $2.58 or higher if you make shorter or fewer dives. These cost do not include the expenditures for underwater photography. A relatively good Nikonos system with strobe and accessories costs about $1,200 to $1,500. Film cost and processing is $12 to $15 per roll. Many divers now use underwater video cameras.

The travel costs reflected above were taken from a detailed expense record of a traveling diver. It includes only modest expenditures for beverages and other recreational activities. Tropical dive trips can cost from $600 to $2500 or more per week depending on the location, class of accommodations, dive vessels, quality of food, *quality of dive sites*, and countless other factors. A review of one dive tour brochure show costs currently ranging from $1300 to $1800 for one week Caribbean dive trips. It is likely that air travel and resort prices will continue to increase each year.

What type of diving vacation do you want? Twenty-five divers spending three to five days on a 65-foot sail boat can be a relatively inexpensive vacation. However, for some individuals such an experience would be extremely uncomfortable and stressful.

SELECTING A DIVE RESORT OR BOAT

An in-depth review and analysis of tropical dive resorts and charter boats is beyond the scope of this publication. Rather, the reader is referred to *Skin Diver Magazine* for descriptive reviews of the major resorts/charter boat operations and to *Undercurrents* for a critical analysis of selected dive resorts and dive operations. To my knowledge, *Undercurrents* (published by Atcom Inc., Atcom Building, 2315 Broadway, New York, NY 10024-4397) is the only publication that critically reviews and rates diving resorts. Inquiries regarding subscriptions and acquiring back issues may be directed to the above address.

Dive shops and travel agents can supply brochures and specific information. A visit to any major diver's symposium or consumer trade show can provide you with extensive information on 50 to 100 dive resorts and live-aboard boats.

Tropical travel and diving can be very expensive. The prudent diver will carefully research tours, sponsors, and resorts/charter boats before investing $1000 to $2000 for a one-week vacation. Many divers shop for bargains. Keep in mind that you get only what you pay for!

Unfortunately, one thing that does not work well in selecting a dive resort or boat package is cost comparison shopping. There are simply too many variables. Keep in mind that comparison shopping is based on the assumption that the product or service offered is identical.

Such comparisons are usually difficult to impossible in dive travel. The cost of a trip to the same general location can vary by $1,000 depending on the number of travel days, the quality of accommodations, meals, transfers, boats, number of dives per day, types of dives, special equipment provided, dive sites, and other activities included in the package price. *Do not base your choice on price alone!*

The first consideration is, *"How much can you afford to spend for a dive adventure vacation?"* Be realistic! You cannot spend two fun-filled weeks of diving in the Caribbean for $300. On the other hand, you do not necessarily need to spend $3,000 for a one-week vacation. If you live in the Great Lakes area, I recommend that you consider $1,200 as the lower limit for a reasonable *quality* one-week tropical diving vacation. This includes everything! If the cost exceeds $1,800 per week, be certain that you are receiving an exceptional experience.

In order to understand the cost of a diving vacation, you should prepare a cost analysis. List all of the anticipated cost. Include those specific items covered in the travel package cost plus incidentals, beverages, tips, and other extras. For example, the bar bill for some individuals may exceed 50% of the cost of diving. Once you have added up your anticipated expenses, add about 25 or 30% to that total for the unexpected.

The travel package may or may not be the best deal. Most Caribbean trips are based on package prices. One of the big package traps is "double occupancy." Persons who desire single occupancy must pay considerably more, provided that a single room is even available. The prudent shopper will analyze both package cost and individual pricing cost. Keep in mind that the organization assembling the package is often making a considerable profit.

In some locations such as Hawaii condos may be rented by the day, week, or month for a reasonable price. Condo living permits divers to economize on meals, especially for breakfast and lunch. In some cases there are no occupancy restrictions and 10 very friendly people can reduce cost considerably. On the other hand, in some Caribbean locations, personal food preparation could be extremely expensive unless you know how to shop for and prepare local foods. If you plan to live cheaply on peanut butter sandwiches, you might be surprised to find that you are paying $10-12 US for a small jar. Also, if you have never shopped for food in a Jamaican outdoor market, you stomach may be in for quite an emotional experience. Low budget car rentals are available in places like Hawaii, however, renting a car in Jamaica is only slightly cheaper than purchasing one in the states.

The traveler has many thing to sort out. I can live for less than $40 per week in Jamaica by shopping native and eating out in native restaurants. I can also spend more than $40 for one meal in a nice Jamaican hotel. It takes time to shop and prepare your own meals. How much are you willing to spend or not spend for a selected vacation life style?

Second, consider the time of year and geographic location. Unfortunately, many divers must adjust vacation time to certain periods of the year depending on their employment or family obligations. Naturally, everyone wants to take a tropical vacation in winter to escape northern cold and snow. This generally means that you will have to pay the premium seasonal rate, especially during Christmas and Easter holidays. During the Caribbean high season (December to April) rooms may be 50-75% higher than in the low season. Unfortunately, the popularity of dive travel during summer months has increased significantly and many popular dive resorts do not give substantial price reductions during these months.

Keep in mind that the diving at some locations is also seasonable. For example, wind and sea conditions can be extremely severe in some parts of the Caribbean during December. You might spend an entire week on an island and have only one or two days that are acceptable for diving. Beware! Many diver resorts offer bargain rates during these times.

Investigate both the typical weather/sea conditions and the dive operator's alternatives, if any, for dealing with adverse conditions. For example, during periods of high winds and heavy seas from one direction some dive services will arrange to transport divers to the lee side of the island where the water is calm and clear. This may be a bit inconvenient, but at least you will be able to dive.

Adverse seasonable environmental conditions are often reflected in bargain dive package rates. Always inquire as to the reason for the bargain rates and specifically request information about environmental conditions during bargain periods. The majority of good diving resorts will be well-booked during the time of year when diving is best and do not have to offer bargain rates.

Summer through early fall months are generally considered as "rainy season" in the tropics. Depending upon accommodations and activities you may be very damp most of the trip. I remember one summer bargain-rate dive trip to Central America. Visibility may reduced to some degree because runoff from the land carried suspended sediments into the ocean. However, even 75-foot visibility is exciting to a northern diver. The rainy season also brings out the bugs! The quality of my diving experience was compromised to a certain extent by the fact that my body was covered with in excess of 200 bites (by actual count). The *no- see-um* is a year-round fact of life at some Central American dive resorts and are extremely abundant during certain seasons. If you are extremely sensitive to insect bites, this should be a factor in choosing your diving vacation time and location.

One of the most asked and least answered questions in dive travel is, "What is the best time of year to go diving is a given location?" For the most part, tropical weather is a bit unpredictable. Storms can appear and disappear over night. Many dive operators are very reluctant to make any promises or even comments. However, most tropical islands do have acceptable diving conditions about 90% of the time. Please do not blame me if you get caught in a hurricane during the 10% unacceptable time.

Third, *"What do you want out of a dive vacation?"* Are you traveling to the tropics specifically for diving? I mean real diving where every minute that you aren't sleeping or eating you are in the water, day and night. Unfortunately, there are only a few resorts that can provide both quality boat- and shore-based diving sites. The human fish with a dive computer may become frustrated by the diving limitations encountered at many resorts. This type of diver should consider selecting a group of individuals with similar diving interests and chartering a boat.

Live-aboard dive boats are increasing in number and popularity. Generally speaking, a live-aboard boat will allow twice as much diving per day compared to a land-based dive operation and a more intimate environment for meeting people and making friends. However, if you are a person who needs both physical and emotional space a live-aboard may be a poor choice. Only serious divers should consider the live-aboard. If you are considering taking a non-diving friend or spouse on your live- aboard trip, I recommend that you evaluate both the vessel and the individual very carefully. Living quarters, food, services, and personal comfort range from luxury to survival conditions. You may wish to consider other options. There is a strong possibility that the relationship will not survive the trip.

Many divers travel to a resort to dive and party. If you are a social creature, some resorts are better than others. You may wish to inquire about special social activities, beach parties, gambling facilities, and so on. A few individuals prefer a resort that places greater emphasis on social activities and less emphasis on diving. They are into heavy partying and occasional diving. Male divers who are primarily interested in female companionship will be very disappointed at most dive resorts. These individuals should consider traveling with a female companion or going to Club Med. On the other hand, there is generally an abundance of unattached (or unfaithful) males at most dive resorts.

These social creatures might have an emotional breakdown if they found themselves at a resort tucked away in a Hondouran coastal jungle where the diehard divers retire under their mosquito nets at 8 PM or go night diving from the beach every night. The quality of the total experience is the important factor. Most resort divers will spend less than two hours underwater each day. That leaves twenty-two more hours to enjoy or be miserable.

Many people travel to the tropics only to go diving. Between dives they sun bathe and/or talk about diving. They want to go diving on the day they arrive and continue to dive up to the time they board the plane for home. Fine!

However, you can get so much more out of a tropical vacation. Have you considered the possibility of a multiactivity adventure travel vacation?

Most travel into the Caribbean involves a stop over in a major city such as New Orleans or Miami. Whenever possible I like to spend one or two days in New Orleans both prior to departure for my Caribbean dive site and upon return. I enjoy the food and music. For little or no additional air fare, you might be able to arrange a stop over at Disney World or some other Florida vacation attraction.

In the Caribbean there are many very interesting attractions. A diver traveling to Belize or an islands off the coast of Mexico should consider taking several days for a land trip to visit the ancient ruins and to explore the countryside. Staying in a back country hotel can be an experience in itself. You might find that trip up a jungle river would be as exciting and enjoyable as diving, especially if you are somewhat of a naturalist. Any visitor to Bonaire should take at least a day to explore the island and see the marvelous flora that grows in the arid climate.

Some adventure travel agents can arrange for jungle, river, or nature tours to be included in your trip package. Unless you have travel experience in Central American, it is wise to arrange for special services before you leave the States or at least establish a reliable contact in the country you plan to tour. Land Rovers, boats, guides, hotels, and tour routing can generally be arranged though such a contact. You must also understand that there may be some risk associated with travel in certain countries. Adventure travel agents and local contacts can advise you of these risks and can often help you plan your travels to avoid possible adversity. Keep in mind that crossing a border into an area of hostility can involve considerable risk.

The real adventurer might go as far as planning a one week mountain trek in Peru and a week of diving in the Galapagos Islands. In reality, there is unlimited opportunity for the adventurous diver to enjoy greatly expanded travel experiences. Your local dive shop specializes in diving vacations, so you will generally have to consult with an adventure travel specialist/agent to investigate and plan combination travel activities. Adding other experiences to you diving holiday might not be as expensive as you think. However, you will have to determine what type of experience you wish to have and areas you wish to visit and shop for an appropriate travel package.

A person who wants to get the most out of his/her diving and adventure travel experience will study guide books, maps, nature guides, and so on as part of trip planning. Books and maps should be acquired well in advance of travel. It may be surprisingly difficult to get maps and guidebooks upon arrival at your destination. Know as much as possible about a country before you arrive. Learn about its history, people, culture, customs, climate, geology, plants and animals.

Research and discussions with persons who have already visited the country can make you travel experience infinitely more enjoyable and complete. Even if you only plan to dive in Bonaire, you should acquire and study the excellent guidebooks that describe reef features and various dive sites. At some resorts you will have to sign up for specific dive sites each day. Some are better than others. Some have specific attractions such as sea horses or vertical walls. If you have specific interests and know your dive sites in advance, you will get much more out of your trip.

Finally, *who will control your diving experience and what limitations, if any, will be imposed on you?* Some dive guide/ operators impose very stringent rules on their clients. For example, the dive guide will select the dive site and dictate the depth and dive time. This is becoming the rule instead of the exception in Caribbean diving. If you are not back on the boat within a few minutes of the designated time, they will come and literally force you back to the boat. The reasons most often stated include safety, legal liabilities, and that many, if not most, tourist-divers are incapable of reading decompression tables or taking care of themselves underwater. In the past 10 years I have really only found on dive operation which *recommends* reasonable limitation and has a dive philosophy stating, "Each individual must assume responsibility for his/her own actions!"

Most Caribbean dive guides are marvelous individuals who wish to everything possible to provide you with a safe, high-quality diving experience. However, I have also personally found some guides/operators so intimidating and the quality of my diving experience so compromised, I feel that I must very carefully research the dive operation prior to investing in a vacation.

I do not especially enjoy short, deep dives. At one dive resort I was told that we would be diving to 100 feet and that we must be back on the decompression bar within 20 minutes of submerging. Fine, if I wanted to spend 20 minutes at 100 feet. But, I had no desire to dive to 100 feet. However, I was informed that I must abide by the group time limit even if I only dove to 60 feet or less. With 2000 pounds of air in my cylinder and a considerable amount of no-decompression time on my EDGE, I found myself heading back to shore.

Ironically, at this same resort anyone could participate in unlimited shore diving. The guides/operator stated "safety" as the reason for placing such limits on the boat dives. However, I could easily swim from the beach to offshore depths of 80 feet, exhaust my air supply several hundred yards offshore, bend myself silly, and create a score of unsafe diving situations and practices, including solo diving, without the expert supervision of a qualified dive guide. Needless to say, the policy and attitude of the dive operation significantly compromised the quality of my diving experience and vacation. I would find it difficult to return to that resort.

In defense of the dive guides and operators I must acknowledge that there is some justification for strict control of divers at resorts. In a study conducted by Homer Fletcher, a noted California diving instructor, approximately 82% of a group of certified scuba divers tested could not properly calculate a typical repetitive dive sequence (two dives in a single day). Many *certified* divers arrive at resorts well-equipped, but, their ability to buoyancy compensate and handle themselves in the water is marginal. Some cannot even assemble a scuba properly. One dive charter operator in the Florida Keys indicated that nearly 70% of the divers on his boats lacked satisfactory physical fitness for serious ocean diving.

How many dives can you safely, comfortably, and realistically make in a day? This depends on depth, location, convenience, nearshore conditions, individual physical condition, equipment, personal adjustment to the tropical environment, and a host of other factors. May enthusiasts travel to the tropics with visions of making five or six dives per day.

It is possible for you to dive day and night and make this many dives at a few resorts. But, is it safe? Unless you limit all of your diving to less than 50 feet and pay close attention to your repetitive dive schedules, you may find yourself in painful difficulty by the end of the week. The only realistic way to approach such repetitive and multilevel diving is with one of the new decompression microprocessors. ***And, even this is no assurance that you will not extend yourself beyond physiological limits or exceed the limits of your electronic device.***

The average recreational diver will probably find that a maximum of three dives per day is realistic. Some will make four, others will make only one or two, especially near the end of the week. The cumulative effects of the tropical heat, sun, exercise, body heat loss and other activities will take a toll on your body by the end of the week. Generally, only those individuals with proper thermal protection, a high level of physical fitness, and a real desire to dive will sustain a full diving schedule throughout the week. Late nights, drinking, and partying can compromise both the desire to dive and personal safety. ***Do not dive with a hangover and when fatigued! The rewards are simply not worth the risks!***

Other divers may be more interested in comfortable accommodations and a gourmet's cuisine. I found a resort in the Outer Bahamas where the diving is fair, the rooms are nice, and the food, prepared by European chefs, is out of this world. I would return to that resort just to relax and eat for a week.

Planning for a tropical dive adventure holiday begins with an assessment of your personal life style and requirements. First, objectively and realistically answer the following questions:

* How much money can I afford to spend?

* What are my major goals for this vacation? Primarily diving? Sightseeing? Sun bathing? Rest and relaxation? Gambling? Partying and drinking? Romance? Or, what combination of activities?

* Do I want a combination land tour and diving holiday?

* Do I want to travel alone? With a companion? Small group? Large group?

* Do I want to live on land at a resort or on a boat? Or, do I want a combination boat/resort holiday? Do I want to live on a sailboat or power boat?

Once you have developed some insight into the type of dive adventure that best fits your needs and life-style, find a friend who has issues of the last two years of *Skin Diver Magazine* and read about the various resorts and dive holiday opportunities. Keep in mind that most dive magazines are in the business of marketing dive travel. Consequently, article tend to glamorize a particular dive resort or live-aboard boat and seldom include critical comments. It is unlikely that a dive magazine will allow an author to criticize a resort/boat on one page and successfully collect thousands of dollars for advertising that resort on another page. Once you have found several resorts or charter boats that are of interest to you, see if you can locate past issues of *Undercurrents* with critical reviews of those operations.

Now it is time to visit your dive tour agent. Dive tours may be arranged through local dive shops, travel agencies that specialize in dive tours, or any local travel agency. Dive tours should be arranged with an agent or agency that has experience in dive tours. Unfortunately, most travel agencies/agents do not have the in-depth knowledge of dive resorts and diving to understand and appreciate some of the unique requirements and concerns of the diver. Ideally, you should deal with a travel agent who is a diver and who has had extensive experience in dive travel. On the other hand, the local dive shop generally does not have the capabilities of airline scheduling and making other travel arrangements. Some first-class dive shops have developed excellent relationships with a local travel agency to handle travel arrangements. The professional travel agent can best do the following:

* Check seat availability on flights;

* Help you find the lowest air fare and best travel time value;

* Instantly make and confirm airline reservations;

* Write and print out airline tickets;

* Check for room availability and bargain rates in major hotel changes; and

* Reserve rooms and rental cars in gateway cities.

Keep in mind that many travel agencies will not be able to provide information and rates or book accommodations in many obscure or offbeat areas. I doubt that you local agent has a computer link with the Mopan Hotel in Belize City. Keep in mind that that hotel still uses a *rooster* for wake-up calls.

Consult with more than one shop/agency! I have found that the cost of a dive trip to the same location, with the same accommodations, on the same flights, and with the same diving activities can vary by up to several hundred dollars. Do be careful when comparing these costs! Be aware of seasonal specials and compare the specifics of the dive package. Some packages offer one boat dive per day and others provide for two boat dives per day. Others will offer one two-tank boat dive per day. Some include a night dive and others provide night dives at additional cost. Some have unlimited shore diving opportunities at no additional expense and others may have a significant additional charge for air/cylinders. You may find that you will have to develop a personal comparison chart in order to better analyze the offerings.

Keep in mind that the rules can change within a few months. One Eastern Caribbean resort had advertised unlimited shore diving. Upon arrival I found that each dive beyond two per day (boat or shore) cost $17.50 US and that you could not make a shore dive without a guide. This applied even if you only wanted to spend 10 minutes taking a picture in 6 feet of water with you buddy. *Be certain that you have all of the details of your specific dive package in writing.* do not rely on magazine articles, brochures, or the spoken word of a travel agent.

Now that you have identified several resorts and tours that are of interest to you and within you budget, interview local divers and instructors who have actually visited the resort. You can meet these divers at club meetings, through friends, in the dive shop, or through agency referrals. However, do keep in mind that the dive shop or travel agency is not likely to provide you with the names of persons who were dissatisfied with a trip or resort.

There are many excellent resorts and dive operations that do everything possible to make your holiday enjoyable and complete. Some travel agents, dive guides, and resort/boat operators may consider the above suggestions for evaluating/selecting a dive resort/boat to be a bit excessive. However, when divers are investing $100 to $150 per dive, they must be assured that they are getting the maximum return for that investment. And, twenty minutes underwater at a poor dive site under the supervision of Mr. Macho is not my idea of good return on an investment.

SELECTING A DIVE-TRAVEL COMPANION

There are many types of people and divers. Selecting a proper diving and traveling companion can be one of the most important factors in planning your trip. Selecting an individual of questionable compatibility can produce disastrous results.

Some divers simply plan to travel with a group under the sponsorship of a local dive shop or instructor. It is likely that they will know people in the group and will be comfortable with a selected/assigned roommate and variety of dive buddies. Such trips are pre-scheduled by the dive shop and, basically, all the individual diver has to do is to pay and show up.

Other divers will sign up for a trip with a dive tour agent. Often they will not know anyone else on the tour. The agent will assign a roommate and the diver will select a previously unknown dive buddy from the group or other divers at the resort. Be careful with this method!

The more adventurous diver may elect to not travel with a group. Rather, he/she may wish to select a compatible companion and reserve a room at a dive resort for a week as part of a more extensive trip. By traveling with a carefully selected companion you are assured of a reasonable degree of interest and diving compatibility. Travel and diving is an experience that is often most enjoyable when it can be shared with someone. Furthermore, if you have properly selected a companion, you diving experience can be much safer.

In selecting a dive-travel companion keep in mind that you will probably only spend about 10 to 15 hours underwater during a week's trip. This leaves about 155 hours during which you will share a room, meals, waiting in airports, flying, sightseeing, and leisure interest. You may or may not develop relationships with other people that you meet during your travels. If your travel plans include stop overs or land excursions, the amount of time and experiences shared with a companion will be even more.

Dive-travel companions often develop very close personal relationships which involve extensive travel, social activities, educational involvements, and lasting friendships. In selecting this person, in addition to diving qualities, you may wish to consider fundamental personal and social factors. The following are some of the factors which you may wish to consider:

* Will this individual make a good traveling companion and roommate? Let's take an extreme example. If the potential traveling companion is a smoker and you are not, this could lead to continuous conflict regarding seating in restaurants, sharing a room, selecting airplane seating and so on.

* Are you and your potential companion's life-styles and interests compatible? They say that opposites attract. Unfortunately, you may both be miserable if you do not have similar interest and compatible life-styles.

* Would you be comfortable with this individual in most social and diving situations? Your dive- travel companion must be socially compatible. You will no doubt spend a considerable amount of time with this person in a social environment. If he/she makes you uncomfortable or do things to embarrass you, the trip could be very unpleasant. If you are a more conservative person who does not enjoy all-night drinking parties and your potential companion likes to close the bar every night, this could also be a problem.

* Is this individual financially responsible and capable of paying his/her own way?

There are thousands of divers who would sell their soul, and a lot more, for an adventurous diving holiday. Many do! And, many individuals do pay for this companionship. The world is full of freeloaders. Do you want to buy a dive-travel companion? Develop an understanding regarding the relationship and finances up front.

* Is there any reason that would lead you to feel that you could not trust this individual? Honesty and trust are important factors in any relationship. This is especially true in diving and adventure travel. You must be able to trust the other person to assist you in the event that you get into trouble and to not not only get you in trouble. The relationship can also not be founded on deceptions and dishonesty.

Ideally, diving buddies should have the same skills training and use identical equipment. This assures that each diver is completely familiar with the operation of the other divers equipment and increases the possibility for a similar and compatible response in an emergency situation.

Although two individuals might not have the same amount of diving experience, each should have a reasonable amount of experience. The diving activities will have to be selected for compatibility with the least experienced individual. A veteran of 10 years of extensive tropical diving can not expect a recently trained novice to safely participate in deep drift dives without progressive acquisition of experience. Diving buddies must be also physically compatible or make adjustments to neutralize any areas of incompatibility. Could you rescue your buddy in the ocean? Could your buddy rescue you in the ocean?

As a general rule a good diving buddy should also be in reasonable physical shape, a good swimmer/water person, knowledgeable about diving and the marine environment, and have a positive attitude to diving and traveling. A good diver will develop awareness and anticipation regarding their buddy's needs and the requirements of the environment. This diver demonstrates good judgment before and during the dive. A good diver establishes and maintains underwater orientation.

Every diver has some idea of the qualities look for in a diving buddy. Finding a diving buddy that you can also share travel and adventure experiences may be a bit more complicated than you might think. Keep in mind that the quality of your dive-travel experience depends on this selection. For additional information consult a booklet titled, *Selecting a Scuba Diving Buddy*. This booklet is available from the Michigan Sea Grant College Program office on the university's North Campus.

PACKING FOR A TROPICAL DIVING VACATION

An adventurous diving trip in the tropics is glamorous, exciting, and one of the greatest challenges any traveler can imagine. However, within a few air hours you find yourself in a foreign country and remote location away from the secure familiarity of hometowns and common language. You leave behind the corner drug store and K-Mart. Even if you are on a fully guided tour you should still equip yourself for *self-sufficiency*.

What's the big deal? Many travelers simply throw a few T-shirts and shorts into a bag and "make-do." Sure, you can do that and, no doubt, have a good time. However, I feel that you can have an even better time if you plan and organize your travels. For example, lets take wardrobe. It is an adventure in itself to develop a travel wardrobe that is versatile, cool, comfortable, and attractive. During your tropical travels you may emerge from a steaming, bug-infested jungle to feast in the elegance of a fine hotel dining room. You may spend the day baking in tropical sun and exploring the reefs of the warm, clear Caribbean waters. However, when the sun dips below the horizon and you are embraces by the cool breeze of a romantic tropical night, a sweaty T-shirt and dirty shorts might just dampen your mood or that of a "potential companion."

Changing life-styles, dive adventure vacation opportunities, discount air fares, and inexpensive package tours have unleashed a new breed of footloose, fun-seeking, and slightly strange traveler. The world's tourist centers are adjusting to and even enjoying new, relaxed dress codes. Consequently, the modern day traveler can pack less and make a wardrobe go further. Basically, almost anything goes.

Selection of a travel wardrobe is much a matter of personal preference. Many travelers simple throw a few things into a suitcase and go.

However, the prudent traveler will carefully select clothing that is functional and comfortable for the climate, activity, mode of transportation, class of accommodations, and local customs.

Let's look at a special breed of traveler — the American scuba diver. To many scuba divers the term *wardrobe* implies a pair of jeans, a sweat shirt, shorts, a swim suit, running shoes (no socks), and 42 T-shirts for a one-week trip. Underwear is optional. And, for most dive resorts and charter boats this wardrobe is very appropriate.

What is truly appropriate? That question is becoming more difficult to answer all the time. What might be very appropriate at a casual dive resort in Bonaire might be completely inappropriate at a fine hotel in Nassau. Some items of clothing seem to enjoy international acceptance. For example, everyone, everywhere is wearing jeans today. Add an attractive and fashionable sport shirt or, even a dress shirt/blouse, and you might even be considered trendy.

However, I do not personally find many of the *trendy clothes* to be either attractive, functional, comfortable, or appropriate for tropical travel. In fact, tight denim jeans are, in my opinion, downright uncomfortable in the tropics. Maybe it is just the "007" mystique, however, the image of a gentlemen wearing a nice suit and a woman in a beautiful evening dress dining on the terrace of a fine restaurant under a tropical moon stirs the soul.

I tend to be a bit conservative in selecting a travel wardrobe. Keep in mind that you want to select clothing that will be comfortable, functional, neat, and appropriate for the climate and social surroundings at your vacation destination. A dinner jacket will be *out-of-place* if everyone else is wearing a T-shirt and shorts. On the other hand, a T-shirt will be out-of- place if everyone else is wearing dinner jackets. There are always exceptions! The eccentric diver will no doubt wear a dinner jacket and shorts.

One general rule for travelers is *"pack one-half the clothes that you think you will need and take twice the amount of money!"* Pack light and tight! Clothing is very informal in the tropics. You can go almost anywhere in shorts, sandals, and a T-shirt. For the most part, suits, sport coats, and neck ties are foreign objects in the diver's wardrobe. However, be certain to inquire prior to leaving home if you are planning to dine in fine hotel dining rooms. A few still require a coat and tie.

Keep in mind that luggage allowances are more restrictive for overseas travel than for domestic travel. In domestic travel you may be limited to three pieces of luggage including your carry-on bag. The size and weight of each bag may also be limited. For example, one air line limits luggage size (sum of length, height, and width) to 62 and 56 inches for the two checked bags and 45 inches for the carry-on bag. A weight limit of 70 pounds applies to each bag.

Some overseas air lines, especially those operating smaller inter-island flight aircraft, are much more restrictive. You may be limited to two bags with al total weight of 44 pounds. On small aircraft, size can be critical. Large bags have simply been left behind because they were too bulky to fit into the luggage compartments of small aircraft. Select luggage that is as compact as possible.

Be certain to attach an rugged identification tag with full name, business address, and telephone number securely to all bags. Tagging is required by airlines. In addition, include the same information on a card secured to the inside of your luggage. In the event that your luggage is lost and the outer tag accidental removed or damaged, this inside identification may be the only way of identifying the owner.

If someone really wants to get into your bag they will do it, locked or not. However, locking does discourage the casual thief and may prevent the luggage from accidentally opening during rough handling. If you use key locks, carry two sets of keys. Small combination locks also work quite well and can be quickly opened for customs inspection.. Some divers secure zippers with expendable plastic wire ties. These ties will generally have to be cut at customs; nail clippers do fine.

In the tropical Caribbean travelers enjoy warm temperatures throughout the year. A light cotton jacket or sweater provides added comfort on winter evenings. On the other hand, Hawaii has a daytime temperature range of 80 to 95° in summer and 70 to 85° F during winter months. At night winter temperatures can drop to 60° F. Furthermore, if you plan to venture to higher elevations in Hawaii, be prepared for cool temperatures and cold rain; snow may be encountered at elevations of 4,500 feet in the winter on Hawaii and snow, driving rain, and below freezing night temperatures are possible at any time of year at higher elevations.

Fabric and clothing style is a matter of personal choice. Traditionally, cottons have been the choice for tropical climates. The cotton absorbs perspiration and tends to cool you body as the moisture evaporates from the cloth. Cottons are certainly the choice for arid environments. However, in high humidity environments on might consider the use of a light weight polyester-cotton blend. This fabric tends to absorb moisture and dry more quickly than pure cotton. Heavy cottons seem to never dry in a humid environment. Select clothing that is loose fitting so that air may circulate between your skin and the fabric.

The Caribbean Dive Resort

Most resorts frequented by American divers are, you might say, *casual*! The quality of accommodation and palatability of the local cuisine tend to be directly proportional to the amount of money that the diver is willing to invest. The traveling divers is not so much the Ugly American today, just a Cheap American. If you pay under $600 per week for room, board, and diving, dinner dress *might be* as elegant as a clean T-shirt. The higher the cost of your trip, the more care required in selecting a wardrobe.

Be an individual! Dress for your personal physical and emotional comfort. Your trip from home to Bonaire will often begin at 9 AM and end at 9 that night. You will spend a few cramped hours on two or three different air craft, several hours in a gateway airport (such as Miami International), and about an hour in airline and customs lines. Actually, the ambient environment will generally be air conditioned (airport and airplane) unless you are going to the Central American Caribbean coast and islands where airports and airplanes (on the ground) can be quite hot.

Dress in comfortable, loose clothing that won't show the trials and tribulations of spilled drinks, dirty seats, and hours of sitting. I generally wear light weight blue or khaki slacks (poly-cotton with spandex) and a full cut shirt with large pockets (worn out, not in). Casual pants with an elastic waist are comfortable. You will have to walk some in airports, so select a shoe that you can cover some distance with yet remove easily during the flight. If you are a "chiller" — do not do well in cold air conditioned areas — consider carrying a long sleeve shirt that you can pull on over your travel shirt in you carry-on.

Once on the island dress generally gives way to shorts, T-shirts (or other short sleeve shirts/blouses), and sandals. The wise traveler will always have a pair of cool, lightweight slacks to replace shorts in the event that they cannot handle the strong tropical sun. Thirty relaxing minutes in noonday sun with untanned exposed legs (and feet) can lead to hours of discomfort. The prudent individual will also include a long-sleeve shirt. A sun hat is, in my opinion, a necessity for both men and women. A pair of socks, even with sandals, can prevent sunburned feet.

Evening can be anything from a greasy barbecue on the beach (consider eating elsewhere), to a elegant meal at the better resort down the road, to casual dining on the terrace, to a cocktail party. Dress for such dining might be dirty shirt and shorts (unless no-see-um season); nice sun dress/skirt and white slacks; shorts and polo shirt; nice, clean casual clothing, respectfully.

The actual number of shirts, shorts, dresses, and underpants that you pack depends on your personal preferences and life style. Some people can easily survive for a week in the tropics with a one T-shirt, a pair of shorts, sandals, a tooth brush, and a bottle of *eau de Cologne* (the cheap, strong stuff). Others prefer to pack a limited number of clothing items and along with a small clothes line, pins, and soap. Many people will pack two or three pair of slacks and shorts along with a fresh shirt and underwear for each day of the trip. As a rule, must people tend to take more items of clothing than they actually need. What do you need to remain comfortable, clean, and moderately attractive to your fellow travelers?

A Dive Boat Trip

The first step in selecting a wardrobe is to analyze your trip from a standpoint of climate, social surroundings, and activities. I feel this can best be accomplished through analysis of the types of trips that a scuba diver might take. My first example is a *low budget* holiday on a dive boat during the month of July. The boat is based out of Miami and the trip consist of traveling to and from Miami and spending 5 days at sea in the Bahamas. A group of 5 divers will be traveling from Detroit to Miami by automobile and eat most of their meals at McDonalds while in transit. Keep in mind that there is very limited space for hanging or storing clothes and *no facilities for washing clothes* on the boat.

Casual dress is the order of the day. The basic wardrobe consist of T-shirts/tops, shorts, bathing suits, and deck shoes. A multipurpose sweat suit is appropriate for after dive warm up, evening lounging on the deck, sun protection, and sleeping. Add a windbreaker/raincoat, sun hat, underwear, and personal hygiene kit and you are ready to go. Keep in mind that some low-budget dive boats do not furnish towels or washcloths; bring your own.

The above wardrobe should do quite nicely for for both men and women on this type of trip. Naturally, there will have to be some adjustments for sex and personal taste. Pack it all in a small, soft-sided bag that can be easily rolled up and stowed. With the addition of a lightweight summer dress or slacks for evening wear and a nicer shirt, this same wardrobe would also be adequate for most dive resorts.

Keep in mind that dive boats are getting larger and more luxurious. Some live-aboards have evening cocktail hours and social events. Large ocean liner style vessels offer an number of social opportunities. Dress for these larger and more luxurious boats may be more in line with good land-based dive resorts. However, American divers will probably always observe a more casual dress code.

A Multiactivity Trip

Let's make the second dive trip a bit more exciting and adventurous. Our divers will fly from Detroit to New Orleans where they will rent a car and spend the better part of three days and two nights enjoying the sights, sounds, and food of this exciting southern city. Then they will fly to Belize City (Central America) where they will relax at the Mopan Hotel overnight.

The next morning they will depart on a Land Rover tour of the jungle and ancient ruins of Belize for three days and two nights. Late in the afternoon of the third day they will return to Belize City and board an 80-foot dive boat.

For the next 7 days they will cruise and dive the coastal waters of the Central America. There are only 10 divers plus the captain/crew on this dive boat. There is a little more space for stowing clothing and relaxing on this boat. Meals are more formal and family style and are often preceded by a cocktail hour on the aft deck as the late afternoon sun begins to sink in the west.

After a week of sunning and diving our divers will return to Belize City where they board a plane for New Orleans. After a night of dining and relaxation in New Orleans, they will fly home. There is also the possibility of spending two or three extra days in Belize City if someone forgets to confirm the airline reservations at least 72 hours prior to departure.

The flight to New Orleans is fast and comfortable. The rental car is waiting at the airport and our happy travelers drive to a small, elegant hotel in the French Quarter. The summers days and night will be hot and somewhat humid. The days will be highlighted with brunch at Brennen's, shopping in the French Quarter, river cruises, oyster bar snacks, and touring old plantations. Evenings will be spent dining in New Orleans' finest restaurants and listening to Dixieland jazz.

For summer air travel I recommend comfortable slacks, a sport shirt, and casual shoes such as moccasins or walking shoes. A woman might consider a comfortable summer dress or attractive blouse/slacks outfit. Cool and comfortable! Although many women and some men would wear shorts for summer air travel and daytime touring, I tend to be a bit more conservative and recommend comfortable, neat slacks for men and cool, casual dresses for women. I just do not feel it is appropriate to wear shorts to Brennen's. Travelers must always have comfortable walking shoes.

For evening wear, some men may wish to include a lightweight summer suit or sport coat/slacks and women may wish to include a simple, cool evening dress. Most divers are extremely casual and will probably find this type of dress to be a bit excessive, if not down right distasteful. A few of the finer restaurants, will require a coat and tie, even in the summer. A tie! Why would any one who wishes to eat in comfort on a hot summer night want to wear one of these social tourniquets? Why would a restaurant proprietor do this to a diver? Possibly he also hates his mother!

If desired, our travelers may make arrangements to store their dressy clothes at their New Orleans hotel while they are in Central America. Before leaving for the backcountry, adventure travelers often check their city and travel clothes at hotels in some countries.

On to Belize! The flight from New Orleans to Belize will no doubt be hot and crowded. A traveler should dress as coolly and comfortably as possible, however, they should not arrive in any foreign country looking like a *hippy* (I know the word is old fashioned, but I imagine you get my point). I feel that you can clear customs much easier if you are dressed in a neat and more conservative fashion.

In Caribbean and Central American countries I find that most native men and women do not wear shorts on city streets, only tourist. In some Caribbean cities local law and/or custom prohibits wearing tight shorts or bathing suits on city streets, in restaurants, and certain public areas. Such attire is reserved for the pool or beach.

Above all, do not wear olive-drab or camouflage pattern clothing to Central American. In fact, military-style clothing should not be part of you wardrobe when traveling to any foreign country. Some authorities even recommend that you do not wear shirts with epaulets or trousers with patch-type cargo pockets. Some local authority may get the impression that you are a mercenary or, at least, a potential troublemaker. Let me assure you that being detained and questioned by Central American officials is absolutely at the bottom of my life's adventure list.

The Mopan Hotel in Belize City is low-key and very casual. Although the surroundings are casual, I would still discourage wearing shorts to dinner. Backcountry hotels can be quaint and comfortable but minimal by most American standards. Still, conservative dress is desirable. A person dressed in shorts might not be admitted to some hotel dining rooms.

A tour through Belize can be hot, sweaty, and wet. Ten feet into the undergrowth the traveler will encounter millions blood thirsty of mosquitoes. Thirty feet into the undergrowth of some Central American countries you may find a few guerrillas with M-16 (CIA issue) stingers. Although I have worn shorts and a heavy coating of insect repellent, I do recommend that jungle traveler carry long pants in shoulder bag or day pack for times when the mosquitoes become a problem. And, since mosquitoes carry so many tropical diseases, some travelers prefer to wear long pants all the time. The same goes for shirts. You can always turn up long sleeves, but you can't roll short sleeves down. Lightweight hiking boots and appropriate socks are desirable.

Dive boat dress need not be too different from that listed for the first trip. However, some individuals, especially women, may want to be a bit more fashionable for the afternoon cocktail party and evening dining; not necessary, just a matter of personal social taste.

So there it is! The traveler must have a wardrobe for three distinctly different activities and environments. Also, keep in mind that laundry might be possible, but difficult and inconvenient. I forgot to add one thing. On one of my earlier trips to Belize, the 44 pound weight limit did apply and I paid $50 in overweight charges. What would you pack for this trip? Some can pack it all in their carry-on bag plus a nylon clothes bag carried in their dive bag. Others may require a separate duffel bag or suitcase.

Diving equipment and items that will not be use for the jungle trip may be checked at your Belize City hotel or sent to the dive boat before departure for land travels. I find that a small duffel bag or general purpose carry-on bag is adequate for the land trip. In addition to backcountry clothing, I include a sweater, jacket (or umbrella), moccasins (evening wear), extra handkerchiefs, a swim suit, running shorts, a sport shirt and a pair of casual pants for backcountry travel.

Naturally, the jungle traveler will carry selected nature guides, photographic equipment, first aid kit, toilet tissue (unless you care to use your hand and water like much of the world's population does) and a water bottle. It is not unreasonable to include a small survival kit in your shoulder bag. When staying in small village hotels it is far more comfortable to change into some casual clothes for evening dining and lounging rather than wearing dirty jungle clothes. Some people include a lightweight sweat suit for lounging and protection from insects while sleeping.

The personal hygiene kit contains all of those necessary grooming and personal care items. The quantity of consumables items such as shampoo, rinse, and toothpaste depends on the length of stay and the availability of replacements at local shops. I often carry small bottles in my luggage and large refills in my dive bag for long trips.

In the final analysis, wardrobe is a matter of personal preference and need. Just remember that careful wardrobe planning and selection can make you trip much more comfortable. Divers who spend their vacations at high-class resorts will want to include more items such as tops, sport shirts, shorts, sundresses and so on.

However, remember that you will be able to wash some things in the bathroom sink and drip dry. Some hotels also have washers and dryers for guest. Consult brochures and you travel agent for information on available services Plan each trip and learn from experience.

The Carry-on Bag

The carry-on bag and it's *contents* is fundamental to all travel, especially diving and adventure travel. The choice of a carry-on bag is a matter of personal preference. Some travelers prefer a simple single compartment, open top bag, whereas others carry a large camera bag or small suit case. Small backpacks, large handbags, and duffel bags can also be used as carry-ons. Simply remember that the bag must fit under the aircraft seat or in the overhead compartment and cannot exceed 22 x 14 x 9 inches for most commercial airline flights.

Also, keep in mind that you will no doubt carry this bag almost everywhere you go during your travels. It serves as a shopping bag, camera bag, small gear bag, and lunch bag. For long airplane flights it will contain everything from books and writing materials to personal care items. When traveling by automobile or Land Rover you will carry you camera, lens, film, binoculars, notebook, snacks, swimsuit, and knife in this bag. In the jungle you can carry your camera gear, a small first aid kit, insect repellent, and a water bottle. At home, it may be used as an all-purpose bag.

The first consideration in selecting a carry-on bag is to determine the size and style that will best fit your needs. Some people prefer to have two bags, one for business or "clean" travel and another to drag through the jungles of South America. Individual preference, location, travel mode, activity, life-style, and carrying requirements will serve as your guide. I recommend that you select all of the items that you plan to carry in the bag, lay them out on a table, and estimate the bag size and configuration that best fits your needs. First, let's make a list of items that a traveling diver *might* wish to carry in this bag:

- Prescription mask;
- Depth gauge, compass, and decompression computer;
- Underwater camera, strobe, and other expensive or fragile photographic equipment;
- Standard camera, lens, film, and accessories;
- Personal documents such as passport, international driver's permit, special medical information, diver's logbook and certification card, airplane tickets, travel schedule, hotel reservation confirmation, special travel instructions, etc.;
- Personal hygiene kit (selected items);
- Prescription medications;
- Swim suit;
- Selected items of clothing;
- Stationary, stamps, pen, and address book;
- Notebook for records and recording travel information;
- An interesting book(s) to read during the flight and stopovers;
- Snacks such as candy bars, granola bars, etc.;
- Prescription glasses, sunglasses, contact lens, contact lens care items, etc.;
- Pocket calculator (foreign currency calculations, etc.); and
- Car keys.

Photography equipment is the curse of the traveling divers. If large housings and strobes are to be used, consider special shipping containers and check these items as luggage. Many traveling divers make a special effort develop compact photographic systems that are acceptable for carry-on. Many divers will carry a separate bag/case containing an underwater camera outfit. Some divers pack film in checked luggage in order to avoid x-ray exposure, however, with increasing security problems even this luggage may be x-rayed. A reasonable number of rolls may carried in your carry-on. Consider a small protective lead lined bag or request hand inspection. Placing the film in a clear plastic bag enables the inspector to see the entire contents and avoids the difficulties of handling numerous small boxes. This decreases the likelihood of delay at the inspection area.

I always include a small personal hygiene kit in my carry-on bag. Most items can be packed in checked luggage. The carry-on kit includes items that might be used during the flight and travel day or in the event that your checked luggage is temporarily lost. Consider including personal medications, razor, toothbrush and paste, essential cosmetics, comb, brush, birth control medication or devices, etc. Essential medications should never be transported in checked luggage.

Long flights and airport layovers are excellent times to review decompression tables with your buddy, study marine life identification and guide books, or review an underwater camera manual. Many individuals include several paperback books for recreational reading and trading with other travelers. I always carry a notebook or writing pad for recording thoughts and a travel log. These are an excellent times for catching up on correspondence.

Many authorities advise travelers to carry their traveler's checks, passports, and currency in money belts, belt wallets, or specially designed underarm/necklace type wallets instead of in their carry-on bag. This is good advise. A shoulder bag or small back pack is an easy target for a *snatch thief*. They can pull a should bag from you arm as they speed by on a motor bike. In a crowded airport terminal placing the bag on the floor or a seat for a few careless seconds can result in disaster. If you loose everything but your passport and money you can still survive with relative ease. Without these items the traveler's life can become quite complicated.

In selecting your personal carry-on keep in mind that this bag will be your constant companion. You will carry it on you shoulder or back from one end of a busy airport to another. During small aircraft flights you may have to hold it on you lap, as well as on crowded buses and in taxis. Consider weight and size relativity to your own size and strength.

As previously mentioned, style and design is again a matter of personal preference and need. Large camera bags are excellent for camera equipment and some other items. However, they are expensive, somewhat limiting in carrying capacity, and *obvious*. If you carry a large camera bag you stand a much greater chance of having your carry-on stolen in airports, restaurants, and on the street. For the average thief, a large camera bag represents the possibility of several hundred to several thousand dollars in cash in many foreign countries.

I have carried camera bags and camera cases; however, I presently place my lens and extra camera body in foam padded bags/containers and place them in whatever carry-on I am using for a particular trip. I have also reduced the number of extra lens that I might carry during my travels by purchasing a zoom lens for my SLR camera.

Carry-on size bags come in many configurations ranging from the single compartment style to ones with ten or more little compartments and pockets. Compartments are great for organizing, however, you must remember what compartment you put various items in in order to avoid lengthy searches.

How much clothing can or should you pack in your carry-on? Well, that is a question that only you can answer. It depends on your mode of transportation, the purpose of the trip, you personal life-style, and many other factor. I have seen college students survive for a week with three T-shirts, a pair of shorts, a pair of jeans, and running shoes. Obviously, they can pack everything the need for their entire trip in a small carry- on.

On the other hand, most of us like to be a bit more complete in the selection of our wardrobe. If a person is skillful in selecting and packing a wardrobe, they can pack everything in their carry-on that they will need to travel and live comfortably and in style for a week. Personally, I need a little more space. First, I am a traveling diver. My carry-on is filled with the type of materials listed above. Second, I wear a size 15 shoe. One extra pair of shoes would nearly fill a carry-on bag.

When packing my carry-on bag I generally include a few select items of clothing which will allow you to live in reasonable comfort, style, and dignity for 12 to 24 hours in the event that your luggage is temporarily misplaced by the airline. For travel to the tropics usually include a short sleeve knit sport shirt or T-shirt, a change of underwear, running shorts, lightweight casual pants or shorts, a swim suit, and sandals. In addition some travelers include a light sweater, winter or summer, for added comfort on air conditioned aircraft. When flying south in the winter I leave room for the windbreaker and sweater that I wear to/from the airport.

The extra clothes that you include in your carry-on may also be useful in other emergencies. During one trip I had the misfortune of spilling a cup of coffee on myself. The extra shirt and pants made the rest of my trip much more comfortable. Your carry-on bag and it's contents are some of the most important considerations in preparing for your travel experience.

Additional Suggestions

Every *seasoned traveler* can offer helpful hints for a trip such as the ones described below, and I am no exception. In selecting and packing your personal clothing and equipment, consider the following:

You may encounter rain; a small folding umbrella can be useful on city streets, foot trails and open river boats.

Select field clothing that will blend more easily with the background; avoid white and bright colors since these colors can scare wildlife.

Include a quart or 2 pint size water bottles and powered drink mix.

A multipurpose pocket knife (Swiss army-type) can be very useful, even a necessity, for most travelers.

Field guides and selected reference materials can make you adventure experience much more complete; however, you can't take a complete library; coordinate with other travelers.

Type a card with your name, address, specific health/medication information, and persons to contact in the event of an emergency; seal it in plastic and carry in your shirt pocket at all times.

A small flashlight is useful for nights at remote hotels or lodges where the power may be turned off or fail.

An alarm clock will keep you on time for breakfast and departure; no wake-up calls in the jungle.

Tissue mini-packs and premoistened towelettes can make the day much more civil if you find dirt and sweat offensive; a personal hygiene necessity for some individuals.

Take several watertight plastic bags (zip-locks will do) to carry everything from snacks to wet clothing to cameras and film (protect from moist environment).

Take an ample supply of film; film purchased abroad can be unreliable and expensive.

Take a compact pair of binoculars; you may be disappointed if you don't.

Take a generous supply of sunscreen and insect repellent.

A compact, select repair kit might be useful (needle, thread, buttons, nylon cord, etc.).

Sunglasses are a necessity for most people; spares if you wear prescription glasses.

Books, writing materials, and compact "backpacker-designed" game sets can be nice for a rainy evening in a backcountry lodge.

Take your compact, personal first aid kit with you in your shoulder bag.

When traveling in populated backcountry consider keeping your passport, money, and other important documents in a waterproof plastic bag and carry in your shirt pocket or elsewhere on you person; passports are worth a lot of money on the black market and they can disappear if left in rooms and Land Rovers.

When entering and traveling in Central/South American, African, and Middle East countries avoid carrying your equipment in military surplus ammo cases or other military type containers; jungle warfare-type clothing is also likely to attract unwanted attention.

Self-Sufficient Travelers

An adventurous diving trip in the tropics is glamorous, exciting, and one of the greatest challenges any traveler can imagine. However, keep in mind that you often find yourself in a foreign country and remote location away from the secure familiarity of hometowns and common language. You leave behind the corner drug store and K-Mart. Even if you are on a fully guided tour you must equip yourself with a high level of self-sufficiency.

For the adventurer, the need for independence is even greater than for many other international travelers. Whether your adventure in scuba diving in the Caribbean, rafting an East African river, or backpacking in a park near your home, you have decided to vacation by taking part in the world around you, not just watching others. And this means that you most stand on your own two feet, from start to finish.

Planning, researching, and organizing is the secret to successful and enjoyable adventure travel. To the seasoned traveler many of the suggestions given in this handbook will seem obvious. "Doesn't everyone know or do that?" Another might say, "Why are you making such a big deal out of selecting clothing or equipment and packing?" "Relax, throw in a couple of extra T- shirts and go for it!" To each, their own! For the person who has never been to Bonaire or Belize or New Orleans, the thought of preparing for such an adventure can be overwhelming.

INSURANCE AND THE TRAVELING DIVER

I advise all travelers to have insurance policies which will cover their possessions and health. Crime is epidemic throughout the world. Standard compensation for lost luggage is only a pitiful fraction of the cost of your diving and photography equipment.

Injury and illness can result in expenses beyond the limits of you imagination. You may be so ill or seriously injured that you will require evacuation by helicopter or an air ambulance to fly you home. An air ambulance from an island in the Caribbean could cost $15,000 alone. A single hyperbaric chamber treatment can cost $2,000. The average treatment cost for a diving injury is slightly over $6,500 and treatment of a serious injury can easily exceed $30,000.

Health Insurance

Hopefully, you will never be injured while traveling or diving. However, if you are, you must have complete insurance coverage. Does you medical insurance policy cover hyperbaric treatment for decompression sickness or air embolism? Does it cover you for injury sustained while diving in the Red Sea?

You must take time to read the small print before purchasing a policy. In some policies this small print can be tantalizing or even borderline dishonest. Watch for exclusions! Some people might be surprised to find that their insurance specifically excludes coverage if you are injured while participating in certain sport or adventure activities in some foreign countries.

Health care insurance policies can vary considerably. The prudent traveling diver will review his/her policy to assure that the following, at a minimum, are covered:

* Does your policy pay for hyperbaric treatment of air embolism and decompression sickness plus follow-up therapy?
* Are you insured if your injuries are sustained while traveling and diving in the country to which you plan to travel?
* Will your insurance pay for an air ambulance back to the United States? Helicopter evacuation of an injured person?
* Are you covered for hospitalization in a foreign country? Physician services?
* Are there any specific exclusions in your policy that might forfeit payment for injury or illness that occurs during your planned travels?

I seriously doubt if most traveling divers honestly know if their medical insurance policy will cover the types of injuries or illnesses that they might sustain while traveling and diving abroad. Do you?

If your insurance policy does not cover medical cost for the treatment of diving injuries and payment of air ambulance service, consider a special diver's policy that does cover these cost. A diver's policy is available through the Divers Alert Network (Box 3823, Duke University Medical Center, Durham, North Carolina 27710) and other companies that specialize in diver's insurance. Regardless of your current medical coverage, I feel that it is wise for all divers to consider this special DAN diver's policy.

Insurance for Equipment and Personal Property

Loss of luggage is a fact of modern day travel. Generally, the loss is only temporary and your luggage will arrive on the next flight. However, any time you travel, especially to developing countries, you do risk permanent loss. What do you do? Do you leave everything valuable at home and travel with a T- shirt and pair of old jeans carried in a paper bag? Do you forgo the pleasures and comforts of nicer clothing, cameras, and convenience items? Do you purchase special "travel insurance" policies? How can you protect yourself?

There is no simple answer and there is no single solution to meet everyone's personal needs. First, plan to pack clothing, recreational equipment, and other items that you feel will make your trip comfortable and pleasant. Second, accept the fact that you might lose everything! Keep in mind that almost anything can be replaced. If you have an item that is irreplaceable, leave it in a safe place at home. Third, develop a replacement strategy before you lose it!

Replacement strategy involves "having enough money to cover your losses." If you are independently wealthy, you can stop reading here and go back to your travel brochures. However, most divers cannot afford loss of cameras, diving equipment, and clothing. Thus, we must turn to that great American institution called "insurance."

The word insurance brings many questions and misconceptions to the diver's mind. What kind of insurance should I purchase? How much coverage is needed? Will insurance really pay for the replacement of my equipment and clothing? Where do I get my insurance?

When I first started to travel extensively throughout the United States and abroad, I went to the friendly insurance agent that writes my homeowners policy. Some divers may have apartment or renters insurance. Others, especially students and young people, may still be covered under their parents homeowners policy. Keep in mind that every insurance company and policy is different. The coverage that one person has through company "X" may or may not be the same as that provided by your policy! Each individual must determine the exact terms and coverage of their personal policy.

For example, my home policy covers loss of my furnishings, clothing and other personal property up to a limit of $25,000. However, for loss of items *away* from my home (such as during travel, theft from my car or office, etc.) the maximum coverage is only 10% of that figure or $2,500. For the average traveler $2,500 is fairly reasonable coverage. But, what about divers and photographers?

Have you ever calculated the *replacement cost* for your diving equipment, luggage, and travel clothing? Do it! And have a good stiff drink on hand when you read the total. The key word here is *replacement cost!* Unless you have specified and paid an additional premium your insurance carrier may pay only the current market value of your *used* equipment. For example, your MX-2001 regulator might cost $500 to replace today, however, the value of the regulator that you lost is only $125 as a used regulator. The insurance company is only obligated to pay the value of an "equivalent" item. I pay $29 extra insurance premium annually on my $25,000 coverage to have replacement cost coverage. Therefore, I will get $500 for my regulator loss.

Is $2,500 enough coverage if I am an underwater photographer? No! I have gone one step further for my camera equipment. Keep in mind that there is *unscheduled* and *scheduled* coverage. Under the unscheduled coverage terms of my policy, normal loss circumstances such as fire, theft, and vandalism are covered. However, what if I flood the housing or drop the camera overboard in 700 feet of water? Right, it is not covered! My insurance agent told me of a client who went on a pack trip in the Grand Canyon. His expensive cameras and other equipment were being carried on a mule. *The mule slipped and fell off of a 1,000 foot cliff.* Under his regular insurance coverage, the company *did not pay*! If these items had been "scheduled" (specifically listed in his policy and an extra premium paid) he would have received full replacement payment. I pay about $2 per $100 value for selected scheduled items.

Is $2,500 enough coverage for my clothing, luggage, and diving equipment? Not really! My decompression computer alone cost nearly $600 and my wet suit cost nearly $350. If I were traveling in a colder climate, my dry suit with underwear would cost about $1500 to replace. I can extend my "away from home" coverage limits at a cost of $11 for the first additional $1,000 coverage and $9 for each $1,000 beyond that value up to a total additional coverage of $6,000.

Keep in mind that coverage under my homeowners policy is for 365 days per year, 24 hours per day at any location unless otherwise specified in the policy. And be sure that your insurance covers your equipment in all geographic locations to which you plan to travel and en route. A special travel policy may only cover you for a short specified time period, on a specific trip, and/or at specific locations. How many weekends do you travel to dive? How many nights do you leave more than $1000 worth of diving equipment in your car outside of a bar after class? How many days per year do you carry your cameras?

I pay approximately $120 extra per year to cover *scheduled* photographic equipment, an additional $3,500 coverage on *unscheduled* items away from home, and replacement cost for all of my personal items (including home furnishings and clothing). This may sound like a lot of money to some, however, have you ever dropped a Nikon camera into a raging river in an effort to save your own life? At least, I have peace of mind when I have to change planes in San Juan. Those of you who travel the Caribbean know what I mean.

Now that you have read this far, *do not believe a thing that I have written!* Go get your personal insurance policy and read the fine print. If you can't find it or you do not understand the insurance policy language or if you are simply unsure, make an appointment with your insurance agent. And, do not accept verbal explanations of coverage or conditions. Ask to have conditions that are not clearly stated in the policy put in writing. Also, find out in advance what you must do to file and PROVE a loss. You must know all of this before you leave for a trip.

When preparing for a major trip I anticipate that I might lose my luggage and equipment. What can I do in advance to make dealing with such losses easier? First, I make a list of all items that I plan pack for the trip by bag or suitcase. I leave one copy at home and carry a copy with me on the trip (with my passport and other papers). Be certain to include serial numbers of cameras, lenses, regulators, decompression computers, and so on.

I generally list the retail value of all expensive items such as regulators, camera housings, and dive computers. Sometimes I even estimate the replacement valve of my clothing and specify it on my list. In the event of a loss, this information can be very useful when filing claims and preparing police reports.

Always keep your receipts when you purchase diving, photography, and other expensive equipment. Be certain that your name and the serial number of the equipment is on the receipt. This may be your only proof that you actually purchased the item.

I always make certain that I pack my equipment in bags that do not have diving symbols, store names, etc. printed on the outside. *Do not advertise the contents of you luggage!* Keep it plain and simple!

Always acquire information and conditions pertaining to losses from your carrier and travel agent. Generally, this information is printed on your airline ticket back and tour information brochures. If not, request this information, *in writing*, from the carrier and tour agent. Do not accept the verbal explanation of a travel agent or ticket agent.

In the event of a loss, always report your loss to the carrier immediately. Complete appropriate forms and be sure that you receive a copy. If your losses occur in a hotel or location not associated with transportation services, file a police report and obtain a copy for your files. Ask the hotel management to prepare a letter acknowledging your losses, the location, the time, circumstances, etc. Obtain the name and address of a person in authority that your insurance company can contact if necessary. If your losses are extensive, an immediate and direct contact between your insurance agent and the hotel/resort manager may be very beneficial in processing your claim. Include the name, address, and telephone number of your insurance agent with your travel papers.

You should always travel with enough extra money (credit cards, travelers checks, etc.) so that you can purchase necessary items to continue your trip. Some carriers have specific conditions under which they will reimburse you for some
situations and cost.

There is no single or simple solution. Hopefully, you will never experience a significant loss during your travels. However, it pays to be prepared. A few moments of thought and some additional insurance coverage can give you considerable peace of mind.

TRAVEL DOCUMENTS

A passport will facilitate easier entry into another country and more expedient re-entry to the U.S. upon return. Many Caribbean countries and Micronesian islands do not require a passport. However, in most of these countries some proof of citizenship such as a birth certificate or voter's registration card is required. A driver's license is unacceptable. On the other hand, countries such as Australia and Belize absolutely require a valid passport and you will not be allowed to board an airplane to one of these countries without producing a passport.

I encourage an person planning to travel outside of the U.S. to obtain a passport. This is probably the best form of identification that you can carry for overseas travel. A new passport now cost $42 ($35 if you have an old passport issued within the past 12 years) and is valid for 10 years.

You can obtain information and usually apply for passports at a county clerk's office or major post office. You can apply in person at a passport agency in Boston, Chicago, Honolulu, Los Angeles, Miami, New Orleans, New York, Philadelphia, San Francesco, Seattle, Stamford, or Washington. Consult a phone directory for the location of these offices. You will need an application, two identical photographs (taken within the last 6 months), and a certified birth certificate. Passports may also be obtained by mail if you have had one within the past 12 years (issued after your 16th birthday).

In addition to a passport, some countries such as Australia require a visa — an endorsement/stamp placed on your passport by an official of the country you wish to visit. Each country has it's own regulations regarding visas. Consult your travel agent and/or the consular representative of the country you wish to visit for information. Foreign consular offices are located in major cities such as Chicago, New York, and Washington. Travel agencies handling overseas travel generally have this information. If you need a visa, be certain to apply several months in advance of your planned trip. Delays are not uncommon.

Most dive operations request that you produce a diver's certification card in order to prove that you can dive. In reality the certification card proves nothing about your present diving skills or knowledge and I recently encountered a diver operator in Hawaii who didn't even request it. Regardless, your most current certification card must be included included with your travel papers.

A few dive operators will ask to review your logbook. In reality, this is document can provide the divemaster with a better insight into your current diving capability through that frequency, depth, and environments of past dives and the time interval since your last dive. I record dive information on a small slate during the day and transfer this information to my logbook each night.

Other papers and documents that you might consider including in your documents folder are as follows:

* Most recent medical examination report;
* Eye glasses/contact lenses prescription;
* Equipment checklist with serial numbers;
* Camera registration for U.S. Customs;
* Wardrobe/personal items checklist;
* Special medication prescriptions;
* Written information on specific medical problems;
* DAN insurance card;
* Health insurance identification cards; and
* Written instructions on what to do and who to contact if you are seriously injured and cannot act on your own behalf (especially if you are not traveling with a relative or close friend).

AIR TRAVEL

Most Americans are seasoned air travelers and air travel is the major form of transportation in dive travel. Knowledge of the size an type of aircraft that you will be traveling on during various portions of your trip is important in determining what you will wear and how you will pack. Airplanes may range from wide-body commercial jets to small inter-island propeller aircraft to sea planes or helicopters.

On large air-conditioned jets you will be quite comfortable in slacks and a shirt. Some travelers who chill more easily include a lightweight cotton sweater or jacket with their carry-on items. Travel in lightweight loose, comfortable clothing that will be appropriate for your tropical destination. On inter-island flights without air-conditioning shorts and a polo shirt may be more comfortable.

Do not carry weapons or illegal drugs. Airport security systems are capable of detecting almost anything from a small knife to marijuana. Never include dive knives, scissors, guns (real or toy), or mace in your carry-on bag. Any potential weapon may be confiscated. However, I do generally carry my small Swiss army knife in my carry-on bag.

There is a good chance that you will travel on two or more flights to reach your destination. Traveler to the Bahamas and Caribbean will generally fly from their hometown to a gateway airport such as Miami, Atlanta, or Dallas where they will change plane for their overseas destination. Be certain that you have sufficient time to make connections at your gateway airport. It is wise to plan a minimum two hour stopover for connecting with your overseas flight. To minimize the possibility of luggage loss when changing airlines, most travelers check their luggage from home to the gateway city and then recheck it to their final destination. Be certain to check the destination tags when you check you luggage.

During your flight, eat lightly and keep alcohol and coffee consumption to a minimum. Breathing the dry air in the aircraft will cause dehydration. Consumption of large quantities of water and apple juice is recommend; avoid beverages containing caffeine. On long flights, especially when changing time zones, sleep as much as possible. On long overseas or cross-country flights I often take a sleeping pill to promote sleep. This seems to help in dealing with jet lag. When you are awake, get up, walk around the cabin (conditions permitting), and do some isometric exercises in your seat.

Upon arrival at you overseas destination you will be welcomed by two different individuals. First, an immigration official will ask for your passport or proof of citizenship and the immigration document that you complete during your flight. This official will also want to know how long you intend to stay and where you will be staying. Generally, your passport will be stamped and you will receive a copy of the immigration form. Do not lose this form since you will have to return it upon departure. Keep it with your ticket and passport.

Next, you will present your luggage to a customs official who will ask questions regarding it's content. This inspector will be looking for fire arms, explosives, illegal drugs, large sums of cash (undeclared), contraband, and fresh plants, fruits, or vegetables. Have your luggage unlocked and ready for inspection. This official has the right to require you to open any or all bags. The inspection may be no more than a few questions and a marking of your bags or it may be quite lengthy and complete — probably something to do with the officials sex life.

Be certain to reconfirm your return flight shortly after arrival at your destination. Flights departing from islands are often overbooked; failure to reconfirm your reservation may cost you your seat. I remember a group that spent three extra days in Belize City because of failure to reconfirm the return flight.

Do not attempt to dive on the day of your departure. Although some publications and tables do indicate that you can fly with a four hour or less surface interval following a no-decompression dive, DON'T! The risk of decompression sickness is ever present in divers. In some rare cases, symptom onset is delayed for up to 36 hours. Flying soon after diving is a foolish risk. Most resorts and dive operators do not permit diving on the day you are flying and encourage you to have at least 24 hours following diving you fly. Even this is not complete insurance against developing symptoms of decompression sickness, especially if you have been an aggressive diver throughout the week. There is also a FAA regulation that prohibits flying immediately after diving.

Your preflight hours can be spent cleaning and drying equipment, sightseeing, and relaxing before your long journey home. Take care in packing and use your checklist to assure that you do not leave anything behind.

Go to the airport early and plan to check in for your flight at least one hour before departure. Some traveler check in two hours before departure. Early check in can assure you a seat if the plane is over booked. Have your passport, immigration form, ticket, and departure tax money ready. Whenever possible allow for 2 to 3 hours in your gateway city. Caribbean flights are often delayed and some additional delay can be expected at customs, especially during high travel times.

When you re-enter the U.S. you will have to pass through immigration and customs. Today this is a rather simple and comfortable procedure for U.S. citizens in good standing. There can be long lines and some delay especially during peak travel times. Do not attempt to bring home animals, plants, fruits, or vegetables regardless of what the foreign salesperson says. Souvenirs made from endangered animal hides or turtle shells will be confiscated by customs officials. Many travelers return with their full allotment of booze; duty will be charged if you exceed your allotment. You may wish to impose on no drinking friends to increase you return capacity.

Do not attempt it return to the U.S. with any illegal drugs or marijuana. The risk is too high and the penalty too severe. Keep in mind that the islander who sold it to you may have already collected a reward for identifying you to officials before you even left the foreign country. Let me assure you that a strip and body cavity search will not rate high on you list of erotic experiences.

Relax and enjoy your flight home. If you have a long stopover in a gateway city I recommend that you take advantage of the day rate at the airport hotel (if available). Short term stopovers may be passed away with a long, relaxed meal in the airport hotel dining room. You may pay a few dollars more than you would in an airport lobby snack bar, however, the difference between the lobby and rooftop dining room at the Miami airport almost beyond description.

LOST LUGGAGE

The airlines and other carriers throughout the world have spared no expense in their training of personnel in the art of misplacing luggage. You may plan a simple trip from New Orleans to Belize City. God and revolutions permitting, you will arrive at your Central American destination. However, your luggage may continue on to enjoy the sights in several other Central and South American cities. Twenty-four to forty-eight hours later your free-spirited luggage may rejoin you, tired and worn from its exciting adventure.

Unfortunately, anytime you travel, especially in the Caribbean, you may find yourself at a beautiful island resort with only the clothes you are wearing and items that you had the foresight to pack in your carry-on. *Lost luggage is a fact of life! Accept it and learn to live with it! You can!*

First of all, tears, foul language, temper tantrums and fake coronaries do not impress airline personnel. Years of training and experience protect them from emotional involvement. Simply fill out the appropriate forms carefully and politely. Do not be the Ugly American! Second, take 10 mg. of Valium which you packed in you carry-on for just such an occasion. Third, prepare to initiate an Emergency Plan. Five such plans are summarized below:

Plan 1: Relaxation

No doubt you are tired and hungry. You took the vacation because you needed to get away and relax. So spend the day eating and sleeping. Try it, you might like it!

Plan B: Shopping and Sightseeing

Most tourist and divers spend at least 1/2 to a full day shopping and sightseeing. Why not do just that on your first day without your luggage and diving equipment? Your luggage is having a good time in some other city or country. Why shouldn't you! Relax and enjoy! Find a friend, rent a car, and have a beautiful day.

Plan C: Skin Diving and Sun Bathing

If you are a diver you should have your prescription mask in your carry-on bag. Why not borrow or rent a pair of fins, a snorkel, and a small BC and enjoy a day of skin diving, beach combing, and sunbathing. The may be some fast food places on or near the beach and, maybe, even some fast women (or men). There may even be a nude beach!

Beach walking, swimming, and skin diving can be a great way to relax and enjoy the day. A word of caution! Take special care to prevent sunburn. Don't compromise the rest of your trip with a first day sunburn.

Plan D: Go Scuba Diving

Most resorts are prepared for such losses and will have a complete selection of rental equipment for your diving pleasure. If you are a diver, all that you need is your C-card and credit card. At some resorts you won't even need the C-card. Expensive? Yes! Worth it? Absolutely, especially if you have your heart set on scuba diving. You just can't travel without contingency funds. You are spending $1200 for a diving vacation. Spend another $50 and enjoy yourself.

Plan E: The Final Option

Express your outrage and anger to the airline, resort operator, and your fellow travelers. The take the next flight back to the mainland and home. If you are that uptight, *do it*! You are probably also an unsafe diver and another unsafe dive is the last thing that we need on the island.

TIPPING

Tipping is a fact of life throughout most of the world. Local customs imply tipping porters/baggage handlers, taxi drivers, waiters/waitresses, maids, and dive guides in most countries. The bigger the tip, the better the service. For example, if you want extra towels in your room you might try tipping (or bribing) the maid on your first day.

Many of the service people you encounter rely on tips for more than 50% of their income. Most dive resort hotels automatically add a 15 to 20 percent service charge to your hotel and restaurant bill. This surcharge is both legal and, some say, appropriate. This goes into a general fund to be divided among employees, probably after management has taken a cut. *Gratuities are now included in most dive travel package prices.* Be certain to consult your dive package information packet or your agent for specifics on gratuities and local tipping customs. Keep in mind that tipping may be prohibited in some underdeveloped societies. Such quaint customs will probably disappear as we enter the twenty-first century. If in doubt, ask your tour leader or the hotel management what local custom is.

Generally, dive guides and boat crews are not included in the hotel gratuity program. Be sure to consult you dive travel agent in advance to see if the package gratuity also covers diving operation personnel.

PERSONAL SECURITY

Crime is epidemic throughout the world. Tourists, especially us rich Americans, are singled out as easy victims. The criminal element may even exist among your fellow travelers. I have already discussed insurance and inventory list. Common sense precautions can prevent or, at least, minimize your losses.

Defensive Traveling

First, never take anything that you do not plan to use. Remove unnecessary credit cards, membership cards, pictures, and papers from your wallet. Keep in mind that you will not use your department store charge cards in Belize City. If you do not plan to rent a car, leave you driver's license at home. In other words, by reducing the number of cards and important papers to a minimum, the impact of a stolen wallet won't be as severe.

I generally travel with only one credit card; no more than two. A foreign thief can run up thousands of dollars in charges before the overseas cancellation notice is effective, generally in the first two hours.

Pickpockets, Snatch Thieves, and Burglars

When possible, I keep my extra money, credit cards, and documents in the hotel safe. Most dive resorts provide this service. Locking these items in your luggage or hiding them in your room is not adequate protection.

Pickpockets make an excellent living overseas. I generally carry money and credit cards in my front pants pocket. The rear pocket is easy. A go at the front pocket is more likely to be detected, if attempted at all. Money belts, elastic calf wallets, and neck wallets are carried by some travelers.

Pickpockets often work as teams and use every trick from dumping ice cream on you to having old ladies drop a bunch of coins to distract you. When you stop to help the old lady, an accomplice picks your pocket or grabs your luggage. There is one general rule for avoiding pickpockets and snatch thieves — never carry a shoulder bag, especially if it contains either your passport, air ticket, or money. They are prime targets since they can be razor-cut or snatched easily. A shoulder bag can be skillfully emptied by slitting the underside with a razor. A traveler can be injured when a snatch thief grabs the bag from a moving motorbike. Your belongs are also an easy target on the beach while you sleep or swim.

Keep track of your luggage at all times. Do not leave it sitting on the curb when you arrive at the airport. Be certain that it is tagged and placed on the conveyer belt or cart. Unattended luggage is an easy target and can disappear in seconds. This is especially true of carry-on bags; never set your carry-on bag down and leave it unattended for even a few seconds in any public place including rest rooms. Keep track of your luggage during airport departure and arrival, taxi loading and unloading, and hotel arrival and departure.

Keep in mind that a thief can quietly enter your room while you sleep and remove your valuables in a few minutes. If this can happen on the 12th floor of large hotels in the states, it certainly is possible where ground floor windows and doors of island hotels are left open for ventilation. Some travelers have even lost their watch from their wrist while they sleep. Lock your hotel room at night while you sleep. However, the lock requires a key, leave it in the lock in case of fire. Securing you valuables before retiring instead of leaving them on the table by a window is a reasonable precaution. Improvised trip alarms may also be designed by those with more creative minds.

Most annoying is the theft of documents and items which are valueless to the thief, but extremely important to you. Passports and air tickets often fall into this category. In some countries the casual thief may not be able to benefit from an airline ticket. Often it is advisable to leave your suit case unlocked in your room so that the thief can rummage through it for the nonexistent valuables rather than steal the entire suit case. Often you can recover these items by offering a good reward. Certain elements of police departments have good contacts with the criminal community. Broadcasting the reward through taxi drivers, hotel employees, town guides and the like. You might be surprised at the results.

Mugging and street theft is rare, however, when it does happen it is more likely to occur in large cities such as San Juan, Kingston, and Nassau. I have known of divers who have been mugged in these cities, especially late at night. If you must venture into the streets late at night, travel in groups on lighted streets.

It is often said that you should carry some money to prevent a disappointed mugger from becoming vicious. Keep in mind that your diver's Rolex can be an invitation to a street mugger. Some seasoned traveler wear a cheap wrist watch, especially if they dive with a microprocessor. If you are approached in a criminal fashion, don't attempt to fight over the $10 in your pocket — donate it to the needy without comment or unnecessary delay. I have often carried an old wallet with 10 or 20 one-dollar bills (appears to be a bigger haul on a dark street) and an expired credit card (with some numbers destroyed) when my travels include stays in strange cities.

If attacked, scream, kick, and run — mainly, run! Even if you are civilian trained in martial arts keep in mind that there is a world of difference between practicing with your fellow students and dealing with a mugger on the street. Instead — and best of all — exercise extreme retrograde mobility.

Also, do not carry weapons in foreign countries. I have heard diver speak of carrying their "dive knives" when they go out on the town. Let me assure you that you do not want to be caught carrying a weapon by the local police. As far your defense capability with a knife, I doubt if few readers really have any idea of how to use a knife. I can guarantee you that there are people on the streets that can fillet your entire body before you can find your weapon.

The degree of security required will depend on the location. Most group leaders will inform you if there have been problems in the past. In fact, theft at dive resorts in the Caribbean is apparently very minimal. However, use common sense precautions and reduce your personal risk.

Money Management

Travelers should carry a small amount of money in cash and the rest in traveler's checks. The cash should be in small bills — ones, fives, and tens. Small bills are desirable for tips, taxi fares, drinks, and so on. Many travelers carry 20 to 30 one dollar bills for hotel and airport tipping. Distribute your cash and traveler's checks among two or more locations. Be certain to keep a record of your traveler's check numbers separate from the checks. You will need the numbers if they are stolen or lost.

It is wise to make purchases and pay for local services with local currency. Ideally, exchange U.S. dollars for local currency at a bank or currency exchange immediately upon arrival. The U.S. dollar will generally always be accepted, however, you will not generally receive a favorable rate of exchange form local merchants and taxi drivers. Do not exchange excessive amounts since you may lose a few dollars when you covert the extra to U.S. dollars at the end of the trip.

Keep in mind that you will generally have to pay a departure tax at the air port when you leave a country. Occasionally, this tax must be paid in local currency. Have the correct amount with your ticket and passport at check-in.

Keep your money with you at all times. Do not leave it in your room while you go diving or to dinner. Some divers place it in a watertight box or plastic bag in there dive bag.

Bribery

Bribery is immoral and offensive — an insidious disease. Although travelers should generally refuse to pay a bribe, there are rare occasions where it is almost essential. Fortunately, the need bribery is rare at most popular overseas dive locations. All travelers should recognize when someone is hinting for a bribe and if they are not bribe-conscious they may suffer. *Never offer a bribe unless you are fully conversant and current with the customs of the country.*

If you you are warned in advance or sense that a a bribe is expected you can place a few dollars inside your passport or other document that you are handing over. This enables you to deny that you knew the money was there. Another method if you are said to be in violation of a local law or faced with a potential arrest situation, is to say, "In my county we often pay an on-the-spot fine, is that appropriate here?" If this is followed by a friendly gleam in the eye, you can conclude that a bribe is generally in order [1].

Do not assume that an official who accepts a bribe will be prepared to do anything illegal. Through bribery you are attempting to persuade the individual to do his job, or not do his job; or to do it more quickly or more slowly. You do not bribe him to break the law. He will be angered at the mere suggestion [1].

For the adventurous and slightly crazy diver who travels to and through extremely politically sensitive and warring counties ready cash for bribery is an important item in a survival kit. If you happen to be in the wrong place at the wrong time and all hell breaks loose, your only escape might hang on the ability to bribing taxi drivers, half-drunk soldiers or guerrillas, and ticket agents or pilots.

Drug Dealers and Deals

Drugs are readily available in most tropical countries. Some Bahamian and Caribbean Islands are major drug gateways to the United States. The advise relative to drugs is simple. Do not take them with you! Do not buy them when you get there! If approached, and you will be, politely say "No thank you!" and walk away. Do not invite conflict or trouble. You can not win with the dealers, the police, or customs!

READING AND RESEARCH

There are hundreds of books, booklets, and pamphlets on traveling and various geographic locations frequented by travelers. There are books on how to travel such as *Trouble Free Travel* [2] and *The Tropical Traveler* [1]. If you care concerned about health problem you might consult a book such as *The Traveler's Medical Manual* [3]. A visit to your local library or bookstore could provide you with information on everything form geography to flora to history and local customs for the area you plan to visit. Don't be content with just the information that you find in *Skin Diver Magazine* and the travel brochure.

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Manuscript completed: 17 June 1990

NOTES:

CHAPTER 8-4

SURVIVAL IN TROPICAL WILDERNESS

The tropics, a zone approximately 2,500 miles wide that circles the earth at the equator, has a broad variety of climate, vegetation, and terrain. Here we find the tropical rain forest or jungle, the mountainous rain forest, mangrove and other swamps, savannas or open grassy plains, and semiarid coastal areas. In addition, there are thousands of small volcanic or carbonate rock islands.

Few travelers ever consider the possibility that they might find themselves in a survival situation. If a large jet crashes in the jungle or ocean, the chances of surviving the crash are low. However, if you are a more adventurous traveler you will no doubt fly over jungle and ocean areas in small planes at one time or another. And, the possibility of surviving an emergency landing in a small plane are much higher.

You may travel by motor vehicle into the interior of tropical countries to visit ancient ruins, observe wild life, or seek out new dive sites. Your vehicle may become disabled or you might be forced by hostile natives (i.e., Central American military factions) to abandon it.

Could you survive in a life raft at sea, in a jungle, or on a uninhabited island for several days? A complete discussion of survival is far beyond the scope of this paper, but adventurous tropical travelers are encouraged the at least read a manual on survival. Several civilian survival manuals are available in local bookstores. Since a number of the survival manuals that I have reviewed concentrate on mountain wilderness survival, be certain that the manual you select includes information on survival in the tropics and at sea. I found the *Air Force Manual 64-3, Survival* (training edition) to be an excellent manual with information on survival in all climates. This manual was the source for much of the survival information presented in the handbook. A civilian manual that contains much of the information included in the Air Force manual is titled, *The Survival Book* [1].

I cannot overemphasize the importance of preparing for a survival situation. In all probability, you will never really have to survive for days in a jungle or on an island. However, taking a few moments to think about it, reading a manual, and including a few basic items of survival equipment in your kit could make the difference someday. Unfortunately, most civilians never have the opportunity to enroll in a wilderness survival course. If you ever do, please take advantage of the opportunity.

Regardless of how much survival equipment you have available and how good the techniques for its use, ***you must still deal with yourself***. Man's psychological reactions to the stress of a survival situation often renders him incapable of utilizing available resources. One of the most important requirements in surviving is the ability to immediately accept the reality of the emergency situation and react appropriately.

Whether you are alone or in a group, survival may depend more on ***personality*** than upon the danger, weather, terrain, or nature of the emergency. You will be afraid! Whether this fear will lead to panic or act as a stimulus to greater alertness, whether fatigue will overcome you or you will successfully draw on your physical reserve to survive, even whether you will be severely sunburned or insect bitten, all are, to a large extent, dependent more upon ***you*** than the situation or environment.

The greatest enemies to your survival will be fear, pain, cold, thirst, hunger, fatigue, boredom, and loneliness. Everyone has experienced these, but few individuals have known them to the extent that they have threatened their survival. The more you know about these factors and their effects on you, the better you will be able to control them, rather than let them control you. Fear can be your worst enemy! Don't let it control you!

For most people, dealing with fear and anxiety (unconscious fear) will be the most important factor in survival. Fear and imagination can plague nearly every individual who is face-to- face with possible death. Fear can turn to blind panic and cause even experienced, knowledgeable individuals to injure or kill themselves in the intensity of terror. Fears that must commonly be controlled include fear of the unknown, fear of being alone, fear of animals, fear of darkness, fear of discomfort, fear of suffering, fear of death, fear of society's response to their situation, and fear of personal guilt. Some individuals will be so overwhelmed with the situation they will simply give up and do nothing — one of the surest ways to lose your life. Others will panic and attempt to run from the situation. This can lead to exhaustion and loss of the physical ability to survive.

The lack of drinking water is a critical factor. In fact, water is the single most important factor in determining survival. Without it the presence or absence of food is of little importance. You can survive many days without food if you have water. ***Do not attempt to drink sea water!***

Whenever traveling in or flying over remote areas, I encourage people to carry a small survival kit. I am certain that most readers will feel that this is an unnecessary precaution in modern day travel. That is quite all right. Most divers probably didn't care for my opinions on buoyancy compensators either. The contents of a simple survival kit are listed at the end of this paper.

JUNGLE SURVIVAL

The first thing that you must do in any emergency such as an airplane crash is to remove yourself from physical danger such as fire and tangled debris and evaluate your physical status. Are you injured? How serious are the injuries? Following this assessment, perform what ever first aid procedure that might be required. Loss of blood can lead to shock and weakness. Even minor cuts and abrasions may become quickly infected in the jungle.

When the first aid is completed, sit down, relax, and calmly evaluate your situation. You may want to get out of the jungle as fast as you can. This is a result of fear of the unknown! Do not panic. Get any signal devices ready for immediate use and make an inventory of everything that you have that might help you survive. The first few hours are hours of decision.

Can you or the crash site be seen from the air? If you can determine that your position is plainly visible from the air, the you may wish to stay put and await rescue. If you are visible and not subject to physical threat, this is probably the best course of action. When your air craft does not arrive at its destination, a search will no doubt begin immediately.

On the other hand, if you find yourself in a situation where you are not visible from the air and the jungle canopy completely obscures your location and signal devices, you may have to travel to an open area if you wish your survival experience to be of a short duration. If you elect to travel, keep in mind the the biggest problems you face are care of injuries/illness, food and water, insects, and orientation. Your first aid supplies and skill can do much to curb illness and prevent infection. Proper clothing can protect you from insects. Water is generally readily available.

A plentiful supply of water is most important in the hot jungle. There is little air movement and you will sweat profusely. Drink several quarts per day. In jungles of the Americas, adequate water may be found in streams, springs, and pools. The problem is purity! Do not drink surface water without boiling or chemical purification. The few minutes spent purifying water may prevent weeks of illness or even save your life. Rain water is safe to drink if it is caught directly from the atmosphere. You can construct a catchment unit from plastic, nylon cloth, or sheets of metal. Also, rope-like vines and bamboo contain water that may be extracted for consumption. When seeking water from plants, you must keep one important rule in mine — ***never drink from a vine that has a milky sap!***

Where there are coconuts your survival problem is much simpler. Coconut palms grow near seashore, but may sometimes be found far inland. The coconut supplies you with food and drink. The rest of the plant can provide the trained individual with materials for shelter, clothing, and food. Coconut milk is best for drinking when the coconut is about half grown and the husk is green or light yellow. Coconut milk rates next to water and is better than beer as a thirst quencher. Do not drink the fluid of mature nuts as it contains oil which acts as a laxative and may cause abdominal pain.

Food is actually of minor importance in a short-term survival situation. For the unskilled individual, the energy expended in acquiring food may exceed that gained from the consumption of that food. In fact, you should have about ten days of body energy if you conserve it. If you face the possibility of a longer term survival experience, especially if you must travel back to civilization by foot, food does become a factor.

There are many food source plants in the tropics. However, keep in mind that many plants are poisonous and there are certain rules that must be followed in selecting plants for human consumption. If you do not know the plant or the rules, do not eat it.

There is an ample supply of food from animals in the tropics. Animals, birds, fish, and lizards caught with traps and snares provide excellent meat sources. The hindquarters and tails of lizards make delicious meals. Fish can be caught in streams using a spear, net, or hook/line. Be certain to cook all jungle animals and fish to kill the parasites and improve the taste.

What hazards do you really face in the jungle? First, you will not be at the mercy of snakes, man-eating cats, and hostile natives. Deep jungles are probably much safer than large cities and you will probably never see a poisonous snake or a large cat. Attacks by crocodiles, alligators, and caymans are rare and can be avoided by crossing rivers on a raft or scaring them by splashing water. The most feared fresh water fish in the South American tropics is the piranha. This fearless and voracious fish is more likely to be found in clear backwater bayous and eddies rather than swift muddy streams. Blood can attract them by the thousands and they can tear a victim's flesh from the bones in a matter of minutes.

There are poisonous snakes in the tropics, but you probably will not see them. By wearing shoes and taking a few simple precautions you are at little risk of being bitten. When moving about at night, inspect the ground with a flashlight or torch. If possible, sleep off the ground and inspect your bed before your get in. Do not put your hand on trees or into bush or grass without looking first.

The greatest hazard of the tropics is the flies, ticks, mosquitoes, and other insect pests that carry and spread disease. This means that you must take precautions at all times. Be careful about water, food, and personal cleanliness and keep your body well covered.

Bloodsucking leeches are common in damp forest in some parts of the world such as the Philippines and southeast Asia. In these areas special precautions are warranted. Stay out of water in areas that you know are close to human habitation. Any water body, especially still ones, may contain larval forms of human parasites. They can enter your body through the skin or in drinking water. Flukes are a risk in equatorial South American and Puerto Rico.

What you don't know may well constitute your greatest danger. For most individuals the jungle is a new, strange world — an unknown world. You may simple become frightened and panic do to lack of knowledge. If you intend to travel extensively in the tropics, take every opportunity to learn about the natural environment and the human population.

COASTAL AND ISLAND SURVIVAL

In a tropical emergency you are far more likely to land on or near a beach or coral island than in a jungle. Most of the air routes are over water. Much of the information on jungles is also applicable to these areas. Immediate measures must be taken to prevent sunburn and sunstroke. Major health hazards also include insect bites and careless consumption of poisonous fish.

One of your first concerns in coastal/island survival is finding a fresh water supply. Many coastal areas and islands have an ample supply of water, while others do not. In the Pacific, large volcanic islands generally have plenty of fresh water. On the other hand, fresh water may be very scarce on small volcanic and small coral island. One these small islands water may be trapped in small holes or hollows in the rock.

Keep in mind that near shore salt water may be found in these depressions as a result of wave and storm activity. Do not drink salt water!

If you are stranded on a rock island with little or no evident water supply, immediately construct water catchment devices. Small pits or holes can also be prepared in soft rock to catch rain. Upon treeless atolls or coral islands there is usually a plant known as pigweed or purslane. It is a short, nondescript plant that covers the ground in patches. It has a reddish hue and the stems are fleshy. All parts of the plant except the roots may be chewed for moisture content.

On seashore beaches, fresh water can often be found by digging a hole behind the first roll of sand dunes. Stop digging as soon as you hit water. The first water you strike will be fresh or nearly fresh; if you dig further you will hit salt water. Dig several shallow holes to increase the amount of available water.

If you are stranded on a barren tropical island with little or no vegetation, you must take immediate measures to prevent or reduce loss of body moisture and protect yourself from the sun. Sunburn and dehydration can greatly reduce your ability to survive. Shelters may be constructed from plants, large pieces of debris found on the beach, aircraft parts, and so on. Also, if materials are available, construct a hammock or sleeping platform. Do not sleep on the ground if at all possible.

Always have signal device available to attract attention of passing boats or air craft. If there is a considerable amount of burnable debris, collect it an make a signal fire that can be lighted at night to attract the attention of nearby vessels or air craft.

If stranded on a beach or small coral island, you should have no difficulty staying alive indefinitely by eating fish, shellfish, and mollusks. Crabs and lobsters can be caught by hand or with a simple spear. Mollusks can be found on rocks and in sand at low tide. Turtles and turtle eggs are good food. Sea urchins eggs, found on top of the body inside the shell, are edible raw or boiled. Soft-bodied and black and reddish long spine needle sea urchins are poisonous and should be avoided. Although all of these organisms may be eaten raw, cooking is recommended.

Most tropical fish are safe to eat; however, there are a few species that have poisonous flesh or organs and severe illness including vomiting can result. Although there are no simple rules to identify poisonous fish, the worst species have small mouths and round or box bodies with hard, shell-like skins covered with bony plates or spines. Notable examples include puffer fish, cow fish, file fish, trigger fish, and porcupine fish. Barracuda may or may not be toxic depending on their diet. Be aware to avoid fish with poisonous spines such as scorpion fish and sting rays. Physical injury from the spines and venom can be serious.

The best all-around plant food for survival is the coconut palm which characteristically lines tropical coasts. The bread fruit tree may also be found on or near tropical coast in some regions.

SURVIVAL AT SEA

If you and the plane survive a water crash, evacuate the aircraft and get into a life raft as soon as possible. If a raft is not available use whatever flotation gear you have available. This is the obvious key to survival. The same principle applies to boating disasters. With the increased number of live aboard dive boats, the chances of having to face a sea survival situation have increased for the traveling diver.

If possible stay upwind and clear of the aircraft or boat; avoid floating fuel. Assemble the survivors and perform any first aid that is necessary and possible. Look for missing persons and take inventory of the situation. Salvage floating equipment and items that might be of use for survival. Check raft/flotation gear for leaks. In the raft, be careful to avoid damage with sharp objects and shoes. Put out a sea anchor. Keep calm and save water and food by saving energy. Have signal devices available for immediate use and maintain a constant alertness for vessels and air craft. Lash all equipment/supplies to the raft.

In tropical seas, protection from the sun and obtaining drinking water will be the most difficult problems. Some life rafts will have a supply of canned water. Ration it fairly for the number of persons involved. Some rafts are equipped with solar stills and rain water catchment containers device must be assembled and ready for use. Prevent loss of body water with shade and/or covering yourself with damp clothing to reduce sweating. Do not drink sea water or urine.

Survival foods should be used in accord with container instructions and distributed fairly. Remember that you can survival for days with little or no food as long as you have water. Most open sea fish are edible. Use line and hook and/or fish nets. Clean fish immediately and eat them before they spoil. Do not eat liver or eggs of fish. Do not eat a fish with an unpleasant odor, pale/slimy gills, sunken eyes, flabby skin, or flesh that stays dented when depressed. All birds are potential food and some will be attracted to the raft. They can be caught with baited hooks or snares arranged on floating objects behind the raft. Birds may possibly be grabbed by hand just after they have folded their wings if they land on the raft.

Maintain watch for land, even a small island. This greatly improves your survival situation.

If you must survive in tropical water without a life raft you must be prepared to deal with sharks. They may be attracted by noise, splashing, or blood. Keep your clothes and shoes on. If sharks have been seen, be especially careful in eliminating body waste. Urinate in short spurts to allow for better dissipation. Pass fecal material into your hand and throw it as far away as possible. The same applies to vomiting.

Stay as quiet as possible and float to save energy. If there is more than one person, consider tying yourselves together so that you will not become separated. If a shark is spotted, face outward. If a shark approaches attempt to ward it off by kicking, stiff-arming, and slapping the water.

CONCLUSION

If your flight plan or boat schedule has been file, a search will be started if you do not arrive at your destination. Also, distress signals and radio communications may alert emergency services. Your survival situation may be a short one. Do not panic! Do not give up! A sense of humor and mutual emotional support is very important.

REFERENCE

1. Nesbitt, P., Pond, A., and Allen, W., *The Survival Book* (New York: Funk and Wagnalls, 1959).

LIST OF SURVIVAL KIT CONTENTS

With a few exception (marked by "*") you will already have many of your survival kit items included in your diving/travel outfit. Simply transfer them to your shoulder bag or carry-on for small aircraft and back country travel. The marked items (*) take up little room in a carry-on bag compartment. Some of them can be sealed in a small plastic bag and left in you carry-on for years.

Knife (small Swiss Army type for campers/hikers; although I routinely carry one in my camera bag, you may encounter some problems at security check points)

Fishing kit* (10 – 20 feet of strong line and a few hooks, leaders, sinkers, and lures; some authorities recommend a small gill net — about 1.5 inch mesh — which is excellent for fishing in streams and near shore)

Compass and map* (copy a map of the area you will be travel by vehicle or flying over in small aircraft from an atlas or guidebook and pack it in your carry-on bag/shoulder bag)

Waterproof matches*

Flashlight

Water purification tablets*

Insect repellent

Anti-sunburn lotion

Sun hat

Sunglasses

Small mirror* (for signaling; small smoke signals and flares are
desirable, however, you may encounter some problem transporting them on commercial aircraft)

Water container*

First aid kit (compact kit for cuts and abrasions with pain medication)

Snare wire* (about 10 feet of copper or steel wire)

Food (I commonly carry granola bars and other snacks for long flights and stopovers anyway)

Mosquito netting* (or protective clothing; consider wearing along sleeve shirt and long pants instead of shorts; you can up the sleeves; if stranded in a jungle you will be much better off than individuals wearing short or sleeveless shirts and shorts)

Metal container* (a 16 ounce metal cup or container may be used to boil water and cook food; if the container has a tight seal top it may also be used for packing the survival kit)

Manuscript revised: 19 November 1989

CHAPTER 8-5

TERRORISM, HIJACKING, AND THE TRAVELING DIVER

Recreational and scientific scuba divers are becoming more adventurous travelers. Diving and vacationing at Caribbean resorts has become routine. Many divers now travel to Red Sea, Mediterranean, and Central American countries in search of better and more adventurous diving and many of these countries actively promote dive tourism. During a recent military action scientist and technicians at a tropical marine laboratory were attack and held hostage for a brief period of time.

Some of the counties that now cater to dive tourism may be considered as high-risk areas in terms of the potential for terrorist attacks against individuals. Terrorist groups operate freely throughout the Middle East and Mediterranean. The political unrest and open warfare in Central America has become a fact of life. Unfortunately, American civilians and military personnel are walking targets for terrorists.

Anytime you fly, especially in politically sensitive areas, you can be a victim of a terrorist hijacking. Since this is a relatively new phenomenon for American travelers, many people do not know how to act or react if it happens. The following guidelines for dealing with a terrorist hijacking situation were adapted from the *Marine Corps Gazette* for civilian travelers [2].

Trip Planning

In planning a trip, especially one which involves travel to or stopover in a high-risk area, select a route with the least stopovers. Every landing increases the chance that new passengers may be terrorists. In small airports with lax security or in a friendly host county, terrorists can often and easily slip weapons onto planes. If a stopover is scheduled in an unstable country, discuss the possibility of a different route with your travel agent, even if it involves flying more miles or for a longer time.

Seat selection can also be a factor. Should a hijacking occur, a window seat protects you better than an aisle seat, except in an emergency when you would be required to exit your seat rapidly. In an aisle seat you can be singled out more easily and even struck. Hijackers do not like to lean over other passengers to hit you or get to you.

Personal Appearance and Conduct

One of the first rules of survival in a terrorist situation is to maintain a low profile — blend in. Do not wear expensive clothes and jewelry or carry elegant, high-priced luggage. This singles you out for the hijackers as a member of an elite social class which they generally hate. Also, it makes you a mark for every common thief along the way.

Nondescript clothing is best. Avoid wearing apparel that is clearly of United States origins such as cowboy hats, boots, or decorative belt buckles. Military personnel should avoid wearing uniforms and carrying luggage/items that clearly identify them as Department of Defense travelers.

Military personnel and men of military age should avoid Marine-style high and tight (clipped-to-the-scalp) haircuts. In today's real world, a neatly trimmed military appearance can get you killed. The 1985 TWA hijacking and the murder of four Marines in El Salvador attest to this fact [2].

Whenever traveling through potentially high-risk areas do not loiter in public areas of an airport for extended periods. Whenever possible, proceed expeditiously through security checkpoints to secure areas to await your flight. In airports and on the plane, do not discuss your religious or political beliefs with strangers or fellow travelers. Do not vocalize thoughts regarding local politics, customs, culture, people, and so on. Such discussions, even among friends, may be overheard by terrorists and later become a reason for singling you out.

Hijacked!

Should a hijacking occur, the key to immediate survival is to remain calm. Do not talk to fellow passengers. Very quietly calm the passengers around you and stop them from talking. Nervous hijackers might think that you are discussing a plan to collectively rush them.

Avoid any action that will attract the hijackers' attention. Do not stare at the hijackers. Never make sudden moves or call-out for attention. Do not suddenly raise your hands for permission to speak. Any sudden movement or noise might make a hijacker shoot in your direction. Blend in with the other passengers as much as possible. Do not threaten the hijackers with comments on what your government will do to them when they are captured. They already know that risk and, contrary to the American way of life, may consider that giving their life for their political or religious beliefs is a great honor.

Always remember that the person with the gun has the upper hand. Even if you are a martial arts black belt, attempts to attack a hijacker or escape would be foolish. Hijackers are quick to anger and to shoot. Such actions could cost you your life and the lives of others seated around you. Also, be aware that all hijackers may not reveal themselves at the same time. A lone hijacker may be used to draw out security personnel for neutralization by others. Keep in mind that if you are wounded, medical help is seldom available.

Do not become a spokesperson for the group. If something goes wrong, the spokesperson may be the first to feel the wrath of the hijackers. Furthermore, if there is no spokesperson, the hijackers must deal directly with the authorities. This gives the authorities a better picture of the situation and helps to establish a course of action and rescue.

Your life is probably not in immediate jeopardy! Remember that a live hostage is more valuable to a hijackers than a dead one. Help will be on the way! Airplane hijackings are generally the work of a small group or individuals. They seldom hold hostages for extended periods. Remain calm and make your personal survival the most important task.

If you are asked to move by the airplane crew or hijackers, do so without hesitation. Do not complain or ask why, just move! It can save your life. Remember that hijackers are as keyed up and nervous as you are, so do not antagonize them.

Speak only when spoken to! If a hijackers ask you a question or gives you an instruction, comply to the best of your ability. Talk in a normal, calm voice. Avoid direct eye contact when speaking if possible. Your answers or responses should be realistic and concise. Do not patronize or obviously attempt to deceive the hijackers.

Keep your seat belt unfastened as much as possible, especially when the plane is on the ground. Be prepared to hit the floor or exit the plane rapidly. If shooting starts, stay as low as possible and protect yourself behind seats. On the ground there is always the possibility of a rescue action. If you see movements outside the plane, do not do or say anything that will warn the hijackers. Be prepared to protect yourself from gun fire and explosives in what ever way possible.

Remember that there are only a few hijackings each year, so your chances of getting to your destination are excellent. Furthermore, nearly all hijacked passengers do survive the ordeal. Do not let paranoia about hijacking or terrorism ruin your holiday. However, remembering these few simple facts can prepare you for the possibility and may save your life.

Surviving as a Hostage

When traveling and diving in high-risk or politically unstable areas there is the possibility that a tourist could be detained as a political hostage. I remember traveling in Jamaica during a period of political instability and being caught in the middle of a firefight between two rival groups. Tourists continued to visit Jamaica throughout this period of unrest. It is conceivable that the same thing could happen in Central America or a Middle East country today. Although tourists are rarely the intended victims, the fact remains that an American hostage can be a good bargaining chip for terrorists in a vicious game of violence and intimidation. Terror is a tactic, not just an act of irrationality.

Most authorities feel that there are four vital factors that must be understood in order to survive as a hostage. They are: (1) contingency planning, (2) initial reactions and considerations, (3)short-term survival, and (4) abductor/hostage interaction. Keep in mind that most terrorist incidents are very well planned and executed with a great deal of precision. The dynamics of survival are complex and can extend far beyond simply doing what one is told or keeping quiet. The following discussion of hostage survival was extracted from an excellent article in the *Marine Corps Gazette* with minor modifications for the civilian traveler [1].

Mental preparation can reduce the extreme stress associated with a violent abduction. Unfortunately, people generally maintain an "it won't happen to me" attitude . By practicing three simple tasks you can improve your potential for response to a crisis. First, if you find yourself in a sensitive area/situation, attempt to visualize the many possibilities for hostage taking around you. Secondly, Continually ask "What if .....?" as this proves to be a good method of risk analysis. And, third, become more physical security conscious.

Through mental "simulation" and increased awareness of your surroundings, you may be able to reduce risk by simply avoiding certain situations or places. Furthermore, in the event that you find yourself in a hostage situation, this mental preparation can lessen the impact.

Surviving the first few hours as a hostage can be the most critical test. You may be injured or feel that your life is in imminent danger. It may be! However, as previously stated, hostages are seldom the intended victims but are rather a means to the terrorists' end. Stop, think, and control your emotions. During this initial stage your abductors are likely to be emotionally unstable. You have no personal identity for the terrorist and can be killed as a faceless figure. Time affords a humanization period when the captors will gradually accept hostages as people, rather than objects. It is important to understand that the likelihood of survival increases with time.

During this early stage of abduction concentrate on avoiding actions that might be interpreted as potentially threatening to the terrorist. Follow their instructions to the best of your ability. Use this time to regain your composure and adapt to the situation.

Upon regaining composure, analyze the situation to the best of your ability. Make mental notes about your captors and their mannerisms. If possible, determine who is in charge and carefully survey the immediate environment.

Anticipate isolation, threats, and, possibly, physical abuse. Terrorists use these techniques to establish open dominance and control. A certain amount of interrogation can be expected, although each situation will be different. Stay calm and try to remain optimistic.

If food is offered to you and appears to be safe, eat it even though it may be undesirable. Maintaining your strength is important to your survival as you could be held hostage for days or even weeks. Exercise whenever possible. These factors are important to sustaining both your physical and emotional health.

When it appears practical, attempt to develop rapport with your captors. Keep in mind that this is different than dealing with the airplane hijacking. Here it has become obvious that you may be held captive for a lengthy period of time. Speak with them as much as possible and try to discover areas of mutual personal interest (i.e., family, travel, sports, etc.). Refrain from engaging in discussions regarding political viewpoints if at all possible, and always talk in a normal, calm voice.

Beware of the possible unconscious shift in allegiance to identify with, and thus become sympathetic to, the terrorists' cause. This response, known as the Stockholm Syndrome, develops when a long term captive is unable to sustain the fear and anxiety of being a hostage. This response has become so strong in some individuals that they have actually stood, wantonly, between rescuers/authorities and terrorists during final confrontation.

The possibility of being taken hostage is remote. However, any traveler must recognize this possibility does exist. Common sense and an analysis of your surroundings can do much to minimize the possibility of abduction. If it does happen, simply do your best and use common sense. Adapt and concentrate on survival.

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1. Pitts, W., "Surviving as a Hostage," Marine Corps Gazette (January 1986).

2. Von Seyfried, H., "Surviving an Airplane Hijacking," Marine Corps Gazette (January 1986).

Manuscript revised: 23 December 1989

CHAPTER 8-6

DRINKING AND DIVING: IF YOU CAN'T SPIT, DON'T DIVE!

It is a cold, snowy Saturday morning as you drive anxiously to Detroit Metro Airport. Today is the first day of your long-awaited scuba diving vacation in the Caribbean. You completed your training about two years ago but have only dived a dozen or so times in local lakes and quarries.

Your luggage is checked, and finally you board Aquasonic Airline Flight 469 for Miami where you will make connections for your final destination in the Caribbean. A few minutes after the plane reaches cruising altitude a gentle voice announces that beverages will be served for your relaxation and enjoyment. Fruit juices, soda pop, and coffee are complimentary; however, beer and wine are available for $1.50 and mixed drinks for $2.50. It has been a long week of overtime work and final preparations. This is your vacation! Why not start the morning with a Bloody Mary? The stewardess announces that Aquasonic Airline is pleased to introduce their new drink coupon book which allows you to purchase 10 in-flight drinks for $15. Why not? You can save $10! A couple of hours and three Bloody Marys later you arrive at Miami International.

You have booked your diving tour through Scuba, Sun, & Score (SSS) Tours. Since SSS clients from all over the country will be arriving in Miami today, a special courtesy room has been reserved by the company where you can meet your fellow divers, your tour leader, enjoy a few complimentary drinks, and relax before continuing on to the Caribbean in about three hours.

At 2 PM you board Island Buzzard Airline for you final destination — Pleasure Island deep in the Caribbean. Island Buzzard is a new airline and like many developing businesses, it provides *perks* to encourage booking. This island flight includes complimentary rum punch. Fantastic! It's all free, as much as you want. Paradise Island has just launched a big campaign to attract American tourist dollars. So you pass quickly through immigration and are greeted in the customs area by an attractive island host with a tray of small plastic glasses filled with complimentary rum punch. After all of the horror stories you have heard about customs and long delays, this is a delightful surprise. Customs goes so smoothly that you have time for only two glasses of the rum punch.

A taxi whisks you off to your dive resort hotel, which is considered to be one of the best in the Caribbean. Your tour guide has your room key waiting for you when the taxi arrives, and your bags are tagged so that you can proceed directly to your room; the bags will follow. As you enter your luxurious room one the of first things that you notice is a bottle of Champagne, compliments of the hotel management.

Off with the travel clothes, on with the bathing suit. A quick check of your relaxation itinerary indicates that you have only 30 minutes before the Rum Punch Pool Party sponsored by your local dive guides. This will be an excellent opportunity to meet the diving staff and to find a few good diving buddies for the week, not to mention the opportunity to scout out the unattached members of the opposite sex. Dinner is not served until 8 tonight, and your table has already been reserved by your tour guide. You have two full hours to get acquainted, relax, and drink free rum punch. What a way to start a vacation!

Dress is casual at this resort. After the party you quickly slip back to your room and change into you best jeans and wildest T-shirt for dinner. The sun has disappeared below the horizon and the evening is warm, but not hot. The open air restaurant is beautiful, just like the picture in the brochure. Your table is directly on the ocean and you can see small schools of fish waiting for their evening handout. The waiter asks if you and your companions wish to begin with a before dinner drink. You hesitate! Your mind is a bit slow now — lovely companions, tropical moonlight, gentle breeze, and a nice rum punch buzz. For a brief moment you start to ask yourself, "Do I have enough money to buy dinner drinks and wine?" Then reality returns! Your mind clears! You can have all of the dinner drinks you want. Your Scuba, Sun, & Score dive package includes transportation, all meals, gratuities, unlimited diving, and *unlimited beer, wine, and mixed drinks*. What a deal!

The waiter returns in a few moments with your drinks and recommends the house specialty — swordfish steak and a unique complementary wine. You are not normally much of a wine drinker, but why not? It is all part of the package. The dinner is just great. It seems like you have been eating, laughing, and drinking for hours. The very interesting and, you hope interested, person next to you recommends that you all top off dinner with a wonderful after dinner liqueur — Tia Maria. Now, that is what you call dessert!

The night is still young when you and your new friend skip off to the casino. Maybe you can win enough money to buy that underwater camera you have wanted for so long. As in most casinos, drinks are on the house when you are gambling. Now you are really living. The Bond in you is finally surfacing. This is the beginning of a wonderful week and a new life.

About 2 AM you begin to feel very tired and ask to be excused. You won't score tonight. The mixture of rum punch, scotch and soda, wine, Tia Maria, and gin and tonic has made you just a little drunk and a bit ill. No matter! This is your first night on the island. You are allowed to let off some steam after so many months of hard work.

Breakfast is at 7:30. Your tour guide awakens you with a gentle tap on the door and informs you that you should finish breakfast and be on the dock by 8:30 so that you can be briefed on the day's diving activities and get your equipment organized on the boat. As you lift your head from the pillow the room starts to spin slowly, and you attempt to focus your eyes on the small dog that must have had an accident on your tongue during the night. A quick shower and some mouth wash and you are off to breakfast.

There is a large pot of coffee waiting on every table. Boy, do you need it! The breakfast includes a nice 4-ounce glass of orange juice. Wow! Does this juice taste good. You ask the waiter if you can have some more. He says certainly. You drink six more glasses. Time to go to the boat. As you start to leave your table, the waiter asks you to sign for the extra orange juice you ordered — $1.50 per glass. You just drank $9.00 worth of canned orange juice. Only the first one was included in your meal plan.

On the way to the dock you run into your tour guide and complain. He is sorry that you were unaware of the extra charges for additional food, juices, etc. However, he reminds you that if you like orange juice so well, *screwdrivers* can be obtained at the bar from 7 AM to 3 AM the next morning and that the cost of all mixed drinks is included in your tour package. You'll know better tomorrow morning!

On the way to your dive site you soak up the hot tropical sun. This morning you will make a boat dive and return to the hotel for a second dive from the beach. The water is warm and clear — the clearest that you have ever seen. At last you are underwater in the beautiful Caribbean. You forget the slight nausea and headache and drift effortlessly through the coral seascape. Your maximum depth is 70 feet and your air lasts right up to the the USN "no-d" time allowed. You are going to get every minute underwater that you can on this vacation.

When you surface from the dive the dive master offers you a cold drink — coke or beer? Boy, a beer sure would taste good right now and wash the taste of saltwater away. You lie back to enjoy the ride back to shore and your nice, cold beer. You know, that was really thoughtful of the dive master.

As soon as you arrive back at the hotel, you pick up a second cylinder of air for a beach dive before lunch. You and your new buddy check the tables and plan a 40 minute dive to 40 feet. It is such a beautiful day. After surfacing from the second dive, you hurry to lunch. The boat will leave the dock for your afternoon dive at about 2 PM.

Today's lunch is buffet-style on the patio overlooking the ocean. You can't decide whether to have a cold beer or a large glass of rum punch. The rum punch has lots of fruit juice, and you recall that your instructor told you to drink plenty of fruit juice between dives. The orange juice will cost you extra. The rum punch is included in your dive package. Rum punch it is!

The afternoon dive is even more beautiful than the morning dive. About 4:30 you return to your room for a quick shower and an aspirin. You have a bit of a headache. Must be the hot tropical sun. You rest for a few moments and hear a knock on your door. Your interesting new diving companion doesn't want to miss the afternoon cocktail-game party on the patio.

This afternoon's game is "tequila trivia." You love to play Trivial Pursuit, and you are good at it. In this version of the game, you get a shot of tequila if you are the first person to shout out the correct answer. Most of the divers are on the patio by the time you and your buddy arrive, and the game is about to start. The first question is, "What do the letters S-C-U-B-A stand for?" You leap into the air and call out "self- contained underwater breathing apparatus!" Correct! You get the first shot of tequila. As you gulp it down, the crowd cheers. You never have been much of a tequila drinker, and this cheap stuff tastes like something they distilled in a goat's bladder. However, a beautiful lady in a skimpy bikini runs up to you with a slice of lime for you to suck on and that makes it taste much better. In a few moments you answer another question and the ceremony is again repeated. And again! And again! Your second night on the island and you are already a celebrity. You are the "tequila trivia" champion.

The divers from your boat hoist you on to their shoulders and carry you off to dinner. Tonight dinner is even better than last night's and the wine is absolutely perfect. The warm, moonlight tropical night is casting its magic spell. Good food! Delightful new friends! Island music in the background! What more could you want? You are simply *floating*! Then it happens. You feel the gentle touch of someone's fingers against your hand. Fantasy becomes reality — the gentle warm breeze, the sound of the waves beneath your balcony, the complimentary champagne, and paradise.

The sun is rising in the east as you sip the last of the champagne to toast a new day and a new love. In a few hours you and your buddy will again slip beneath the waves to seek new adventure and rewards. A couple of hours later you are awakened by your tour guide. If you do not hurry, you will miss the boat. No time for breakfast. You and your buddy arrive at the boat just as it is leaving the dock. Fortunately, your tour leader put your equipment bags on board.

Today you will be diving the wall at the north end of the island. There will be about a 20-minute boat ride and the water is a bit rougher than yesterday. You are so thirsty. The dive master realizes that you missed breakfast and offers you a coke — you drink two. About five minutes before you arrive at the dive site you realize that you can't control it any longer and, half dazed, you make your way to the side of the boat to feed the fish. Naturally, your diving companions find this a bit humorous and you hear someone say softly, "If you want to play, you have got to be willing to pay!" You did pay — for the deluxe dive package — and you are just beginning to play.

The week passes so quickly. Every dive is a beautiful adventure. You dive to the limit every day. The nights are even more beautiful. Crab races! Tequila trivia! Rum punch parties by the pool! Dancing! Gambling! Romance! This is the beginning of a new life!

Friday morning comes far too soon. You don't really remember coming home from the midnight pool party last night. And you are sure that the little dog is still hiding somewhere in your room. Your muscles ache, at least some of them. Your head hurts and you are a bit dizzy. However, three or four cups of coffee, some aspirin, and a couple of those orange juice screwdrivers and you'll be as good as new.

Today is the big south end deep wall dive — something you have been waiting for all week. They say it is the most beautiful dive in the Caribbean. And this will be your first really deep dive — 120 feet. The boat arrives at the site and the dive master briefs the divers. You will spend 10 minutes at 120 feet and then return to the top of the wall and burn off the rest of your air at about 40 feet. You are instructed to make a 5-minute decompression stop at 10 feet during ascent.

You hurry to get into the water. You don't want to get seasick by staying on the rocking boat in the hot sun. Besides, the scuba harness is hurting your badly sunburned shoulders. You just need to defog your mask and you will be ready to enter. *However, you simply can't spit.* You try to get enough saliva in your mouth to spit and you can't! The dive master hands you a small bottle of defog compound and you are on your way.

The dive is everything that they said it would be and more. There are simply not words to describe the splendor of the wall — being suspended over the transparent dark blueness of the abyssal depths below you. As you glide effortlessly along the wall you touch the beautiful whip gorgonians and admire the tiny black-capped basslets. In your euphoria you reflect on the wonderful vacation and dream of future undersea adventures. You ascend to 40 feet and swim with you companions back to the boat. As you look up you see several divers already suspended below the boat on the decompression bar. The most magnificent dive of your life will be over in a few minutes.

As you board the boat your tour guide hands you a cold glass of champagne — a fitting act of celebration. It is wonderful to be alive! It is wonderful to be a diver! As your boat speeds back to the hotel you realize that you are really tired and a bit shaky on your legs. It has been a long, exciting week and you had a late night. You will have several hours to rest and eat before your afternoon dive.

As you are walking back to your room you realize that your legs are still a bit shaky, a bit weak. You also have a slight backache — probably from lifting tanks on the boat. In your room you lie down for a few minutes and feel a strange sensation in your feet and lower legs. It is a feeling like that you have experienced when you have fallen asleep on your arm — sort of a "pins and needles" sensation. You get up to go to the bathroom and can hardly stand because your legs are so weak and your foot feels numb. What's happening? You make your way to the balcony and call to your dive buddy and tour leader at the pool below. In a few moments they arrive in your room. By now you are having difficulty walking. They help you back to the bed.

It is about four hours later now. You are lying in your bed breathing from an oxygen mask. You can no longer move your legs and you have no feeling below your waist. Fortunately, a diving doctor is staying at the hotel and the small clinic had some appropriate IV medications. The doctor informs you that you are exhibiting symptoms of decompression sickness — the bends. He has placed you on oxygen and started an aggressive fluid replacement procedure since you appear to be extremely dehydrated. How can this be? *You have drank more this week than ever before in your life.* An air ambulance has been called to transport you a hyperbaric chamber facility in Miami.

Nearly three weeks have passed since your accident. The flight attendant announces that you will be landing at Detroit Metro in approximately 10 minutes. A lot has happened in these three weeks. You have undergone six hyperbaric treatments in Miami and spent about two of the weeks in an intense physical therapy program. You have no control of your bladder and apparently no sexual sensation. Your mind drifts!

As the plane pulls up to the terminal you realize that family and friends will be waiting to greet you. What will you say? What will they say? There is the usual confusion and hurry of passengers anxious to get off of the plane and on with their lives. You are in no hurry. You are content to let all of the other passengers deplane before you. As the skycap pushes your wheelchair into the terminal, you see the faces of your friends and loved ones. There is both joy and sadness. It is time for you to get on with your life — a new life!

* * * * * * *

The story you have just read is fiction! However, every event is real. I have seen, experienced, or heard accounts of every one. I have treated paralyzed divers. I have read dive boat tour advertisements that state, *"complimentary beer and wine on tap."* I have listened to a noted dive tour organizer talk about successful efforts to arrange a Caribbean diving holiday which includes all transportation, three dives daily, room, tips, taxes, transfers, parties, T-shirt, and all meals and *beverages* (which specifically includes an open bar policy).

Of even greater concern is the serious promotion of the party atmosphere and the often less than serious promotion of the safe diving aspects of dive travel. Many divers have told me that they drink far more on diving vacations than they do at home. A diver who was making about four dives per day and experienced a mild case of bends was considered as a mild drinker when he consumed only 5 to 6 beers in the evening and went diving at 6 AM. At many, if not most, dive resort restaurants one must specifically request water; far too often the divers will order beer or a rum drink with the noon meal.

It is not my responsibility or purpose to attempt to eliminate consumption of alcoholic beverages or, as some would say, the fun, from diving holidays. I enjoy a drink, in fact several of them, just as much as the next person. However, there is a time and a place for everything. ***The diver who chooses to mix alcohol and diving is assuming a significant risk!***

The late Dr. Charlie Brown classified alcohol as *the grand champ of the downers* [2]. What happens to the body and mind when one consumes alcohol? Alcohol is a depressant drug which slows the activity of the brain and central nervous system. Any drinking causes some temporary effects on the body. Sustained and heavy drinking can result in serious problems.

Alcohol enters the bloodstream through the stomach wall and the small intestine, and requires no digestion. A low level of alcohol, such as sipping one drink, has a mild tranquilizing effect on most people. It may act as a temporary stimulant when one is first starting to drink. This results in increased heart rate and skin temperature. After a drink or two, as the alcohol numbs the brain and central nervous system cells, loss of muscle control, slurring of speech, and poor coordination result. Impaired judgment and loss of inhibition, along with exaggerated feelings of anger, fear, and anxiety also occur.

The physiological and emotional adversities associated with consumption of alcohol immediately before and between dives are obvious. A couple of quick beers between dives can contribute significantly to increasing the diver's cooling rate, reducing muscle control and coordination, impairing the diver's ability to make proper judgments, promoting "risk taking" and triggering fear/anxiety responses (or panic).

Consuming a tropical punch containing 4 to 5 ounces of rum before a dive can place the diver in a state of being legally drunk underwater (.1% blood alcohol). Would a diver ever drink this much before a dive? In some cases, yes! Most people associate the "*quenching of thirst*" with the consumption of beverages. If a good rum punch is available, few divers stop at one! Studies of automobile accidents suggest that this level of blood alcohol increases the likelihood of an accident 7 times; a blood alcohol content of .15% increases the rate 23 times [2].

Alcohol is a relatively *potent diuretic* and tends to increase the flow of urine. It suppresses the release of a hormone that normally retains body fluids. As a result your body loses important fluids and you become dehydrated. The problem of dehydration and fluid loss is further complicated by the fact that our bodies often do not adjust to the tropical climate until several days after arrival. Under normal conditions, our thirst mechanism warns us when we need liquid. For some reason, this mechanism often does not work during the first few days following arrival in the tropics. Even though perspiring increases we do not tend to drink sufficient and proper fluids required to replace those lost and thus acclimate to the tropics. Prudent divers (travelers) will "force" themselves to drink enough water and fruit juices to maintain a urine output of at least two pints of reasonably *clear* urine per day. As stated in one British guidebook, "A few dark-colored drops and a puff of steam are not enough" [3].

Diuresis is also triggered by the consumption of beverages such as tea, coffee, and carbonated drinks that contain caffeine. Most people drink large quantities of coffee in the morning after consuming large quantities of alcohol the night before. This only complicates the situation physiologically. Additionally, chilling (losing heat to the surrounding water), negative pressure breathing, and submergence itself all tend to increase diuresis. It is a well established medical fact that dehydration results in blood thickening and reduced circulatory efficiency. Reduced circulatory efficiency may in turn modify the normal nitrogen absorption/elimination functions and contribute to the formation of extravascular bubbles, i.e., decompression sickness. ***Dehydration may be the most significant single physiological factor that leads to degradation of diver performance and increased susceptibility to decompression sickness in tropical diving!***

Exercise followed by consumption of alcohol can be particularly dangerous, since this combination can cause significant decrease in blood-glucose levels. Low blood glucose leads to general physical weakness and mental confusion as well as interfere with body temperature maintenance [1].

Furthermore, pre-dive consumption of alcohol causes skin vasodilation (blood vessel expansion) and increases the nitrogen uptake in subcutaneous (under skin) fat. The post-dive drink favors rapid release of this nitrogen into general circulation, which, in turn, favors the development of decompression sickness. Alcohol also reduces surface tension thus favoring conditions for bubble formation and growth. Finally, it increases blood plasma fat, which favors fat emboli and blood clotting, both important in the pathogenesis (development) of decompression sickness [2]. These factors all theoretically support the premise that alcohol may increase the risk of decompression sickness. However, further research will be required to determine relationships.

All evidence suggests that drinking and diving are not compatible activities. Alcohol is frequently associated with drownings. An analysis of drownings in the United states and Australia indicates that about 50% of the adult victims have elevated blood alcohol levels [1]. Unfortunately, similar blood studies are not available for those persons who experienced fatal diving accidents. The individual who does drink before and after diving is probably at a ***significantly higher risk*** of accident and/or decompression sickness than those who abstain. Can you drink and dive in moderation? How much can you safely drink in a diving situation? How long should you abstain from drinking before diving? Will a beer between dives really do any harm?

I can't answer these questions! There are simply too many variables. Keep in mind that physiologically you are not always the same person. A level of consumption normally tolerated can produce serious and adverse consequences if you are dehydrated, fatigued, or otherwise physiologically compromised. All of these factors can easily be associated with tropical vacation diving. Some authorities suggest that an individual refrain from drinking alcoholic beverages for at least 6 to 12 hours prior to diving, while others suggest that abstention for 36 to 48 hours is more desirable.

I suggest that all divers and dive resort operators re- evaluate their position on alcohol and diving. In my opinion, promotion of alcohol consumption through parties and games in a diving environment is a questionable practice. The advisability of an open bar policy on dive boats and at dive resorts is also subject to serious reconsideration. The practice of serving complimentary alcoholic beverages between and following dives is questionable.

Ultimately, as an adult each diver is responsible for his or her personal health and safety. The boat and resort operators are only responding to client and social pressures. Our society is a drinking society. And there is big money in satisfying the customer. Availability of alcoholic beverages does not mean that the diver has to drink. It is all a matter of "risk/benefit." *If you are going to drink and dive you must be willing to accept the risk and the consequences!* Did you pay $100 to $200 per day for a vacation to drink *or* dive? Both! If that is what you wish, then so be it. However, sue yourself, not a dive boat or resort operator or your instructor or the doctor, when you find yourself confined to a wheelchair.

As far as the dive operators are concerned, I suggest that making water and fruit juice *readily and attractively* available would be a significant contribution to diving safety that could pay long-term dividends from both a legal and moral standpoint. What is wrong with offering a diver a complimentary can of fruit juice between dives or at the end of a day's diving? It makes a lot more sense.

I know that divers will continue to drink. If a dive resort did not serve alcoholic beverages or a dive boat operator prohibited the possession/use of alcohol, it would probably be out of business within a few months. Just keep it all in proper perspective. And when you wake up in the morning the next time you are at a dive resort, remember ***"If you can't spit, don't dive!"***

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ACKNOWLEDGMENTS

This chapter was published by the Michigan Sea Grant College Program as part of the Diver Education Series — Publication No. MICHU-SG-86-511) and in several diver magazines and newsletters. It is the result of work sponsored by the Michigan Sea Grant College Program with grants form the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and funds from the State of Michigan.

Manuscript Revised: 19 November 1989

NOTES:

SECTION 9

SCUBA DIVING IN COLD WATER AND POLAR ENVIRONMENTS

CHAPTER 9-1

SCUBA DIVING IN COLD WATER ENVIRONMENTS

INTRODUCTION

Scuba diving has become a popular year around activity for many cold climate recreational divers. In addition, there is an increasing interest in aquatic science research in cold water environments. The ever increasing interest in aquatic recreational activities has also developed new response requirements for the public safety or dive rescue teams. The potential survival of a person submerged in very cold water has been well documented. Children have been successfully resuscitated with no apparent neurological damage following 30 minutes or more of complete submergence. Many dive rescue teams now operate in a rescue mode for up to one hour following the known or suspected time of victim submergence.

Cold water diving, whether for recreation, research, or rescue/recovery, is certainly not without some added risk factor in comparison to warm water scuba diving. The inherent complications associated with extreme surface exposures, thermal stress on the divers, equipment function/malfunction under extreme cold conditions and cold climate logistical support place unusual demands on the dive team.

Diving under ice is a special type of cold water diving. The problem of cold water diving mentioned above are further complicated by the fact that divers are working under an ice cover. This requires additional personnel including trained tenders to support the operation. The divers are at much greater risk because of the problems associated with resolving an emergency such as loss of air supply. Direct return to the surface may be impossible. Procedures and training for cold water and under ice diving operations are discussed in detail in several publications [4, 5, 7, 8, 10, 12].

In this section I will primarily discuss diving in cold water without overhead ice cover. For discussion purposes, cold water is defined as water below the temperature of 60° F (15.5° C). This includes open sea diving in polar regions to summer diving below the thermocline in temperate zone lakes. Atmospheric temperatures at the dive site may exceed 80° F (26.5° C) on summer days in Michigan to subfreezing winter temperatures.

This section is intended for educational use in recreational, public safety, scientific, and commercial diver training. Several items are included that are not generally covered in recreational diving courses. For example, most instructional programs do not address topics such as regulator malfunction due to freezing. Although, this is not a common occurrence in recreational diving, it does happen and a diver working in waters below 38° F (3.3° C) should understand the nature of this malfunction and how to manage it. Furthermore, recreational diver training courses and manuals usually include only limited information on dive organization and supervision. When working under adverse environmental conditions such topics become extremely significant for safe diving, especially for scientific dive teams working in remote locations.

DIVER QUALIFICATIONS

All scuba divers should follow a *logical progression in the acquisition of advanced training and diving experience*. I recommend that the diver acquire initial experience in warm weather diving and progress through a series of more demanding cold weather open water diving exposures. I am well aware of the fact that the waters of the Great Lakes area are extremely cold below a depth of 30 to 60 feet even during summer months. However, the diver must also acquire progressive experience in dealing with cold surface conditions. I suggest that the greatest potential cause of a cold environment diving accident originates at the surface during pre-dive preparation and exposure of the divers and equipment to thermal stress.

I am an advocate of reasonable levels of physical fitness for all divers, regardless of diving conditions. However, the cold weather diver can be placed under unusually high physical, emotional, and thermal stresses. A physically fit diver can generally deal with stressful situations better than a physically unfit diver. I recommend that the diver maintain a minimum fitness level of Category III (Fair) on the "Cooper 12-Minute Aerobic Swim Test" [3]. This means that the male diver (age: 20-29 years) must be able to swim at least 500 yards in 12 minutes; 400 yards for female divers.

TRAINING

Unfortunately, many modern recreational diving courses only prepare the diver for diving in tropical or warm temperate region waters. Cold water divers must be familiar with equipment dry suits, handling/operating equipment while wearing gloves/mittens, the nature of equipment malfunctions resulting from exposure to extreme cold, the physiological implications of cold stress, first aid for injuries characteristic to operating in sub-freezing environments, and maintenance of thermal comfort both underwater and on the surface.

Of greatest concern is the number of scuba divers who purchase and use dry suits in open water with no formal training or practice in a controlled or confined water environment. Persons planning to dive in dry suits should participate in a special training program which includes, but is not necessarily limited to, the following:

* Dry suit and undergarment selection;
* Fitting dry suits;
* Suit valve selection and operation;
* Dressing/undressing procedures;
* Weighting and buoyancy control;
* Underwater swimming techniques using a dry suit;
* Prevention of suit leakage;
* Suit/valve maintenance;
* Dry suit repair and seal replacement;
* Emergency procedures for suit flooding, blowup, and loss of buoyancy; and
* Supervised open water dry suit dives.

Trainees must actually experience dry suit flooding and out-of-control ascent resulting from suit over-inflation under controlled conditions. I encourage divers to make at least 4 confined water instructional dives before advancing to *supervised* open water diving. Dry suit training guidelines are available from Viking America and Diving Unlimited International. All dry suit divers are encouraged to read *Dry Suit Diving Manual: A Complete Guide for the Dry Suit Diver* [2].

THE COLD WATER ENVIRONMENT

The temperature of the water may vary from 85° F (29.5° C) in the Caribbean, to 40° F (4.4° C) at 100 feet (30.5 meters) in Lake Michigan, to 28° F (-2.2° C) under polar ice. Air temperature in coastal regions may vary from 120° (49 ° C) in the Red Sea to –50° F (-45.6° C) during winter months in the polar latitudes. The world's lowest natural temperature, –127° F (-88.3° C), was recorded in 1960 at Vostok Station in Antarctica. The combined effect of wind and air temperature, wind chill, can be very hazardous and cause severe cold injury. An air temperature of 0° F (-17.8° C) and a 20 mi/hr (32 km/hr) wind produces a chill factor of –35° F (-37° C). Exposed flesh can freeze within one minute at this temperature [4, 6, 7].

At any given location on the earth the temperature of the water will vary with season, time of day, depth, and meteorological conditions. Extremes in environmental temperature conditions can place considerable stress on both the diver and diving equipment. Thermal protection for both atmospheric and underwater temperatures must be considered in planning and conducting diving operations.

In order to provide divers with an brief overview of environmental temperature variations in the world's oceans and freshwater lakes, I have elected to include selected information form a classic oceanography textbook [11], an unpublished manuscript [1], and a previous personal publication [6].

Heating and Cooling of Ocean Water

The shortwave (or infrared) radiation that reaches the ocean surface, partly from direct sun and partly from the sky as reflected or scattered radiation, by in large heats the world's oceans. Conduction of heat from the atmosphere and condensation of water vapor (precipitation) also impart some thermal energy to the surface waters. This incoming heat energy occurs at the air-water interface or within the upper one meter of water. Heat is distributed to underlying water layers by conduction and vertical mixing.

If averaged over a year, the maximum amount of incoming solar radiation is received in the lower latitudes and the minimum amount in polar latitudes. The earth receives most of its heat between latitudes 40° N and 40° S. If one considers the distance, movement, and geometry of the earth with respect to the sun, climatic zonation and seasonal changes can be easily explained. Because of the earth's curvature, equal amounts of incoming radiation from the sun are distributed over a greater surface area at the poles as compared to the equatorial zone.

Density, Salinity, and Freezing Point

Pure water has its maximum density at about 39.2° F (4° C) with a freezing point of 32° F (0° C). The fact that the temperature of maximum density is above the freezing point plays an important role in controlling temperature distribution and vertical circulation in freshwater lakes.

For sea water, the temperature of maximum density decreases with increasing salinity, and at salinity of greater than 24.70°/oo (parts per thousand) is below the freezing point. At a salinity of 24.70°/oo, the temperature of maximum density coincides with the freezing point (-1.332° C or 29.6° F). Consequently, the density of sea water of salinity greater than 24.70°/oo increases continuously when such water is cooled to its freezing point. For normal sea water (salinity approximately 36°/oo) the freezing point is about 28° F (-2.2° C).

Annual Variation of Surface Temperature

The annual variation of surface temperature in any region depends upon a number of factors, foremost of which are the variation of radiation income, ocean current characteristics, and the prevailing winds. The character of the annual variation of surface temperature changes significantly from one locality to another; however, a few general features can be identified. First, the annual range of surface temperature is much greater in the North Atlantic and North Pacific Oceans than in the southern oceans. For example, at 45°N latitude in the Atlantic Ocean the annual range is about 14.4° F (8° C), whereas at the same latitude in the South Atlantic Ocean the range is only about 7.74° F (4.3° C).

Secondly, the surface temperature range in the southern oceans is definitely related to range in radiation income, whereas the relationship does not appear to exist in northern oceans. The great ranges in the northern oceans appear to be associated with the character of the prevailing winds and, in particular, with the fact that cold winds blow from the continents toward the ocean and greatly reduce the winter ocean temperatures.

Annual Variation of Temperature in the Surface Layers

At subsurface depths the variation of annual temperature depends upon four factors: (1) variation of the amount of heat that is directly absorbed at different depths, (2) the effect of heat conduction, (3) variations in the currents relative to lateral displacement of water masses, and (4) the effect of vertical motion. The effects of all four of these factors are evident in a review of the annual variation of temperature at different depths in Monterey Bay, California.

Three specific oceanographic periods can be identified in Monterey Bay: (1) the period of the Davidson Current (mid-November to mid-February), (2) the period of upwelling (mid-February to late July), and (3) the oceanic period (late July to mid-November). The California Current off Monterey Bay is directed to the south during the greater part of the year. However, during the winter months, an inshore flow to the north, the Davidson Current, is present. The water of this inshore flow is characterized by relatively high and uniform temperature and appears in the annual variation of temperature as warm water at subsurface depths. The upper homogeneous layer is relatively thick with the temperature nearly the same at 83 feet (25 meters) as at the surface and only slightly lower at 165 feet (50 meters).

At the end of February the California Current reaches to the coast and, under the influence of the prevailing northwesterly winds, an overturn of the upper layers takes place. This is generally described as upwelling. During the period of upwelling, vertical motion near the coast brings water of relatively lower temperature toward the surface, and the temperature at given depths decreases. The minimum subsurface temperature is reached at the end of May.

From late May through August, the temperature is much higher at the surface than at 25 meters (83 feet). During this period, the upper 10 meters (33 feet) of water is significantly warmer than at deeper depths. This thin surface layer is heated by radiation, and it is evident that the effect of heating is limited to this upper 10 meter (33 foot) layer. As the upwelling gradually ceases toward the end of August, a sharp rise in temperature takes place at both the surface and at subsurface depths, and the annual temperature peaks in September are a result of radiation heating and conduction and intrusion of offshore water.

Southern California ocean waters show a surface temperature of about 70° F (21.2° C) during summer months; however, below a depth of 60 to 80 feet (18.3 to 24.4 meters) the water temperature drops by about 10 ° F (5.6° C). In the fall the amount of incoming solar radiation is reduced by the change in the angle of the sun relative to the earth's surface at that latitude and the increase in cloudiness. During this period, storm activity vigorously mixes the surface and subsurface layers to form an isothermal water coastal column of 58° to 60° F (14.4° to 15.5° C).

The temperature of freshwater lakes and rivers depends on incoming solar radiation, atmospheric conduction, and condensation as well. However, the temperature in these smaller bodies of water will be more varied and depend on a number of additional environmental factors including altitude, ice/snow cover, local topography (which can affect the amount of solar radiation impinging on the water), volume and source of water flowing into the lake, and the outflow. Outflow generally consists of the upper most layer of water thus constantly removing the heated surface layer.

Temperature variation with relation to season and depth is especially evident in temperate zone freshwater lakes. During summer months, the surface waters are warmed by radiation, and a temperature zonation is established.

In a typical freshwater lake, the upper layer, or **epilimnion**, is composed of warmer and less-dense water and the lowermost layer of cold, dense water, the **hypolimnion**. During late summer in the Great Lakes, the surface water temperature may exceed 70° F (21° C); however, at the bottom, in a typical deep lake, the temperature approximates 39.2° F (4° C), the temperature of maximum density for fresh water. Between these two layers is a zone of rapid temperature change, where the temperature gradient is greater than 1° C per meter depth. This is the **thermocline**.

During the fall months, the lake maintains this well-defined vertical layering until the surface temperature has cooled to about 43° F (6° C). At this point, wind-caused mixing and circulation is effective enough to destroy the thermocline and mix the entire column of water, producing an **isothermal condition** (same temperature throughout the entire water column), with a temperature approaching 39.2° F (4° C). This isothermal condition, designated as the **fall turnover**, is maintained until winter when the lake has cooled to about 35.6° F (2° C).

Further cooling then produces sufficiently less dense surface water with a temperature near 32° F (0° C). This less-dense upper water layer forms a stratification of significant stability and prevents further mixing with the lower water, thus another water stratification period is established and a **reverse thermocline** separates the layers. The bottom water layer is at the temperature of maximum density, and surface ice cover may develop during the winter months.

As the spring sun warms the surface water, it increases to a temperature of 35.6° F (2° C), and the spring turnover begins. This mixing continues until the surface water exceeds 39.2° F (4° C), producing a less dense upper layer, and initiating the summer stratification period.

In the ocean both temporary (or seasonal) and permanent (or main) thermoclines are present in most regions. The thermocline begins at an average depth of about 1,640 feet (500 meters). The main thermocline is virtually absent in polar regions since most of the ocean surface is ice covered in winter and solar radiation is limited during the summer. In the tropics, the thermocline may be very close to the surface. Areas with strong seasonal warming usually have a temporary or seasonal thermocline.

Diurnal Variation of Surface Temperature

The range of diurnal (daily) variation of surface temperature is not more, on an average, than .36 to .48° F (0.2 to 0.3° C). However, local variations in bays and over shallow reef areas may be higher. The range of the diurnal variation in temperature depends upon cloudiness and the wind velocity. Increasing cloudiness obviously reduces the amount of incoming radiation. Although the effect of the wind is somewhat more complicated, the main consideration is that an increase in wind velocity causes more wave motion and mixing in the surface layers so that the heat absorbed in the upper water is distributed over a thicker layer.

Surface winds can cause the structure of the water column to change significantly over a period of a few hours. In the Great Lakes a wind of sufficient duration, velocity, and direction can cause surface waters to flow away from shore, allowing colder bottom waters to rise to replace them. This phenomenon is called upwelling.

Offshore winds tend to produce upwelling; however, winds paralleling the shore may also cause upwelling, since the Coriolis effect will deflect the flow of water considerably. The Coliolis effect, a deflection force acting on a moving body due to the earth's rotation, will cause deflection to the right in the northern hemisphere and to the left in the southern hemisphere.

Some refer to this temporary, localized upwelling as a tilting of the thermocline, since warm water frequently depresses the thermocline on the opposite side of the lake. This author observed one such wind-induced upwelling on the eastern shore of Lake Michigan which established an isothermal water column from the surface to the bottom (approximately 50 feet [15.3 meters] deep) of 40° F (4.2° C) overnight. A surface temperature of approximately 60° F (15.6° C) had been measured the previous day.

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Manuscript revised: 21 June 1990

NOTES:

CHAPTER 9-2

EQUIPMENT FOR COLD WATER DIVING

INTRODUCTION

Most divers will be equipped with standard open water scuba diving equipment. For them most part this equipment is satisfactory for cold water diving; however, there are some special requirements and additional items that must be considered for working and diving in cold environments.

BASIC EQUIPMENT

The selection of mask, fins, and snorkel is a matter of personal preference. Keep in mind that fins with extra large foot pockets may be required in order to fit over the dry suit boot and several layers of socks without cramping the toes or restricting circulation in the foot. Fin straps must be properly adjusted and secured with tape or a retainer before commiting to the cold water diving operation. Strap adjustment or replacement can be quite difficult during the operation; a broken or dislodged strap could increase the risk to the diver. Keep in mind that this applies to all adjustable straps, including the mask strap.

All divers should carry a sharp knife secured to the leg, BC, scuba harness, or arm [16]. Some divers carry large sheath knives on the inside of their leg in order the minimize the possibility of snagging on lines, nets, and aquatic plants. Others prefer to carry compact knives attached to equipment or the arm. Regardless of the type and size of knife selected, carry it in a position where you can get to it with either hand. I personally secure a sharp, compact knife to the front portion of my BC or scuba harness. ***Keep in mind that you must hand your knife with foamed neoprene or dry suit gloves. When selecting a knife and sheath, wear your diving gloves!***

I must again emphasize that surface temperatures may be subfreezing, thus complicating equipment adjustments and donning. Keep in mind that some rubber products become stiffer and have slightly less stretch at subfreezing temperature than at room temperature. Weight belts must have the appropriate amount of weight for a given dive; adjustments under cold surface conditions or in the cold water can be very difficult. Attempting to adjust or repair equipment by cold divers or surface personnel on site increases the possibility of *life-threatening mistakes!*

SCUBA

Most recreational, research, and public safety divers will use the same scuba for all diving, both tropical and cold water. The most common scuba in use at the present time includes a single 71.2 or 80 cubic foot scuba cylinder; a single hose regulator equipped with an auxiliary second stage (i.e., octopus) and pressure gauge; and a combination buoyancy compensator and backpack.

Potential for Regulator Malfunction in Cold Water

In the early 1970s, many cold water diving authorities recommended only the use of double-hose regulators because single-hose regulator malfunction was relatively common in cold environments and under ice diving conditions [4, 15]. U. S. Navy Oceanography Office personnel experienced a 48.6% single-hose regulator malfunction rate during one series of dives [4]. Divers working in Antarctica still use double-hose regulators today [19]. The experiences of various ice diving groups and the mechanism of cold-induced regulator is discussed in detail by Somers [15, 17] and Fullerton [7].

Although cold-induced regulator malfunction is rare in normal cold water diving operations, it can and has occurred. Open water regulator icing malfunction has occurred on deep dives in cold lake water during spring/summer diving in the Great Lakes [2, 11]. *During cold* *water open water dives where water temperature is less than 38° F (3.3° C) the potential for cold-induced malfunction is significant enough that divers must be aware of the possibility.* However, most regulator icing malfunctions occur during ice diving operations when the equipment is exposed to subfreezing surface temperatures with subzero wind chill.

Most recreational diving manuals do not address the topic of regulator malfunction by icing. Consequently, I will include a brief explaination of the problem and common sense precautions for cold water divers.

Cooling of air due to adiabatic expansion from high pressure to low pressure causes moisture in air ow water in the regulator mechanism to cool significantly. Because of the compact design of the first stage of a single hose regulator heat is actually absorbed from the metal. In very cold water the temperature within the regulator housing itself may be well below freezing. Consequently, if moisture is present ice crystals may form to plug orifices or interfere with the movement of regulator parts. Most internal icing appears to cause the regulator to malfunction in an open or free-flow position [7]. However, recent U. S. Navy studies indicate that icing can cause regulators to malfunction either open or closed position due to ice formation on the regulator spring and within the spring cavity or freezing of moisture on the interior of the regulator [10].

Based on studies reported by Fullerton [7], it has been shown that breathing from a single hose regulator in 32° F (0° C) water will not normally cause icing in the second stage. However, free-flowing the regulator for more than 5 seconds may cause icing. In one test, free-flow through the second stage yielded a 5.4° F (3° C) temperature drop in the first stage within 30 seconds. Thereafter, the temperature remained constant. Therefore, it was estimated that in water temperatures below 37.4° F (3° C) in fresh water and 34.2° F (1.2° C) in salt water, potential single hose regulator icing malfunction could be a significant problem. In fact, at one time in the early 1970s, the U. S. Navy established a policy prohibiting the use of single hose regulators in water colder than 38° F (3.3° C) [4].

Over the past decade the single hose regulator has almost completely replaced the double-hose regulator for all diving, including cold water and under the ice. Although cold-induced regulator still occurs, the frequency of such malfunctions has been greatly reduced largely through *better management* of the regulator prior to and during diving operations. Regulator design improvements have also been significant in reducing the frequency of regulator malfunction. Furthermore, double-hose regulators have all but disappeared from the American diving scene. To my knowledge, they are no longer manufactured or sold in the United States and most dive shops do not stock parts to service these older model regulators.

Most modern single-hose regulators are now designed with protected first-stages. The ambient pressure chamber is sealed and filled with air, silicone, or an antifreeze solution in order to protect the internal components from water and debris. Consequently, water which could freeze under the right set of conditions is no longer in contact with moving components.

Some authorities suggest that many, if not most, cold-induced regulator malfunctions occur in the second-stage assembly. Following hard inhalations and/or depressing the purge button to activate high air flow, moisture in the second-stage housing apparently forms ice crystals in the second-stage valve assembly. At least one manufacturer designed a regulator with Teflon (DuPont trademark) coated components and a heat retention unit in the second-stage assembly in an attempt to reduce the potential of cold-induced regulator malfunction.

On the other hand, others suggest that the major cause of cold-induced regulator malfunction is deformation of the diaphragm in the first stage of some model regulators [10]. Under extremely cold conditions and significant regulator cooling the diaphragm material stiffens and will not return to its original position when the demand for air flow through the first stage ceases. Thus, air continues to flow causing an over-pressure in the first stage and subsequent free-flow in the second stage. Based on this line of reasoning, antifreeze compounds, special coatings, and other freeze prevention systems may or may not play a significant role in cold water regulator malfunction.

At this point I must emphasize the the ***potential for regulator icing still exists in all scuba regulators available on the market today.*** Fortunately, the icing generally results in a second-stage *free flow*. This enables the diver to return to the surface for corrective measures without having to rely on a buddy to supply air. In the event of a free flow malfunction you must terminate the dive immediately and return to the surface. Continued use of the regulator for a short period of time is possible, and preferable, to buddy breathing. However, continued free flow will cause additional moisture to freeze on the enlarging ice crystal(s), hold the second-stage valve open, and increase the rate of air flow.

Common precautions used by cold weather/ice divers to reduce the possibility of regulator icing include: (1) protect the regulator from low temperature extremes and wind chill prior to the dive, (2) keeping the interior of the second-stage completely dry before entering the water; (3) *not* breathing from the regulator until underwater; (4) allowing little or no water to enter the second-stage chamber during or between dives; (5) *not* depressing the purge button for more than 5 seconds prior to or during the dive; (6) *avoiding* heavy work loads that would significantly increase the breathing rate and volume of air moved through the valve with each breathing cycle; and (7) assuring that the scuba air is moisture-free.

In a discussion of ice diving techniques, Langerman indicated that he minimized regulator icing by being certain that the regulator is thoroughly dry several days in advance of the dive and then not using (breathing from) it until just before entering the water. Just before the diver leaves the surface, he warms the regulator by pouring hot water over it. Divers are reminded to breath slowly and easily [8].

Langerman also suggest that "the single most important factor which correlates with freeze-related free-flow problems appears to be surface temperature. When the air temperature is well below O° F (-18.9° C), we experience many problems; when the air temperature is above 15°F (-11.1° C), the problem seems to disappear" [8].

Regulator Selection for Cold Water Diving

As previously stated, potential for regulator malfunction due to icing is generally limited to exposures to water temperatures below 38° F (3.3° C). Most of the regulators currently available to recreational and scientific divers will perform satisfactorily within the depth and air demand range common to these divers. However, some regulators do perform better than others in cold water. In 1987, the U. S. Navy published an evaluation of 51 commercially available regulators [10]. Several regulators that proved to be top performing regulators for normal diving were deemed unacceptable for cold water diving.

Alternate Air Sources and Cold Water Diving

The use of an octopus regulator is a standard in the scuba diving community today. Although I feel that there are better emergency air alternatives for diving in extremely cold water and under ice, general public acceptance of the octopus regulator has made it the primary system used by most cold water divers. Keep in mind that the two second-stage assemblies (the primary and the octopus) are both attached to the same first-stage. Consequently, the diver cannot isolate the free flowing second-stage. This means that the octopus is of little or no advantage in resolving the problem independently.

In the event that two divers must breathe from a single scuba, the higher air flow through an unprotected first-stage might increase the possibility of first-stage icing. Langerman finds that the removal of the octopus reduces the incidence of free-flows (regulator icing) underwater during ice dives [8]. In any event, if a diver's scuba malfunctions in a fashion that restricts or eliminates air flow, octopus breathing is an acceptable alternative. However, the dive should be terminated immediately.

The use of a *dual outlet manifold* and *two independent single-hose regulators* is possibly a better alternative for dealing with regulator malfunction. The dual manifold is available for both single and twin cylinder scuba. In the event of a free flow malfunction of the primary regulator, the diver can exchange it for the secondary regulator and isolate (or turn off) the free flowing regulator provided that the diver or buddy can reach the valve/manifold assembly.

Many divers prefer the use of a *compact 15 cubic foot scuba* (or pony unit) as an emergency air supply alternative. Either of these systems allow for an independent resolution of the problem, especially for public safety divers using the single diver down mode. Keep in mind that the divers must train and experiment with equipment positioning under controlled conditions in order for any of these alternatives to work properly under actual field conditions.

Buoyancy Compensation Devices

The use of a buoyancy compensation device (BCD) with a dry suit is consider mandatory by most diving authorities. Many foamed-neoprene dry suit (i.e., air suit) divers used their suits for buoyancy compensation and, thus, did not wear a separate BCD. However, suit manufacturers and instructors have concluding that the dry suit should not be used as a substitute for a BCD.

Keep in mind that a properly weighted thin fabric suit diver should not experience the significant buoyancy loss with increased depth common to foamed neoprene suits and that supplemental buoyancy compensation should be minimal.

The most popular BCD currently in use at present is the vest or jacket style in contrast to the collar style of earlier years. However, some divers still prefer and use the collar style BCDs. The pros and cons of BCD styles will not be addressed in this booklet. Regardless of individual preference, select a BCD and/or position the dry suit inflation/deflation valve(s) so that the BCD will not interfere with the operation of these valves.

Buoyancy compensation device and dry suit inflation/deflation valves are subject to potential malfunctions. These may be induced thermally or otherwise. Malfunction of a BCD inflation unit resulted in an *uncontrolled, full BCD inflation ascent* for one diving instructor [20]. Inspection of both BCD and dry suit exhaust valves following two other diving accidents revealed that the valves malfunctioned in an open position. Consequently, the divers apparently could not maintain air in the BCD or dry suit for compensation or emergency flotation. There is the significant likelihood that poor/inadequate maintenance was a factor in these alleged malfunctions.

Andersen reports on *dry suit blowups* resulting from inlet valves sticking in an open position [1]. Continued manipulation of the valve did not stop the flow of air into the suit and the divers were forced uncontrolled to the underside of the ice. The only method found to resolve the emergency was to immediately disconnect the inflation hose. If this disconnection is not accomplished immediately, the rapid over-inflation of the suit will cause the diver's arms to become immobile or restricted in movement.

THERMAL PROTECTION

The human body is relatively inefficient with regard to heat production and conservation. Since water is a very effective heat conductor, the highest of all liquids, the heat produced by an immersed body will will be lost to the environment approximately 25 times faster than in air. Consequently, the duration of safe exposure for an unprotected diver is limited even in warm, tropical waters. Individual physiological variables, cold water acclimation, and environmental factors must all be considered in determining exposure limits. However, it is immediately obvious the diver must be provided with an adequate thermal protection system, or insulation, in order to perform safely and efficiently underwater.

At the present time, the self-contained diver must rely on *passive* thermal protection provided by foamed-neoprene wet suits and fabric dry suits. In a passive thermal production the diving suit simply insulates the diver from the environment and reduces the rate of heat loss to the environment. In contrast, umbilical supplied divers may use an *active* thermal protection system. The most common system used today circulates a continuous flow of hot water over the diver's body through tubes on the inside of the suit. Self-contained active thermal protection systems are currently in the experimental stage.

The current trend in recreational, public safety, scientific and military diving is to use a dry suit for water temperatures below 60° F (15.5° C). New technology in materials and seam construction has led to recent development of excellent lightweight fabric dry suits. The suits, in combination with new synthetic insulation garments, have provided adequate thermal protection for experimental dive durations of up to 6 hours in 40° F (4.4° C) water at a depth of 70 feet (21 meters) [12]. Both wet and dry suits are discussed below. Information on suit and undergarment materials was, in part, provided by Richard Long of Diving Unlimited International, Incorporated [5, 9].

The Recent Evolution of Thermal Protection Garments

The foamed-neoprene, wet suit was the primary suit for recreational, research and public safety divers for nearly two decades. In the late 1960's a variable volume foamed-neoprene, dry suit fitted with a *waterproof/air proof zipper* and manufactured in Sweden was introduced to the American market under the tradename UNISUIT. During the 1970's this and similar foamed-neoprene dry suits (often referred to as *air suits*) began to replace the wet suit for serious cold water diving.

These suits provided the diver with an air inflatable, waterproof thermal protection suit that could be worn over a variety of undergarments or, in some designs, without undergarments. The primary advantage was that they kept the diver dry. However, since the suits were constructed of foamed-neoprene rubber, the insulation properties and buoyancy characteristics of the suit did vary with depth and, in some cases, an exceptional amount of weight was required to offset the buoyancy of the suit and contained air. The suit could be "inflated" with air from the diver's scuba cylinder or a small independent cylinder. These suits provided major advancement in thermal protection and diver comfort. However, bulk, insulation/buoyancy variation with depth, and, in some cases, sizing continued to be a problem, especially for smaller and female divers.

Modern Dry Suits

Unlike wet suits which rely on only the insulation properties of the foamed-neoprene which change with depth, the modern dry suit encases the diver in a container of dry insulating air within an undergarment which may be inflated or vented to compensate for depth changes. The watertight integrity of the suit is maintained by using a waterproof fabric, watertight seals around the wrist, neck, and face, attached boots, and an environmental barrier zipper.

Various designers and manufacturers use different materials, valves, and zipper lengths. The position of the zipper and valves will vary from model to model. Some suits are constructed of insulative foamed-neoprene while others are constructed of materials which provide only a dry outer garment to be worn over insulating underwear. Depending upon the outer suit material and undergarment combination, dry suits will vary in heat conductivity, buoyancy, flexibility, durability, and cost.

In the early 1980's new technology in waterproof materials and seam construction led to the development of a new breed of *thin fabric* suits. The materials resembled waterproof nylon fabrics that had been used in the construction of outer garments and outdoor equipment such as packs and tents (e.g., 420 Denier urethane sealed nylon). These suits were less bulky, lighter in weight, easier to put on and take off, and more comfortable to wear both underwater and on the surface than their predecessors. The neck and wrists seals were constructed of very thin latex rubber for improved watertightness and added comfort. Some authorities suggest that these new suits have a higher reliability factor for dryness.

The polyurethane materials used for diving suits include nylons (i.e., pack cloth, etc.) and other similar synthetic fabrics that have been treated with a spray or spread coating of polyurethane. The finished fabric is thin, waterproof, neutrally buoyant, and provides no intrinsic insulation. Seams are usually sewn and waterproofed with tapes that are glued or heat fused to the fabric. Although very lightweight and flexible, suits constructed of this material lack elasticity and must be fitted loosely to facilitate donning and movement.

Nylon-butly rubber-nylon trilaminate material is thin, relatively durable, waterproof, neutrally buoyant, and has no intrinsic insulation properties. Seams are sealed by gluing overlapping adjacent panels of material and applying a taping material. The resulting suit is very flexible but lacks elasticity or stretch and must be fitted loosely to facilitate donning and movement. As with all nonelastic suits, the outer protective suit material must slide freely over the undergarment material in order to facilitate unrestricted movement.

Other thin materials include rubber-coated tricot (e.g., Viking suits) and crushed foamed-neoprene (e.g., DUI CF200X suits). The nylon materials do not stretch and the suit must be sized so that there is sufficient material to slide over the undergarments and not restrict diver movement. The tricot and crushed neoprene suits do have some degree of elasticity.

Rubber coating of fabrics such as polyester provides a suit material that is neutrally buoyant, strong, and highly waterproof. The material itself has no intrinsic insulation properties. Seams may be sealed by vulcanizing. The resulting suit is thin, flexible, and slightly elastic. Double material thicknesses are used in parts of the suit that will be most subject to abrasion. The material can be easily and rapidly repaired.

Crushed foam, a material trademarked by Diving Unlimited International, Inc., is derived from neoprene material. It differs from foamed neoprene in that it does not contain any gas spaces. Basically, it is a foamed neoprene that has been permanently compressed or crushed during the manufacturing process. The result is a flexible material that is neutrally buoyant and unaffected by depth. The neoprene core has a heavy- duty nylon laminate on the outer surface for greater durability and a standard nylon laminate on the inner surface. During fabrication, the suit seams are glued and sewn and then sealed with a special elastomeric compound. The resulting garment is very thin, extremely flexible and elastic, watertight, and durable.

All scuba diver dry suits are fitted with air inflation and deflation valves. The various designs are too numerous to be discussed here and new/improved models are being marketed each year. The inlet or inflation valve is generally located in the diver's chest area and connected to a low pressure outlet on the scuba. Exhaust valves may be positioned on the chest, upper arm, or lower arm; the upper arm position seems to be most popular.

Adjustable *automatic buoyancy control outlet valve* which can be activated by changing arm position automatically discharge excessive air during ascent. One manufacturer introduced an air control valve which allows the diver to inflate and *vacuum* deflate the suit through a single valve [10]. However, at the time of this writing, this valve as been recalled for safety reasons.

Undergarments for Dry Suit Diving

Unlike conventional foamed-neoprene wet and dry suits, the thin fabric suits offer little or no thermal insulation. The key to versatile thermal protection is in the selection of appropriate insulating undergarments. The thin fabric suit can be used throughout the year under climatic conditions and water temperatures ranging from tropic to polar. The diver may select from a wide range of undergarments depending on water temperature, climatic conditions, and personal preference.

For summer diving in warmer northern waters or polluted waters the diver many choose to wear only the heavier weight polypropylene underwear similar to that worn by mountain climbers. Colder water divers can select heavier pile or Thinsulate (trademark of 3M) undergarments and wear several insulating layers.

Undergarments are available in various weights (or thicknesses) of synthetic fleece (i.e., polyester pile or fur; bunting fabric), open cell polyester foam, and Thinsulate. All of these materials have performance, insulation, and physical comfort characteristics that can vary with moisture content (e.g., from leakage or perspiration) and compression. One manufacture combines a foil radiant film between a polyester insulating material and a nylon taffeta shell. Undergarments are available in one-piece coveralls or jumpsuit models, jackets, pants, vests, and socks.

Unfortunately, a very limited amount of test information is available on the comparative effectiveness of various insulating garments for divers. One manufacturer has published comparison charts depicting the relative thermal resistance vs. thickness for pile, foam, and Thinsulate [5]. Thinsulate exhibits the highest thermal resistance factor for a given thickness of material. Furthermore, Thinsulate appears to have superior insulation qualities over the other materials when wet.

In one U. S. Navy study of M-400 Thinsulate undergarments worn under a crushed foam dry suit it was concluded that this undergarment "provides adequate thermal protection during air diving and conditions of moderate, intermittent work for up to 6 hours in water as cold as 35° F" [12]. The M-400 Thinsulate tested by the Navy is apparently the same 1/8-inch Type-B Thinsulate used in the current DUI C-4 undergarment [6]. This material resists compression and retains approximately 80% of its insulation capacity when wet.

The Thinsulate used in the construction of diver's undergarments is much more effective, less compressible, and less flexible than that used for ski wear and outer garments. The U.S. Navy study also reported, "Depth dependent degradation of undergarment insulation was not observed between depths of 10 and 70 FSW (feet sea water), and is not anticipated at depths deeper than 70 FSW" [12].

Dry Suit Seals, Hoods and Gloves

Most thin fabric dry suits are constructed with a neck seal collar and without a hood. Most divers apparently prefer the added comfort (physical, not thermal) and suit donning convenience of suits without attached hoods. Suits can be constructed with or without hoods based on the diver's personal preference. One experienced polar scientific diver selected a hood that attached to the suit with a special neck ring. This allowed him to use the suit with a dry hood, a neck seal, or a surface-supplied helmet attached directly to the suit [5]. Most divers use a foamed-neoprene, wet type hood specially designed to seal securely against the latex rubber neck seal of the suit.

Most dry suit divers currently use foamed-neoprene, wet type three-finger mittens with snug fitting wrists seals. One manufacturer has designed a mitten constructed of 3/16-inch thick material over the palm/finger area and 3/8-inch thick material over the back of the hand where the greatest heat loss occurs. The hand still represent one of the most difficult areas of the body from a standpoint of functional insulation. Filling the mittens with warm water before and after the dive is a common practice to extend thermal comfort.

Dry gloves/mittens may be attached directly to the suit sleeve with a special connection unit. Wool or synthetic liners can be worn under the dry gloves/mittens. Dry hand protection is becoming increasing popular.

Selecting and Using a Dry Suit

In selecting a dry suit or any thermal protection garment you must first determine the following:

* What is range in water temperature at locations where I normally dive?
* Will this be my only suit or will I be able to afford both winter and summer suits?
* What type of surface exposures do I expect to encounter prior to and following the dive?
* How deep will I normally dive?
* What is my normal activity level while diving?

First, select a suit or suit system which will maintain thermal comfort over your range of water temperatures, depth, and activities.

Next, select a suit that fits comfortably with the undergarments that you intend to wear for your coldest dives. You must be able to move freely and feel comfortable in the suit. Keep in mind that many fabric suits *do not* stretch and movement is accomplished by the suit fabric sliding on the underwear. Some suits do stretch and thus are designed for a tighter fit.

Take a deep breath; there should be no restriction. Execute a series of range of motion test. You should be able to perform the following without restriction [5]:

* Extend your hands as far overhead as possible.

* Now, bend forward and touch your toes.

* Standing on your left foot, extend your right hand upward over your head and bring your right knee upward to your chest (you may hold on to something to maintain balance); repeat with left side.

* Standing erect, wrap your arms around in front of you as far as possible (i. e., left hand under right arm) and cross your legs.

* In a kneeling position, sit back on your heals and then extend your hands and trunk forward touching the floor with your hands and bring your chin very close to the floor in front of you.

Does the crotch of the suit hang so low that it interferes with walking using long strides? If so, this will probably interfere with your kicking motion. If you must fight a restriction to move, consider a different size or suit model. Remember that you may repeat the movement several hundred times during a dive. Be sure that the boots fit comfortably with heavy socks or special dive boots.

The suit must fit comfortably, however, it must not be too large. Excess suit material and excess length can cause problems. Although, a given size dry suit will properly fit a wider range of people than a given size wet suit, you can not expect to put a medium size individual in an extra-large suit.

The new thin fabric/insulating undergarment diving suits have several advantages over the foamed-neoprene suits [18]. In addition to those advantages already mentioned, these suits can be more comfortable when worn for long durations on the surface because of low bulk and loose fit. A special plastic neck ring is available which allows the diver to relieve the potential discomfort of the neck seal and increase suit ventilation during surface wear. In the event that the diver becomes too warm on the surface, the suit can be unzipped for ventilation or partially removed to expose and cool the upper body. The suits are also very easy to take off between dives.

The light weight suits are very versatile for other diving and aquatic activities [18]. Recreational enthusiasts will find the suits useful for other cold weather/water activities such as boardsailing, rafting, kayaking, and boating. Boaters and adventurers can carry the suit (including mitts and hood) in a small duffel bag for use in the event of an emergency. The suit can be rapidly pulled on over standard clothing to significantly extend the survival time of a person immersed in cold water. Naturally, the suit must be donned before immersion.

Scientists and public safety personnel find that the suits do significantly increase comfort and safety when working from small, exposed vessels under cold and adverse conditions. A special Gore-tex laminate dry suit fabric which is waterproof and breathable was developed for military special forces. This suit is also available to civilian personnel to provide long term protection on the surface and during intermittent shallow immersion.

Selecting and learning to use a comfortable, versatile, and adequate thermal protection system is not an easy task. Although many divers and public safety dive teams still advocate use of the foamed-neoprene wet suit, some authorities suggest that its use should be limited to water temperatures above 60° F. Although air suits are still in use, the popularity of thin fabric suits has increased significantly over the past few years and these suits now dominate the dry suit market. Divers are encouraged to take advantage of dry suit clinics conducted by many local diving equipment suppliers in order to learn about the most recent developments in thermal protection and to swim various suit and undergarment combinations.

Once you have selected a thermal protection system, learn to use it properly and safely. Many experienced divers do not appreciate the different characteristics of dry suits compared to wet suits. I recommend that divers make no less than 10 training dives under controlled conditions before they venture into more adverse environmental conditions. The fact that you apparently master the use of the suit on the first or second dive is no assurance that you will be able to respond properly under stressful conditions.

Divers who use wet suits in the summer or for tropical diving and switch to a dry suit for a cold water dive are probably at more risk of accident than a diver who uses the same suit for all diving. This is due to the fact that they may not be able to use the dry suit proficiently and may be unable to manage themselves or others in a stressful situation. They may be better off if they simply use the wet suit and accept the added cold discomfort and limitations.

Proper dry suit training is necessary for safe and efficient use of these suits. The National Oceanic and Atmospheric Administration Diving Office conducted a series of tests on various dry suits and developed a variable-volume dry suit diver training program [13]. The course includes instruction in suit selection; dry suit "dangers"; blowup prevention and recovery methods; selection and use of weight belts and ankle weights; selection and use of accessories such as fins, fin straps, and underwear; and suit maintenance. Divers are encouraged to consult *Dry Suit Diving Manual: A Complete Guide for the Dry Suit Diver* [3].

Many instructors and diving equipment suppliers conduct special dry suit training workshops. Divers must learn special procedures and precautions for dressing and undressing. One criticism of the thin latex rubber neck and wrists seals is that they can easily be torn through careless handling. The diver may select from several inflation and exhaust valve combinations and must learn the operational characteristics of the valves. Although most dry suits are relatively simple to "patch", the replacement of neck and wrists seals and boots requires special techniques.

Finally, the diver must swim the suit under controlled conditions in order to learn internal air and buoyancy adjustments, swimming characteristics, and emergency procedures to follow in the event of valve malfunction, suit flooding, or over-inflation.

Foamed Neoprene Wet Suits

The invention and commercial production of foamed neoprene was a major contribution leading to the development of lightweight thermal diver protection. Neoprene has been used extensively in the manufacture of diving products since the early 1950s. The foamed-neoprene wet suit is the most notable of these products. Today there are many neoprene compositions and densities with a wide range of surface lamination options. This has lead to the production of numerous products designed for both thermal protection and marketing appeal. The wet suit is the principle thermal protection garment of the diving industry. However, dry suits are beginning to dominate the cold water diving faction of the community.

Observations and discussions with divers suggest that the majority of wet suit purchases are motivated by considerations of price, feel or softness, fit, and color rather than by concerns for efficiency of function and durability. Divers must understand that a diving suit is not just a piece of equipment to be color coordinated with other items. Being fashionably outfitted in color coordinated diving equipment may augment ones self-image on the surface and in lighted underwater photographs; however, keep in mind that the physical properties of light transmission in water defeat this concept underwater. Through selection of a functional serviceable wet suit with optimum insulation properties, the diver's total perception and enjoyment of the underwater environment will be enhanced.

There are many considerations in the selection of diving suit neoprene. Differences in chemical composition may significantly affect the behavior and insulation characteristics of the foam. The choice is further complicated by the numerous options in synthetic fabrics which may be used to laminate one or both surfaces of the foamed neoprene. The resulting combination of lamination and composition are not only colorful but may significantly affect garment performance.

For diving suits, neoprene of 1/8-, 3/16-, or 1/4-inch thickness is commonly used by manufacturers in the United States. In recent years, suit thicknesses of 1, 3, 6, and 9 mm neoprene produced overseas have appeared on the American market. Today, 9 mm suits are most popular for divers in northern/temperate regions and 3 mm suits are used more extensively in the tropics.

Neoprene foam are sponge-like material with a matrix of neoprene rubber surrounding gas (i.e., nitrogen or carbon dioxide) filled cavities. The relative proportion of matrix to cavity number, size and shape of cavities will vary significantly depending on the formula of the neoprene and the manufacturing process. Manufacturers can blend and process a material in order to create specific properties or characteristics.

For example, high density foams have a higher proportion of matrix relative to gas-filled space; whereas, the opposite is true for low density foam. In general, high density foamed-neoprene is less compressible and flexible and has a higher heat conductivity level than lower density foamed-neoprene. On the other hand, higher density foamed-neoprene is more tear resistant and durable. Suppleness The "feel" or supplenesses of the material in terms of softness and flexibility relates, in part, to density.

Foamed neoprene may be manufactured to provide a material with small and uniform or large and irregular gas spaces. The large, irregular spaces result from rupture of the walls between spaces. A closed-cell foam used in the manufacturing of quality diving suits is a material where less than 10% of the cells or spaces are interconnected. Open-cell sponge-like foam, where more than 70% of the cells intercommunicate, is used in the diving industry for the construction of some dry suit undergarments.

Lower density foams are more affected by increased pressure than higher density foams. Taking into consideration that the lower density foam is also more flexible, it is obvious that this material is highly suited for the construction of garments that will be used for surface aquatic sports such as board sailing, surfing, water skiing, and snorkeling. It stands to reason that denser and less flexible neoprene would be a better choice for a suit to be used in deeper diving.

This reasoning may not always be true, and it is important to consider that suit thickness at depth may not be the only factor determining insulation properties. The insulating quality (thermal conductivity) of foamed-neoprene is a function of gas spaces in the material. In comparing foamed-neoprene density to thermal conductivity under hyperbaric conditions, an interesting relationship becomes evident. Although compression is more pronounced in low density foam with an increase in pressure (or depth), the thermal conductivity remains lower relative to a higher density foam until a pressure greater than 6 atmospheres absolute (165 feet or 50 meters).

The important factor of suit fit is, however, more affected by pressure induced neoprene compression in lower density neoprene as compared to higher density material. How neoprene compression and shrinkage actually translates into suit fit at depth depends on a number of factors such as original fit, lamination materials, and so on. In general, the softer and less dense neoprene material stretches easier and may, therefore, allow for a tighter and better fit at deeper depths.

The gas spaces in foamed neoprene respond to the physical laws of pressure in much the same manner as any gas-filled flexible container. The gas space simply decreases in size with an increase in pressure resulting in an overall decrease in volume of the neoprene. The means that there is a three- dimensional size change in the the material. The material becomes thinner and the length and width of the piece of neoprene decreases. This shrinkage results in significant changes in insulation, buoyancy, and suit fit. Because it is the gas-filled spaces that are affected by the change in pressure or compression, higher density foamed-neoprenes are less affected by pressure than low density ones.

Since the insulation properties of foamed-neoprene are imparted by the gas-filled spaces, it is essential that these space remain intact and do not absorb water during a dive. The absorption properties of various neoprene depends on the chemical composition and manufacturing process. Absorption is measured by weighing a piece of neoprene before and after a water immersion/vacuum exposure procedure. The more water that a neoprene absorbs, the greater the reduction in insulating capability.

Foamed-neoprene diving suit water absorption increases with age, use, and abuse. Damage occurs as a result of stretching and crushing as well as abrasion. It is common to squeeze absorbed water from the knee portion of a wet suit following a dive. Knee patches will protect this area from abrasion; however, they will not protect the suit from damage caused by continuous stretching movements and compression.

Foamed-neoprene diving suits are usually manufactured of material with synthetic fabric bound to one or both surfaces. The resulting composite is called a laminate. The synthetic fabrics improve strength by increasing resistance to stretching, shearing, and tearing and provide for more secure attachment of accessories such as knee patches and pockets. They also enable the manufacturer to sew, as well as glue, the seams. Thus, a laminated suit is much more durable than a non-laminated one.

The cosmetic appearance of the suit can be greatly enhanced by the addition of color and sheen, an important consideration in a fashion oriented society. On the other hand, laminates increase the cost of the suit and change the stretch and drape characteristic.

Nylon laminates are most widely used in wet and dry foamed-neoprene suit construction. This fabric is available in several thread weights and weave patterns. Depending on the weave pattern, the nylon may stretch in only one or both directions. If the fabric stretches in two directions, often it will stretch more in one direction than the other. Nylon always possesses less stretch than the neoprene. Consequently, nylon laminated neoprene does not stretch as much as the same non-laminated neoprene. Nylon is available in a wide variety of colors.

A plush or high pile fabric laminate made of spun nylon is also used in the construction of diving suits. The plush knit weave gives a thick pile-like fabric that feels soft and comfortable to the skin. Many feel that it confers an additional measure of insulation to the garment. This assumption is yet to be proven at the time of this writing. Like the thinner nylon, this plush fabric does reduce suit flexibility and stretch. It is more expensive than most other fabrics used to laminate neoprene, and it may provide a greater area to harbor dirt and organism growth in suits that are not properly rinsed and dried following use.

Lycra laminated neoprene suits are increasing in popularity. Lycra lends a smooth and soft feel to the suit and gives it the appearance of being more flexible and easier to don. Actually, lycra covered neoprene has less stretch than the nylon or polyester laminates. For this reason, most suits with an exterior lycra laminate have nylon laminated to the inside surface of the suit. While a lycra covering initially provides intense and vivid color and an overall attractive sheen, the fabric tends to fade and show wear and soiling very rapidly. Lycra laminated foamed-neoprene is most expensive and does not provide a more serviceable product.

Although foamed-neoprene wet suits have been used for diving in all water temperatures throughout the world, including polar regions, most authorities recognize specific limitation. Because of the reduction in insulation resulting from compression, the wet suit is presently considered as a shallow, relatively warm water diving suit. Some manufacturers and diving authorities suggest that its use should be limited to water temperatures above 60° F (15.5° C).

A 1/4-inch or 9 mm wet suit is acceptable for water temperatures below 60° F (15.5° C) if the diver is working in relatively shallow water and can terminate the dive when he/she becomes chilled. However, if the diver must endure long and repeated exposures and/or dive beyond depths of 60 feet in cold water, a dry suit should be considered.

Historically, divers have attempted to increase the thermal range of the wet suit by wearing multiple layers of neoprene. Most quality suits were fitted with spine pads (extra layers of neoprene over the spinal cord in an effort to reduce heat loss in this critical area of the body). Many divers concluded that this was simply a nice innovation to improve physical rather than thermal comfort.

Many temperate zone divers used 1/4-inch high-top or bib-style pants (Farmer John or Farmer Jane) under a 1/4-inch jacket to obtain 1/2-inch of effective insulation over major portions of the torso. Some even added a 1/8-inch vest in an effort to achieve greater thermal protection. Ironically, most diver and wet suit manufacturers give only limited thought to innovative head protection. Yet, the head is probably the most critical heat loss portion of the body.

Foamed-neoprene wet suits have distinct disadvantage and limitation. The material compressed as the diver descended resulting in progressive loss of both buoyancy and insulation properties. The wet diver will experience significant heat loss both underwater and on the surface while engaged in pre- and post-dive activities.

Wet suit fit is very important. A foamed neoprene wet suit must fit the divers body like a second skin. A wet suit should fit snugly. There should be no excess space for water to accumulate and water should not circulate through the suit as the diver swims. On the other hand, the suit should not be so tight that it restricts breathing, circulation, or movement. Divers should consider the purchasing custom tailored wet suits if at all possible. Unfortunately, relatively small increases in body weight can make a 1/4-inch or 9 mm suit very uncomfortable.

Foamed neoprene hoods, whether used with a wet suit or dry suit must be designed and fitted to provide maximum protection for the head, neck, and face. However, the hood should not interfere with proper fitting of the mask and scuba mouthpiece. Proper sizing is very important because the skull is rigid and requires more accurate fit than other suit parts. A poorly fitted hood can cause severe jaw fatigue, a choking sensation, headache, dizziness, and coldness. An extremely tight-fitting hood and suit neck could cause unconsciousness by restricting blood flow to the brain. This condition is known as carotid sinus reflex. Pressure on the carotid arteries in the neck can stimulate the heart to reduce blood flow to the cerebral area. Consequently, symptoms similar to those of hypoxia may be evident and the diver can loose consciousness with little or now warning.

WEIGHT BELTS AND ANKLE WEIGHTS

Standard scuba diving nylon web belts fitted with quick release buckles and lead weights are most commonly used by ice divers. However, the use of special compartmented belts filled with lead pellets is increasing in popularity. These pellet belts are generally more comfortable and less abrasive on thin fabric dry suit material.

Some divers, especially ones using bulky foamed-neoprene dry suits (i.e., Unisuits), have developed weight belts with shoulder harnesses. The shoulder harness prevents accidental loss of the belt underwater and is more comfortable for divers who require very heavy weight belts. NOAA published the following statement regarding the use of shoulder harness weight belts [13]:

> Test were inconclusive in determining if a shoulder harness should be worn. If it is worn, a diver must be fully trained in ditching procedures, as test results did indicate that the belt can hang up. Test results indicate even a shoulder harness that was put on carefully can move around on the diver while he is working in different positions. This causes the harness to hang up and become difficult to remove, especially with scuba back pack.

It appears that the use of shoulder harness weight belts for scuba diving is of limited popularity at the present time. I discourage its use. If the diver feels that he/she needs this type of weight belt, be certain that the shoulder harness is equipped with quick-release devices.

The weight requirements for a dry suit are based on the buoyancy of the suit (for foamed-neoprene suits) and the amount of insulation worn under the outer suit. As with wet suits the weight requirements for a foamed-neoprene dry suit will vary with depth and suit compression. The weight requirement for a thin fabric dry suit will remain approximately the same for any depth. As you gain experience with a thin fabric suit, you will generally be able to reduce the amount of weight since your inflation techniques will improve. It is advisable to start your buoyancy evaluation with 10% to 15% of your body weight plus a 2.5 pound ankle weight on each leg.

Ankle weight are generally lead pellet filled nylon or 1/8-inch neoprene tubes or pouches fitted with a quick-lock buckle. NOAA researchers [13] found that the use of ankle weights kept the diver's feet in a better swimming position and allowed more air to be placed in the legs for improved thermal comfort. They help keep the fins on because of the restricted air flow into the feet. They enable divers to better control themselves if they lose their weight belts and to recover faster from inverted blow- up positions. However, they will tire the diver more during long swims. Five pounds is approximately the maximum for a diver to wear on each leg; 1.5 to 3 pounds is more reasonable.

In order to test buoyancy, enter the water with all equipment that will be use for normal diving and exhaust as much air from the suit as possible. Add or subtract weight until you are slightly negative buoyant on exhalation.

Keep in mind that proper suit inflation is essentially a balance between suit squeeze and a bubble of air in your suit. Inflate the suit only enough to relieve suit squeeze. Overinflation can cause control problems and compromise your safety.

DIVER INSTRUMENTATION

The diver will generally be equipped with a dependable waterproof watch/dive timer, depth indicator, and compass. The use of a console unit which includes a combination depth gauge/automatic activating timer, compass, and scuba pressure gauge is extremely advantageous for diver equipment management and donning purposes. Consider a depth gauge with a maximum depth indicator since a chilled diver is less likely to properly monitor and remember depth. Also, the use of the automatic activating timer eliminates the problem of pushing tiny buttons or rotating watch bezels with gloved hands and remembering to do so.

Remember that the compass is used only for survey and relative position determination purposes and never as a substitute for a safety line if you intend to dive in partially ice covered waters. Several years ago three divers lost their lives in northern Ohio when navigating with compass in a large stone quarry that was only about one-third ice covered.

The console must be properly secured in a position where the diver can monitor the instruments. Do not simply allow the console to hang freely at the diver's side. This increases the possibility of damaging the instruments both underwater and on the surface. Special care must be taken in handling all instruments since the adverse effects of extreme cold can cause brittleness and increase the possibility of breakage or malfunction. Monitor all battery powered instruments carefully since some batteries do not perform adequately under conditions of extreme cold.

The use of electronic decompression/dive status monitoring devices is increasing in popularity for all diving activities. Be certain to read the manufacturer's instructions booklets for these instruments and pay particular attention to information relative to cold environment diving. Battery performance and power drain has resulted in significant reduction in battery life under extremely cold diving conditions [14].

COLD WEATHER CLOTHING AND OTHER PERSONAL EQUIPMENT

Each diver and support person is responsible for providing a complete outfit of cold weather clothing. All persons must have a pair of high quality sunglasses for reduction of hazardous eye exposure on sunny days with snow/ice conditions. Eye fatigue and injury from sun glare can be painful if not temporarily disabling; permanent eye damage is possible. Some dime store and fashion sunglasses are completely inadequate for protecting the eyes in snow or ice glare conditions. Be certain that the sunglasses you select filter out most, if not all, of the ultraviolet and infrared radiation. Side shields are useful on some types of glasses in order to prevent excessive light from entering around the sides.

Many dry suit divers wear their dive undergarments to the site and home after the dive. This is an acceptable practice; however, always bring a complete set of dry clothes in a duffel bag in the event that your suit floods.

TEAM EQUIPMENT

The diving supervisor or a designated assistant is generally responsible for assembling and inspecting all team equipment prior to the diving operation and transporting it to the dive site. As with each individual diver's equipment, the team equipment must be assembled and inspected several days prior to the diving operation. The supervisor should prepare a complete checklist. The group equipment should include, but not necessarily be limited to, the following:

* First aid kit complete with oxygen delivery system and backboard or stretcher;
* Blankets or sleeping bag and ensolite pad (to preserve body warmth of an injured diver);
* Containers for hot water (used to warm hands, thaw frozen regulators, and treat frostbite);
* Containers for hot, sweet drink (for general use and emergency warming of distressed person); and
* Thermometer (for checking air temperature; also mandatory to insure that the proper temperature water is used in first aid for frostbite).

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ACKNOWLEDGMENTS

This chapter, in part, was published in *Under Ice Scuba Diving* (Publication No. MICHU-SG-86-500) by the Michigan Sea Grant College Program as part of the Diver Education Series and in the *Proceedings of Special Session on Cold Water Diving* by the American Academy of Underwater Sciences in 1987. It is the result of work sponsored by the Michigan Sea Grant College Program with grants form the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and funds from the State of Michigan.

Manuscript completed: 8 February 1990

CHAPTER 9-3

ORGANIZING AND PLANNING A COLD WATER/WEATHER DIVING OPERATION

INTRODUCTION

Instruction in dive organization and planning is frequently minimal in many sport diver training programs. Since cold diving operations must be conducted at the highest level of efficiency and safety, it is necessary for all personnel to have a complete working knowledge of organization, planning, and procedures. The information presented here is intended to provide the diver/instructor with a greater insight into the requirements for organizing any diving activity, especially a cold water dive. Additional information may be obtained from selected manuals listed in the reference section [1, 2, 3, 4, 6].

PERSONNEL

Someone must take charge of any group diving operation — a *diving supervisor* (i.e., divemaster, instructor, coordinator, or lead diver). This individual must be an experienced diver and should hold a Divemaster Certification. The diving supervisor is in complete charge of the diving operation. His/her primary function is to organize, plan, and manage the diving operation. This responsibility includes selection/approval of dive site, personnel, equipment, and procedures. When only two or three divers are involved, the most experienced individuals often assumes an informal leadership role and the other dives approve decisions or assist in making the decisions.

The diving supervisor is in charge of the dive and site and is responsible for maintaining safety standards. This individual must have the authority to control all personnel participating in the diving operation and must not tolerate violation of accepted/established diving procedures and safety standards.

The diving supervisor's usual post is on the surface where he/she is in a position to direct divers and support personnel. In the event that the designated diving supervisor chooses to dive, an individual with proper qualifications and a complete understanding of the operation must temporarily assume diving supervisor responsibilities until the original supervisor can resume complete responsibility. The diving supervisor should not be burdened with added responsibilities such as dressing divers, recordkeeping, and so on. The supervisor will direct diver and support persons and inspect each diver before he/she enters the water.

Diver-aides may be used for such tasks as time keeping, helping divers dress, and handling equipment. This is an excellent way to involve persons with too limited experience or training to participate as divers. I discourage the use of persons who are non-divers since they are assuming some responsibility for the preparation of the diver and his/her equipment. A pre-dive instruction session for aides can be very beneficial and improve the general overall safety and efficiency for an operation. Some teams assign an aide to each diver or team. However, avoid an excessive number of aides and bystanders.

Ideally, for diving activities involving a beginning divers or large numbers of divers in the water the supervisor should designate *standby divers* to remain on site and completely equipped. Often these standby divers operate from a small chase or rescue boat, especially if the dive is conducted from a larger vessel at sea. In this case the divers can be in the water within a minute to rescue or assist a distressed diver. This practice, however, can be awkward and cold and is often abandoned in reality. In fact, must dive groups do not formally designate standby divers for recreational diving activities. However, this is a sound practice that is observed my many military and scientific diving groups.

DIVE SITE SELECTION

A cold weather dive site for scientific diving, recreational diving, and training exercises should be selected on a basis of satisfactory water/bottom conditions, accessibility, exposure protection, and shore support facilities. The diving supervisor or dive organizer should select or approve the site at least several days prior to the dive. The supervisor or a person designated by the supervisor is responsible for compiling information on the site including the type of shore, access point(s), expected underwater visibility, water depth, bottom type, and availability of support/emergency services. Charts of many inland lakes and quarries are available from state agencies such as the Department of Natural Resources. If access is to be gained through private land or closed public facilities, permission must be obtained well in advance.

Upon arrival at a shore-based dive site most groups will establish an operations base. Ideally, the shore base should provide heated facilities to accommodate both divers and support personnel. These facilities may be in the form of a cabin, building, camping trailer, pickup mounted camper(s), van(s), or a large tent. Heat can be provided by an appropriate camping-type tent or shelter heater. Precautions must be observed to eliminate fire hazard, stove/fuel explosion, and contamination of the interior with toxic fumes (e.g., carbon monoxide). Several small shelters may be used.

During cold weather, all possible measures must be taken to provide the diver with a warm, sheltered place to dress and undress. The diver must avoid unnecessary exposure prior to the dive since pre-dive chilling will accelerate the onset of cold stress. The shelter is also necessary for the care of potential accident victims and persons who may exhibit symptoms of cold injury.

It may be difficult if not impossible to establish an adequate shore base at some dive sites. Some teams rent nearby motel rooms for dressing/undressing and transport divers to the dive site by vans, 4-wheel drive vehicles, or snowmobiles. Only necessary personnel will be at the actual dive site at any given time and a vehicle will always be available to transport injured or cold individuals back to the motel base. Ideally, radio communication should be maintained between the primary base and personnel at the dive site.

MAINTAINING THERMAL COMFORT ON THE SURFACE

Each individual diver and surface personnel is responsible for providing adequate protective clothing for anticipated surface conditions. Many individuals, especially city dwellers, are not schooled in the art of cold weather dressing. All dive team members and support persons must be prepared to deal with low air temperatures, wind chill, precipitation (freezing rain, sleet, and snow), handling wet equipment, long period of inactivity, and so on.

Clothing should be worn in layers starting with wool or polypropylene long underwear. Over clothes, from the inside out, include wool or synthetic pile pants and shirt(s), jacket(s), and/or sweaters, a hooded down or synthetic fiber-filled parka and a windproof/water resistant outer shell garment. A wool or polypropylene watch cap and scarf or balaclava is recommended for head and face protection. Waterproof boots with wool socks and liners are also recommended. Wool or pile mittens or gloves are absolutely necessary. For extreme conditions, windproof/water resistant overmitts are desirable.

The use of vapor barrier garments should be considered for extremely cold conditions where long period of limited activity exposure is anticipated. Vapor barrier shirt and pants are worn over the polypropylene underwear, and normal outer garments are placed over the vapor barrier layer. A vapor barrier foot protection system consists of a thin polypropylene sock next to the foot with a waterproof vapor barrier sock next. One or more insulating sock layers (wool or pile) are placed over the waterproof sock and a second waterproof sock is pulled over the insulating socks. The foot is then placed in a boot. Foot perspiration will wet the liner sock; however, the insulating socks will be protected from both external and internal wetting. Since perspiration is trapped in the polypropylene underwear and not transferred to the insulating garments when a vapor barrier system is used, completely waterproof outer shell garments can be used without fear of perspiration soaking. Vapor barrier is not recommend for persons who are highly activity or for use at temperatures above freezing. The system appears to be most effective for subzero temperatures and sedate activities.

Support personnel must stay dry and maintain proper thermal balance. Keep in mind that a cold individual undergoes mental changes. The mildly hypothermic tender may be easily distracted from his/her duties, slow to comprehend and respond to an emergency situation, and forgetful. Equipment handling is extremely difficult and uncomfortable with cold, wet hands. Most support persons will wear waterproof shells over mittens or gloves. Some prefer foamed-neoprene wet suit gloves and may select a size that enables them to wear a polypropylene or wool liner. The vapor barrier system also works for hands. Aides should always include one or two pair of extra gloves/mittens in their pockets. Pocket-type hand warmer heating units are also valuable.

When working in exposed locations in the winter, air temperatures will frequently be below 0° F (-18° C)and wind can exceed 20 miles per hour. This combination can produce a equivalent chill temperature of –35° F (-32.2° C). Keep in mind that exposed flesh can freeze within one minute at –25° F. Remember that tenders and support personnel are inactive much of the time, thus producing little heat from exercise as compared to active persons such as cross-country skiers, hikers, and workers. *I recommend that recreational and training dives be limited to wind chill temperatures above –25º F unless a heated shelter can be provided for protection.*

All surface personnel must maintain proper thermal balance. During periods of high activity avoid overheating and excessive perspiring by removing hood, opening parka, or loosening cuffs for ventilation. Keep in mind that exposed ears can freeze (frostbite) within a few minutes in extremely low temperatures, and protect them accordingly. As you cool, replace hood or close garments to maintain thermal comfort. Remove some outer clothing when working in heated shelters.

If divers must travel some distance to the dive site on foot or snowmobile or remain inactive and exposed at the surface, they should wear an insulated parka or exposure suit and insulated boots over their diving suits. Heat lose can be considerable, especially in a wind, and pre-dive/post-dive chilling can result in significantly increased risk of injury or mishap.

PERSONAL PREPARATION

Cold water divers must have adequate pre-dive rest and nutrition. In general, divers will perform better if they are in good physical condition and have adequate rest and nutrition for a week or so prior to the diving operation. At least 6 to 8 hours of sleep and a high caloric intake is recommended for the day before the dive. Some authorities suggest that caloric intake be at least 5000 calories per day for the normal size male.

Breakfast on diving days should consist of food with high carbohydrate content but low amounts of residual because defecation is rather difficult for the suited-up diver. Intake of candy, honey, and sugar-sweetened fluids may be beneficial; however, avoid foods and eating habits that might produce nausea. Divers are warned against radical changes in eating habits and food consumption on diving days without prior experimentation.

Divers must maintain a proper fluid balance. Breathing cold, dry air can cause significant dehydration. Consumption of large quantities of caffeine-containing liquids (e.g., coffee, tea, and cocoa), breathing from scuba underwater, and immersion in cold water all tend to induce diuretic effects (e.g., increase urination). Consequently, dehydration is not uncommon. Water and warm fruit juice are most effective for oral fluid replacement; balanced electrolyte fluids (i.e., Gatorade) should be considered if an individual is seriously dehydrated.

TETHERED SCUBA DIVING

An excellent alternative to conventional scuba diving under adverse cold conditions is tethered scuba diving [5]. Conventional scuba diving procedures require that two divers work underwater as a buddy team. In tethered scuba diving a single diver is deployed.

Tethered scuba diving involves the use of special equipment and procedures. The diver wears scuba fitted with a full-face mask that includes communications components. The scuba also includes an auxiliary independent regulator for use in the event of primary system failure. A combination safety line/ communications cable is secured to the diver's safety harness. A surface tender manages the line and maintains constant communications with the diver.

This procedure has been successfully used on many diving projects where the diver has been required to work in cold, low visibility water. It is difficult enough to dress and deploy a single diver from an open boat with a severe wind chill temperature. Deploying two divers can be extremely difficult. And, in low to zero visibility, the diver may have great difficulty staying together.

Divers are cautioned to receive proper instruction and select proper equipment before conducting a tethered scuba diving operation. A complete explaination of equipment, procedures, and training is given in Tethered Scuba Diving [5].

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ACKNOWLEDGMENTS

This paper, in part, was published in *Under Ice Scuba Diving* (Publication No. MICHU-SG-86-500) by the Michigan Sea Grant College Program as part of the Diver Education Series and in the *Proceedings of Special Session on Cold Water Diving* by the American Academy of Underwater Sciences in 1987. It is the result of work sponsored by the Michigan Sea Grant College Program with grants form the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and funds from the State of Michigan.

Manuscript revised: 9 February 1990

CHAPTER 9-4

THE COLD WATER DIVE

INTRODUCTION

The following discussion is included to assist scientific dive teams working under severe weather and low atmospheric temperature conditions in performing dives safely and efficiently. Recreational divers may feel that the procedures are a bit excessive, however, I can assure these more casual divers that such procedures constitute sound diving practices.

PREPARATION AND PRE-DIVE BRIEFING

The diving supervisor coordinates the establishment of the shore base or dive platform (i.e., boat), and all other pre-dive activities. Generally, tasks assigned and discussed prior to arriving at the dive site. Once he/she is satisfied that all preparations have been completed, the entire team is assembled for final briefing. This briefing will include, but not necessarily be limited to, the following:

* Objectives and scope of the dive operation;
* Conditions of the dive site;
* Dive plan, schedule, and diver/tender/aide teams;
* Other personal assignments;
* Safety precautions and review of environmental/cold hazards; and
* Special considerations.

Many diving supervisors prepare a dive preparation checklist and briefing outline. At the briefing, the supervisor should evaluate all personnel to assure that they are fit to dive or undertake assigned responsibilities. Surface personnel clothing and health status should be evaluated at this time as well as continuously from the time they arrive at the site until they leave. These are the people at greatest risk of frostbite and hypothermia.

Generally the divers will be required to terminate their dive when they experience regulator icing, begin to shiver, reach the specific time limit established for the dive, or reduce their air supply to approximately 500 psig (when using a full 3000 psig cylinder). Some teams are more conservative and require termination of the dive with more air held in reserve. This is up to the discretion of the diving supervisor and can vary with dive sites and conditions.

The divers proceed to dress with the assistance of their aides. Ideally, the divers go to the staging area with all equipment in place except for mask and fins. If the distance from the shore base or dressing area to the dive site is great, scuba may be transported on a sled or snowmobile and donned at the site. The aides assist the divers in donning the mask and fins.

Aides and divers complete a final equipment and status check. The supervisor will also complete a final check and, when satisfied, permit the divers to enter the water. If the divers have been properly outfitted and checked before they leave the shore site this final preparation and evaluation procedure should take only a few minutes.

The comfort and safety of the divers is the primary concern. Take note that almost everything possible is done for the diver by an aide once the diver is ready to deploy. Just before entering the water, warm water can be injected into wet suits to add some degree of thermal comfort. Although this is not a common practice today, it has been used in the past. If a dry suit diver is wearing unattached gloves, hot water can injected into the gloves.

THE DIVE

Generally, most divers prefer slip slowly into the water. This is much better for purging air from dry suits. As the diver submerges he/she holds on to the descent line (if used), adjusts suit air level, adjusts buoyancy, and quickly checks the buddy diver's equipment and status. When both are satisfied, they descend. Breathing slow and easy will minimize the potential for regulator icing.

Each diver is responsible for maintaining the buddy system. Even in good visibility I prefer to see divers no more than 8 feet apart. Divers should avoid rapid and excessive movements that tend to confuse their buddy. Wet suited divers will find that such movements may also increase flushing of water through the suit. Maintaining a moderate level of movement or exercise produces heat and delays the onset of cold stress. Immobility accelerates chilling.

Most lakes and quarries have a thick layer of slit (fine- grain sediment) on the bottom. The careless diver can rapidly reduce the usually clear under ice visibility to zero by stirring up this silt. The divers must adjust their buoyancy and body attitude so that they swim above the bottom and do not disturb the silt with their fins. If visibility becomes obstructed, the diver may ascend further above the bottom and swim in clear water.

In some situations it is possible to encounter currents. This is particularly true where there are restricted bay mouths, straits, or rivers. Winter winds can act on large areas of adjacent open water and create currents which move large units of ice. Tide-induced currents must also be considered in ocean diving.

WHEN TO TERMINATE THE DIVE

Dive termination is determined by one or more of several factors including no-decompression time, cylinder pressure, cold, equipment malfunction, and emotional status. From a standpoint of cold, the diver must terminate with the onset of involuntary shivering and/or diminished manual dexterity. In reality, the diver should terminate when he or she feels uncomfortable or chilled. Generally, the fingers and toes will give the first signs of cold effects. The diver should not prolong the dive exposure to the degree that he/she finds it difficult to handle the safety line or suit/BCD valves.

The diver should plan to terminate the dive with approximately 300 to 500 psig of the air supply remaining as a safety factor. Generally, air consumption will increase as the diver cools. Each dive must, however, be planned independently.

Today there is great concern and much discussion about decompression tables and *revised* no-decompression limits. For cold dives the U.S. Navy instructs their divers to use the schedule for the next deeper or longer dive or both. If the diver is following one of the more recently published and more conservative no-decompression schedules AND is not cold, a normal no-decompression time can probably be used safely [2]. However, if in doubt or cold, the diver is encouraged to use the more conservative decompression schedule for the next deeper dive (10 feet deeper than the actual dive).

DIVING UNDER SPRING ICE

The number of fatal ice diving accidents is relatively few. However, most of the fatal accidents in the Michigan and Ohio area have occurred during late winter and early spring months when lakes, quarries, and ponds are only *partially covered* with ice. The unsuspecting novice diver, probably trained during the previous winter months, is anxious to start the diving season. A scuba diving team may enter a partially ice covered pond intending to swim only in the open water portion of the pond. They lose orientation, venture under the ice by accident, and drown when they run out of air. Accident reports show that both novice and highly experienced divers have lost their lives in this fashion.

Do not rely solely on a compass for diving in partially ice covered ponds. Either use standard ice diving procedures or dive with a safety line attached to a boat that will follow the diver. Some divers will elect to tow a large float that will catch on the edge of the ice. The float must have sufficient size and buoyancy so that the divers can not pull it under the ice shelf. Do not use the lightweight line generally used for towing surface floats/flags in open water; use a heavy line.

REWARMING THE DIVER

When the diver surfaces, remove breathing apparatus, BCD, weight belt, fins, and mask as soon as possible. If the distance to the shore base is short, the diver may carry the scuba and weight belt in place; for longer distances use a sled. Immediate injections of "comfortably" hot water (100 to 110° F) into wet suits and mittens are beneficial. ***BE CAREFUL TO NOT BURN THE DIVER WITH EXCESSIVELY HOT WATER!*** Do not remove the mittens or hood in cold air. Remember that wet flesh can freeze within a few minutes. *Be cautious when applying hot water to exposed skin of divers who have been exposed to extremely cold temperatures.* Divers have experienced severe blistering and peeling of the skin following the application of too hot water. The diver apparently doesn't realize that he/she is being scalded [1].

If there is to be considerable delay in undressing the diver, remove mittens and hood in a protected location, dry hands and head, and don insulated mittens and hat. Moderate exercise will promote rewarming. Breathing warm air in a heated shelter will also significantly increase the warming rate. The diver should remove the diving suit and don dry clothing as soon as possible. Dry suited divers are at a considerable post-dive advantage compared to wet suited divers. Unless the dry suit has leaked significantly and the under garments are uncomfortably wet, the dry suited diver can simply don additional outer garments without the discomfort of exposing the wet body to often less than satisfactory conditions.

The preferred method of rewarming a chilled diver is to allow the diver's own biological processes to rewarm his/her body over time with plenty of rest. Drinking warm liquids is considered beneficial. If aggressive rewarming is required in order that the diver may return to diving immediately or conventional rewarming appears to be inadequate, the diver may be immersed in a tub of comfortably hot circulating water. Neither showers or still baths appear to be as satisfactory as a circulating tub immersion. The water must circulate around the body to maximize heat transfer. In the absence of a circulating tub, use one of the other methods. Do not remove the diver from the tub until sweat appears on his/her forehead [3].

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ACKNOWLEDGMENTS

This paper, in part, was published in *Under Ice Scuba Diving* (Publication No. MICHU-SG-86-500) by the Michigan Sea Grant College Program as part of the Diver Education Series and in the *Proceedings of Special Session on Cold Water Diving* by the American Academy of Underwater Sciences in 1987. It is the result of work sponsored by the Michigan Sea Grant College Program with grants form the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and funds from the State of Michigan.

Manuscript revised: 9 February 1990

NOTES:

CHAPTER 9-5

DEALING WITH COLD WATER DIVING EMERGENCIES

INTRODUCTION

Cold water divers and support personnel must be prepared to resolve emergencies such as breathing system malfunction, suit or BCD inflator malfunction, suit flooding, uncontrolled ascent, and loss of consciousness. Keep in mind that most of the emergencies discussed below can be prevented through the use of proper equipment and procedures, and safety precautions. And those that do occur can generally be easily resolved.

Self-discipline is the key to the diver's safety. The diver must discipline every move that he/she makes both on the surface and underwater. Many fatal and nonfatal diving accidents occur each year because a diver did not know and observe his/her personal limitations or those of the equipment being used. The cold water diver must know when to terminate or abort a dive. A cold diver is at a higher level of risk and is less likely to respond promptly and properly in an emergency.

Personally, I have far more respect for the diver who simply says, "I'm too cold, that's all for me!", than the thermal macho (or machette) diver who guts it out to the bitter cold end to prove that he/she is a better(?) diver. I know that the first diver will still be of some use in an emergency and will probably end up saving the "better diver" someday. Don't push to the absolute limit in any diving situation, especially in cold water. I have seen some divers go so far that they do not have the physical strength to pull themselves from the water or walk once they are out. Cold can do strange thing to both body and mind.

REGULATOR MALFUNCTION

Regulator malfunction is relatively common and of great concern to all divers. The mechanism, nature, and prevention of regulator icing is discussed in a paper titled *Equipment for Cold Water Diving*. In the event that the regulator malfunctions, the diver(s) should immediately return to the surface. If the regulator is free-flowing, the diver can continue to breath from the regulator. Remember, however, that continuous free-flow will probably increase in rate as the ice crystal enlarges and unnecessary delays may result in high flow rate and significant air loss from the scuba. Some divers have described the free-flow experience as "literally blowing the regulator out of my mouth" or "painful."

Some divers/dive teams will switch to the alternate (and separate) air supply immediately and isolate (turn off) the malfuncting regulator. Naturally, both divers in a buddy team will return to the surface. At the surface, air is turned off and the regulator first- and second-stages can be thawed with warm water, if necessary.

If sufficient air remains in the scuba, the divers may descend again to check the function of the regulator. If the regulator is functioning properly, they are generally allowed to continue the dive. Usually, each instructor and dive team will establish a policy regarding dive continuation.

If the regulator malfunction shuts-off the diver's air supply, immediately switch to an alternate air source and terminate the dive. Although such malfunctions are rare, the possibility must still be considered. Do not use the regulator again until the cause of the malfunction has been determined and corrected.

BLOWUP

A diver may lose his/her weight belt, accidentally over-inflate a BCD or suit, or experience a suit/BCD inflation valve free-flow malfunction. Any of these conditions can result in an uncontrolled ascent or blowup. The stricken diver must begin exhalation immediately in order to reduce the possibility of pulmonary barotrauma and attempt to discharge excess air from the suit or BCD.

If the suit or BCD valve is free-flowing, the diver must *disconnect the hose*. If possible, place one hand over head in order to break the impact with any overhead object. Above all, remain calm and exhale. Unless the malfunction is corrected immediately, anticipate being on the surface within a few seconds. Even if you resolve the situation terminate the dive. The diver must be observed for signs of pulmonary barotrauma.

Many divers fear blowups, either in a head-up or feet-up (inverted) position, if they accidentally lose their weight belt. The following information on blowup was summarized from a NOAA study [1]:

1. The rate of ascent varied by only a few seconds between a diver losing his/her weight belt in a head-up or a head-down position.
2. The rate of ascent resulting from weight belt loss could be better controlled by divers wearing "fabric" suits than those wearing foamed-neoprene dry suits.
3. All attempts to recover from a feet-first blowup were successful with the first 15 feet after the weight belt was dropped.
4. The use of ankle weights helps the diver get his/her legs down quicker. The ankle weights also apparently reduce the amount and rate of air movement into the foot and, thus, reduces the possibly of fin loss.
5. If the weight belt is lost in water depths of less than 20 feet, the diver must vent air from cuffs and/or neck seal as well as the exhaust valve. The exhaust valve alone cannot expel air fast enough to control the ascent. However, venting from cuffs/neck seals is extremely difficulty for divers wearing the heavy mittens common to cold water diving situations.
6. Venting by opening the suit zipper is difficult and almost impossible in the inverted position (and when wearing suits with back-entry zippers.
7. Ascents resulting from loss of the weight belt in depths greater than 20 feet can be controlled by using the exhaust valve; almost normal ascent rates can be maintained.

The following recommendations are based on the NOAA study [1]:

1. Emergency blowup venting procedures must be taught; however, they must be taught and practiced under very controlled conditions. The diver should be secured so that they will not lose complete control and ascend out-of-control to the surface.
2. Ankle weights should be worn when possible. They aid in keeping the feet down in blowups and help keep the feet in proper position at all times. They give stability and help keep fins on in the event of air getting into the feet.
3. Front-mounted BCDs should not be worn with suits that have exhaust/purge valves located in the chest.
4. Divers should not be allowed to use variable volume dry suits until they have had adequate training.

Many foamed neoprene suit equipped-divers have used shoulder harness weight belts in the past in order to increase comfort of wearing extremely heavy belts and reduce the possibility of losing the belt underwater. The use of this type of belt is discouraged. It the diver feel a need for a shoulder harness weight belt, it must be equipped with quick release devices on the shoulder straps and the diver must be trained in releasing the belt in an emergency.

There are two methods of recovering from an inverted position blowup: the forward roll, where the diver curls inward, and the back roll, where the diver extends and arches his/her back. The back roll is the preferred method for recovery because: (1) it provides the diver with better directional attitude for purpose of recovery of a lost weight belt, and (2) it reduces the ascent time, although not significantly. During the forward or curl roll, the diver loses downward thrust and begins ascending while curling around [1, 2].

The diver can practice blowup recovery using a descent line and a second safety diver/instructor. The instructor holds the student down and depresses his/her inlet valve to put air in the suit. Be careful to not overinflate the suit during initial practices; use progressively increasing amounts of inflation. The student start to drift (ascend) upward and immediately starts venting and flaring procedures. The instructor holds on to the student with one hand and a decent-ascent line with his other in order to control the student's ascent. Both head-up and inverted blowup recoveries must be practiced.

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ACKNOWLEDGMENTS

This paper, in part, was published in *Under Ice Scuba Diving* (Publication No. MICHU-SG-86-500) by the Michigan Sea Grant College Program as part of the Diver Education Series and in the *Proceedings of Special Session on Cold Water Diving* by the American Academy of Underwater Sciences in 1987. It is the result of work sponsored by the Michigan Sea Grant College Program with grants form the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and funds from the State of Michigan.

Manuscript revised: 9 February 1990

NOTES:

CHAPTER 9-6

THERMAL STRESS AND THE DIVER

INTRODUCTION

The human body is homeothermic, or warmblooded, and must constantly interact with its external environment in an effort to maintain thermal equilibrium. It basically operates in a very narrow temperature range. Slight cooling of the body can produce discomfort, and continued cooling can cause serious, if not life- threatening, physiological changes. The same is true if the body is heated. Cold induced deterioration in both motor and mental processes is considered to be the major limiting factor relative to diver performance, comfort, and safety. All divers have experienced hypothermia, or a subnormal body temperature, in varying degrees at one time or another. Most divers associate cold stress and hypothermia with polar or temperate region waters and fail to recognize the *thermal drain* that can be associated with diving in the tropics. On the other hand, hyperthermia, or abnormally high body temperature, may unknowningly place some divers at high risk.

HEAT LOSS

Thermal balance and immersion heat loss are affected by a number of variables. The first of these is obviously water temperature and the effectiveness of the diver's thermal protection garments. The length of exposure becomes a critical factor, as does the magnitude of metabolic heat generation. The individual's body fat composition; body mass and surface area; and physiological/psychological acclimatization must also be considered. In generalized terms, an individual of large body mass produces more heat and can tolerate longer exposures to cold water than a small, thin individual.

As the body begins to cool there is a mobilization of its heat generation and insulation resources to resist the cold. This response is characterized by peripheral vasoconstriction (constriction of circulating blood near the body surface) and increased metabolic activity in an effort to prevent a drop in the body's core temperature. Active movement of body tissues generates heat, carbon dioxide and water. As the body continues to cool the most obvious metabolic activity will take the form of shivering thermogenesis. Thermogenesis is simply the generation of heat.

The first diver evidence of heat loss, just below the comfort level, is *cold sensations*. This is followed by cutaneous vasoconstriction and, then, increased muscle tension which are not obvious to the diver. Even before a person begins to shiver visibly, muscle tension is measurable on an electromyogram. Normal core temperature is 37°C. At 36°C sporadic shivering begins. This initial shivering can be suppressed if the diver makes a conscious effort and, in fact, a working diver may not exhibit shivering at this point because of muscular activity. As the diver continues to cool, shivering increases and causes a further rise in oxygen consumption. As the diver reaches the stage of uncontrollable shivering, the oxygen consumption is two to five times the normal [1]. By this time the dive should have been terminated and rewarming procedures initiated.

When the core temperature drops to 35°C, the diver will experience mental confusion and impairment of rational thought. Death by drowning is a real possibility. A diver should never *push* or *be pushed* to this point. Continued exposure to cold and decreasing the core temperature below 35°C causes loss of memory, poor articulation, sensory and motor degradation, and amnesia [1]. Many investigators believe that cold creates a distraction in the diver that interferes with his or her work, and indeed, safety [2]. Childs observes, "distraction due to discomfort may cause the diver to ignore threats to his safety underwater and finally, realizing he is in danger, he may be in further difficulty because of loss of power and dexterity in his hands" [3].

In order to better understand *heat loss* and the use of diver thermal protection systems, it is necessary to consider the areas of the body where metabolic heat is produced. About 16 percent of the metabolic heat is produced in the brain, about 56 percent in the core of the trunk, and about 18 percent comes from total skin and muscle. The remaining 10 percent comes from the total skeleton, connective tissue, and other structures [4].

Divers tend to concentrate their thermal protection around the trunk and often compromise protection to the head. It is interesting to note that the head, a relatively small portion of the body, produces a great deal of heat. Furthermore, the peripheral vasoconstriction effectiveness varies considerably from one part of the body to another. The hands and feet experience considerably high vasoconstriction and cool very quickly [4]. This results in reduced finger dexterity, tactile (touch) sensitivity, and kinesthetic (musculoskeletal) sensation. However, total heat loss in these areas is low. On the other hand, scalp circulation in the head does not experience this vasoconstriction or *shut down* [1]. The amount of continual heat loss can be quite substantial if the head is not properly protected.

SILENT HYPOTHERMIA

Divers have only recently developed an awareness of *silent or undetected hypothermia* resulting from long, slow body cooling. Field experience showed that after several days of work in 27°C water temperature scientific divers were reluctant to continue to dive. Divers working in the temperate waters of southern California sometimes *forgot what they were doing*. Polar divers often neglected to complete their research task. In most cases the divers generally would not indicate that they were cold, just fatigued or unwilling to dive again [5].

What was the problem? The participants at the "Prevention of Cold Injury" workshop sponsored by the Undersea Medical Society and National Oceanic and Atmospheric Administration reached the following conclusion, "The fatigue and impaired cognition [was] due in large part to the slow body cooling of divers even in tropical waters" [5].

For years scientists failed to make the connection between cold and diver fatigue for three reasons: (1) thermal macho; (2) lack of appreciation of the importance of thermal protection equipment; and (3) the insidious nature of undetected hypothermia in long, slow body cooling. *Thermal macho* is perhaps best described by Diver/Engineer Robert Stinton of Diving Unlimited International. To quote, "Divers will rarely admit that they are cold. So they become fatigued and are reluctant to dive again. But they will never admit it's because they are cold except in the most extreme situations. Even if they say they're not cold, they pay the price in reduced performance, fatigue, and loss of motivation" [5].

Several authorities on cold water immersion suggest that long, slow cooling of the body does not stimulate the shivering response and thermogenesis. When cooling is encountered by a swimsuit-clad diver immersed in 28 to 33°C water or diving in wet or dry suits in 15°C or colder water, the mean skin temperature can remain close to the usual comfort zone (33° C). Consequently, the thermal drain from the body to the water is insidious and hardly noticed by the diver until the core temperature drops 1 to 2°C and shivering supervenes [5].

Bachrach considers silent or progressive hypothermia as "perhaps the major hazard to the diver in cold water" [2]. In commercial diving, investigators have implicated cold as a major cause of diving casualties, particularly the silent, progressive, insidious onset of hypothermia of which the diver is unaware [3, 6].

Divers often disregard the possible cumulative thermal effects of repetitive diving. Following the initial dive the diver returns to the surface where he/she may experience superficial skin rewarming, but, little or no recovery of depressed core temperature. Each successive dive creates additional and cumulative thermal drain. This is why many divers are often too fatigued to care for their equipment following a day's diving activities and may sleep on the way back from the dive site [7]. This *thermal debt* may continue to accumulate over successive diving days. Sport diver complaints of getting colder toward the end of a week of tropical diving are not uncommon, especially if the diver is not using some form of thermal protection. One such female diver described her tropical experience, "After a few days of diving I would return to my room and huddle on the floor under a hot shower for an hour after a dive." It takes time, rest, food, and, sometimes, aggressive rewarming procedures to replace lost heat energy.

REWARMING THE DIVER

The preferred method of rewarming a chilled diver is to allow the diver's own biological processes to rewarm his/her body over time with plenty of rest. Remove the diver from the water to a warm, protective shelter where the suit can be removed without added thermal degradation. The diver should dry as soon as possible and dress in adequate warm, dry clothing.

If aggressive rewarming is required in order that the diver may return to diving immediately or conventional rewarming appears to be inadequate, the diver may be immersed in a tub of comfortably hot *circulating* water [8]. Neither showers nor still baths appear to be as satisfactory as a circulating tub immersion. The water must circulate around the body to maximize heat transfer. Do not remove the diver until sweat appears on his/her forehead.

DETERMINING PERFORMANCE DEGRADATION AND DIVER STATUS

One simple method of determining performance degradation is by monitoring the diver's hand writing [8]. Have the diver sign his/her name prior to entering the water. When the diver surfaces, have him/her sign under the first signature again. Repeat this procedure for each successive dive. If the signature shows a continual degradation, this indicates a lack of blood flow to the muscles of the lower arm area and, therefore, the accumulation of a thermal debt. In male divers the testicles will rise to maintain thermal balance as the body cools. One authority suggests that an indication that the diver is completely rewarmed is when the testicles descend to normal position again [8]. This may or may not be a reliable indicator of thermal recovery.

HYPERTHERMIA IN DIVING

If the body is exposed to high ambient temperatures, it can gain heat. Consequently, the body must increase the amount of heat that it loses in order to prevent a rise in core temperature. Through vasodilation, or increasing the size of the peripheral blood vessels, more blood is carried to the periphery where it can be cooled.

Under certain conditions this process can be somewhat limited. If the diver is encased in a hot, humid environment such as a hyperbaric chamber or a *diving suit* with direct exposure to the sun, the heat loss process may be insufficient. Normally, the evaporation of perspiration will promote significant cooling of the body's surface and, thus, loss of heat from peripheral circulation. What happens if the ambient environment will not facilitate evaporation? Apparently, little heat loss occurs and the increasing peripheral temperature is transmitted to the core [4].

Overheating can lead to heat aesthemia when a person just doesn't feel well; heat cramps; heat exhaustion; and heat stroke [4]. The onset of problems can be alleviated only if the danger signs are recognized. In the case of heat cramps, for example, the painful muscle spasms develop with increasing regularity as the concentrations of sodium and chloride ion in the blood and tissues decrease. Heat exhaustion occurs next. In heat exhaustion the diver will start sweating profusely, experience a lowering of blood pressure, and feel weakness and vertigo. The end result is a heat stroke in which the diver develops an extremely high fever and lapses into coma. Sweat glands stop functioning, and the body temperature rises at an alarming rate. This condition can be terminal.

The adversities of hyperthermia are rare in most scuba diving situations. However, some divers dressed in thermal protection suits and exposed to hot sun and high ambient temperatures for significant periods of time on boat decks or beaches have complained of *not feeling well* and have exhibited symptoms that suggest the early stages of heat exhaustion. One diving suit manufacturer acknowledges heat stress as a potential problem and recommends specific precautions for divers exposed to high temperature surface conditions [8]. Pouring cool water down the neck and sleeves of the wet suit diver can be very effective. Divers who must remain dressed in dry suits may be cooled by placing their hands and wrists in ice water, blowing air into the suit, and placing cool, wet towels or running water over the head. Divers and dive teams using dry suits for warm weather diving operations should anticipate such problems in divers experiencing long surface exposures while suited and take specific precautions.

SUMMARY

Both cold stress and heat stress problems should be anticipated by divers. Silent or progressive hypothermia associated with long, slow cooling of the body appears to not produce shivering and thermogenesis until significant core temperature drop has occurred. Cumulative effects of hypothermia are evident in tropical as well as temperate and polar area diving. The increased use of dry suits provide improved thermal protection against cold; however, hyperthermia is potentially of greater concern during warm weather surface exposure.

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ACKNOWLEDGMENTS

This chapter was originally published by the Michigan Sea Grant College Program as part of the Diver Education Series — Publication No. MICHU-SG-86-502. It is the result of work sponsored by the Michigan Sea Grant College Program with grants form the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and funds from the State of Michigan.

Manuscript completed: 1986

CHAPTER 9-7

RECOGNITION AND MANAGEMENT OF HYPOTHERMIA AND COLD INJURIES

INTRODUCTION

Cold stress and hypothermia have been discussed in Chapters 5-5 and 9-6. In addition to hypothermia, divers and surface personnel must be aware of other potential injuries common to the cold weather environment such as frostbite, snowblindness, and carbon monoxide poisoning [3]. Although snowblindness and carbon monoxide poisoning are not specifically classified as cold injuries, they are both associated with working in cold environments. In addition, the cold environment diver should be familiar with the management of burn injuries that may result from mishandling or malfunction of a shelter heater. Fire hazard is of especially great concern for polar workers and adventurers. Burn management will not be discussed here, but divers and support personnel are encouraged to consult appropriate first aid manuals.

HYPOTHERMIA

Hypothermia is known and feared by all cold weather workers. Anyone working outdoors in severe cold must be aware of the possibility of hypothermia and guard against it. The general physiological effects of decreasing core temperature are summarized as follows:

98.6°F	Normal core temperature
98.6 to 96°F	Shivering begins
95 to 91°F	Violent shivering; speech difficulities
90 to 86°F	Shivering decreases; muscles become stiff; erratic or jerky movements; thinking not clear but maintains posture
85 to 81°F	Victim irrational, loses contact with environment
80 to 78°F	Unconsciousness
Below 78°	Death

Divers and support personnel must be able to recognize the signs and symptoms of hypothermia in themselves and others. Be alert and constantly evaluate your own condition. If you exhibit any or several of the following symptoms or observe them in other members of the team, take immediate measures to reduce heat loss and provide supplemental heat:

* Intensive shivering;
* Severe fatigue or slowing of activity;
* Feeling of deep cold or numbness;
* Poor coordination and stumbling;
* Poor articulation; speech difficulty;
* Disorientation, irrationality, and poor judgment;
* Decrease in shivering followed by muscle stiffening;
* Blueness of skin;
* Intense thirst;
* No desire for food;
* Hallucinations; or
* Depersonalization.

I can not overstress the need for *awareness* of these conditions. The condition can be subtle; silent hypothermia has been discussed previously. Given prolonged exposure, extreme cold, high heat loss, and heavy exertion, an individual can be rendered hypothermic without recognition of the lesser signs and symptoms.

If *mild hypothermia* is suspected, move the victim to a heated shelter as soon as possible; protect from wind and cold. Replace wet clothing with dry and begin *passive* heating by placing the victim in a sleeping bag or under blankets at room temperature (77-90°F). The theoretical advantages obtained from slow, passive rewarming are avoidance of the rewarming temperature *after drop* and hypotension, and the slow resolution of spontaneous fluid shifts. Slow, passive rewarming is a safe and simple method for mild hypothermia. One should assume that otherwise healthy individuals who are exposed to cold are volume (fluid) depleted. For conscious and cooperative victims, forced drinking in the absence of thirst is recommended. Water and warm fruit drinks are the most effective. Avoid coffee, tea, and cocoa [2].

If a victim is cold and has any of the following signs or symptoms, consider that person to have severe hypothermia [1, 6]:

* Depressed vital signs.
* Altered level of consciousness, including slurred speech, staggering gait, and decreased mental skills.
* Core temperature of 90° F or less.
* No shivering in spite of being very cold.
* Associated significant illness or injury that is present or that may have permitted the hypothermia to develop.

If the victim is cold and does not have any of these signs or symptoms, he/she is considered to have mild hypothermia.

The basic treatment for a severely hypothermic victim is as follows:

* Treat very gently.
* Remove wet clothing/diving suits. Replace with dry clothing or dry coverings of some kind.
* Insulate from the cold.
* Add heat to the head, neck, chest, and groin externally, or internally if a system for breathing warm moist air is available. Avoid attempts to warm the extremities.

The first responder must prevent further heat loss at the core. This can only be done by insulating the entire patient, plus adding heat to the core area.

Application of heat can be accomplished using warm objects such as hot water bottles, chemical heat packs (wrapped in a towel), warmed rocks (wrapped in a towel), human bodies, etc. Monitor closely and be certain to protect patient's skin from burns.

* Do not rub or manipulate the extremities.
* Do not give coffee or alcohol.
* Do not put the patient in a shower or bath.
* Warm liquids may be given only after uncontrollable shivering stops and the victim has a clear level of consciousness, the ability to swallow, and evidence of rewarming already.
* If severe hypothermia is present, treat as above and transport to a medical facility.

Treatment for severe hypothermia with no life signs is as follows:

* Provide the basic treatment as indicated above.
* Carefully assess the presence or absence of pulse or respiration for one to two minutes.
* If no pulse or respiration, start CPR.
* Obtain a rectal temperature if possible.
* If you are less than 15 minutes from a medical facility, do not bother trying to add heat.
* If you are greater than 15 minutes from a medical facility, add heat gradually and gently.
* Reassess the physical status periodically.
* Transfer to a medical facility in all cases.

The above procedures were taken from a booklet titled, "State of Alaska Hypothermia and Cold Water Near Drowning Guidelines" [1]. For additional information consult this booklet. At present there is some degree of controversy within the medical community regarding administering CPR to a hypothermic individual. Some authorities specifically state that a hypothermic person should not be given CPR in the field. In a recent discussion Martin J.

Nemiroff, M. D. indicated that the Alaska Guidelines [1] remain as the most acceptable alternative for the first responder to follow.

Slow, passive warming is the best procedure for field management in most diving related situations. Medical assistance is generally available within a few minutes to a few hours. *Active rewarming of severely hypothermic victims in the field is potentially risky and should only be attempted by specially trained individuals.* Persons involved in polar expeditions and remote location diving operations must be schooled in advanced methods of hypothermia management.

FROSTBITE

During exposure to cold the body reduces the flow of blood to the surface blood vessels in order to maintain the body's core temperature. The hands and feet are most affected by this reduction in surface blood flow and, due to great skin area, cool rapidly. The ears and nose, although receiving a large amount of blood, protrude from the body and are, therefore, very susceptible to cooling.

As the skin temperature drops below 50°F all sense of touch and pain are lost. If the temperature continues to drop, most circulation to the area will cease and frostbite occurs. The water in the cells of the skin and capillaries freezes and tissue injury results from the expansion of the ice and the resultant cellular chemical imbalance.

Most persons working or playing in cold weather have experienced *frostnip* at one time or another. This is superficial, reversible ice crystal formation associated with intense vasoconstriction. The skin blanches, and becomes numb with a sudden and complete cessation of cold and discomfort in the affected part. The skin will appear pale, grayish-white in color and feel cold to the touch.

As soon as whitening is observed shelter the area from the wind. Cover with dry, insulating, wind proof material. Put you back to the wind or, ideally, find protection in a warm shelter. If possible place the affected area next to a warm area of the body. *Do not rub the area or apply snow!* This only injures the tissue and increases the risk of "tissue death" and subsequent gangrene. A tingling sensation and even some localized pain may occur during rewarming. Once normal color and consistency of the area is obtained normal work can be resumed.

Many persons confuse frostnip with *superficial frostbite*. In superficial frostbite the water in the skin and subcutaneous tissues immediately adjacent actually freezes. The frozen part will appear white or grayish-white and be frozen on the surface. When pressed (before thawing) the tissue under the skin will be soft and pliable. Treatment of superficial frostbite involves active heating of the area or affected part. This must be accomplished in a shelter where the victim is warm and protected from the wind.

Most of the damage from freezing occurs during the transition from liquid to solid state and vise versa. Rapid thaw decreases the injury by decreasing the amount of time that the cells are exposed to the most damaging conditions. The ideal thawing temperature is somewhere between 37.8 and 43.3°C (100 to 110°F), never to exceed 44.4°C (112°F). The most effective temperature appears to be 42°C (108°F); thawing temperatures above 42.8°C (109°F) can cause increased discomfort [2].

Immerse the affected part in warm water at approximately 42°C (108°F). To measure the temperature accurately a thermometer should be available. Water that is too hot can cause extreme discomfort and damage the tissue. If a themometer is not available the temperature can be tested with an "unfrostbitten" finger; it should be comfortable to touch and not burn the finger. If the affected area can not be immersed in water, pour water over towels and apply to the area.

The thawing process requires about 30 to 40 minutes and should not be prolonged after complete rewarming. Thawing is judged to be complete when the part is pliable and color and sensation have returned [2].

The diver will seldom be faced with the possibility of *deep frostbite* which involves not only freezing of the skin and subcutaneous tissue but also deeper structures, including muscle, bone, and tendons. Do not attempt to thaw in the field. This condition is critical and requires immediate, rapid evaculation to a medical facility. Incomplete thawing and/or immediate refreezing results in severe damage which may lead to gangrene and subsequent amputation.

During and after rewarming the skin becomes numb; mottled, blue or gray; and it will sting, burn, or swell for a period of time. Blisters may appear within 24 to 48 hours depending on the site and extent of injury. If blisters do appear, do not break them since the possibility of infection is everpresent. Maintain sterile conditions. If the blisters do break, cover with a sterile soft, absorbent dressing and monitor for infection. It is best to consult a physician, even though thawing procedures appear to have been successful.

Heavy breathing resulting from strenuous exercise at temperatures below –25°F *can cause freezing of lung tissue*. The victim may experience shortness of breath and cough up blood. This may be followed by a period of asthmatic type breathing. If exercising vigorously at extremely low temperatures and you experience any of these conditions, stop, put your back to the wind, and draw your hood face tunnel over your face. This allows you to rebreath some warmed, humidified, expired air.

SNOWBLINDNESS

Divers and support personnel occasionally work on the ice for long periods of time in direct bright sun. The reflected ultra-violet rays can cause snowblindness. Victims experience a sensation of grit in the eyes with pain in and over the eyes, watering, redness, headache, and intense pain upon additional exposure to light. The symptoms, like those of sunburn, usually do not become apparent for hours following the exposure. Snow blindness will heal in a few days; however, a physician must be consulted. Cold compresses and eye bandages will provide some relief. Avoid ointments and other medications except as prescribed by a physician. Caution the victim against rubbing his/her eyes.

CARBON MONOXIDE POISONING

Whenever a stove or fueled heater is used in a shelter or confined space, the danger of carbon monoxide accumulation always exists. Carbon monoxideis odorless and can render a person unconscious with little or no warning. All divers and support personnel must be aware of the symptoms of carbon monoxide poisioning and know appropriate first aid procedures. The symptoms include:

* Headache;
* Dizziness;
* Weariness;
* Nausea;
* Yawning;
* Ringing in the ears;
* Heart beat abnormalities; and
* Redness of skin, especially nail beds and lips.

Victims must be removed from the contaminated environment as soon as possible and administered 100% oxygen. Avoid exercise and sudden exposure to cold since this only increases oxygen requirements and may cause the victim to collapse and even cease breathing. Be prepared to administer resusitation. Immediately transport to a medical facility for treatment and/or observation.

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ACKNOWLEDGMENTS

This paper, in part, was published in *Under Ice Scuba Diving* (Publication No. MICHU-SG-86-500) by the Michigan Sea Grant College Program as part of the Diver Education Series and in the *Proceedings of Special Session on Cold Water Diving* by the American Academy of Underwater Sciences in 1987. It is the result of work sponsored by the Michigan Sea Grant College Program with grants form the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and funds from the State of Michigan.

Manuscript revised: 8 February 1990
Manuscript revised: 20 February 1990
Manuscript revised: 26 July 1990

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