LANG

PROCEEDINGS OF SPECIAL SESSION ON COLDWATER DIVING

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AMERICAN ACADEMY OF UNDERWATER SCIENCES
COLDWATER DIVING FOR SCIENCE SYMPOSIUM

29 OCTOBER - 1 NOVEMBER 1987
UNIVERSITY OF WASHINGTON
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FOREWORD

These proceedings contain seven invited papers which were presented during a special session on coldwater diving at the American Academy of Underwater Sciences' *Coldwater Diving for Science...1987* Symposium, October 29 to November 1, 1987 at the University of Washington, Seattle. The Symposium proceedings of contributed papers were published separately and are available from the AAUS.

The primary goal of the Academy is the safety of the individual diving scientist. The United States of America maintains an active role in research programs in polar and subpolar environments. A portion of this research is conducted underwater in waters that are numbingly cold. Because of the extreme environmental conditions both above and below the water surface, an extra measure of preparation and training is required. As new researchers and diving scientists are attracted to such environments they must be properly prepared if they are to productively pursue their research goals.

The Academy has produced this resource document to assist in preparing researchers for what they might expect in coldwater environments. This document serves as a preliminary written record by compiling the knowledge and experiences of long-time coldwater researchers for the benefit of less experienced colleagues. In the past, this experience has been passed down by word of mouth. In order to establish a more organized method of information transfer, the Academy has also organized a Polar Diving Workshop, which can be held at regular intervals.

In addition to the topics of coldwater physiology and diver training, new technology in exposure protection suits and insulation are covered. The important aspects of logistics in coldwater environments and Arctic/Antarctic regions are also addressed.

We thank the contributors for their efforts and input to these proceedings and for their interest in advancing the practice of scientific diving in the coldwater environments.

Michael A. Lang
Charles T. Mitchell
Editors

CONTENTS

THERMAL PROBLEMS DURING COLD WATER DIVING

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The maintenance of normal body temperature is imperative for the unhindered performance of workers. Our understanding of the functioning of the thermoregulatory system in normobaric conditions has led to the design and development of equipment and protective clothing preventing excessive displacements of body temperature of workers exposed to thermal extremes. The effects of hyperbaric environments on the mammalian thermoregulatory control system remain unresolved. The present review focuses on the thermal problems encountered by cold water divers and suggests possible effects of pressure and inert gas narcosis, respectively, on the maintenance of thermal equilibrium. The frequent reports of hypothermia during diving may not only be associated with the increased magnitude of heat loss as a result of the high density air, or cold water environment, but may in part also be due to an alteration in the autonomic responses to a cold stimulus. Cold exposure may also significantly impair divers' performance, by affecting manual dexterity and mental acuity, thus it may indirectly add to their risk of accident and injury. With the progress that has been achieved in underwater technology and life support systems over the past few decades, hypothermia should become a technological impossibility, occurring only as a result of unforeseen circumstances.

INTRODUCTION

Man initially dominated only the tropical regions of the Earth, and as a result is considered a tropical animal. Thus, from an evolutionary perspective, the human thermoregulatory system is most efficient in maintaining body temperature within the fairly narrow limits of 37° ± 1°C in tropical climates. Though the efficiency and versatility of the human thermoregulatory system assisted in man's migration to moderate and thermally more extreme environments in search for food and new habitats, it is the human traits of inventiveness and creativity which has enabled the human species to survive and populate all regions of the Earth. Human ingenuity has enabled the development of technological solutions to the problems of protection from the environment.

The advance in recent decades of exploration of the polar regions and continental shelves in search of natural resources has placed a greater reliance on technology to sustain life under these adverse conditions. Undoubtedly, some of the greatest challenges to life support technology have been posed by the harsh subsea environments, where divers provide valuable support for offshore drilling operations.

The susceptibility of divers working in cold waters to hypothermia or cold strain may be analyzed by discussing the effects of hyperbaria on the major components involved in the maintenance of their thermal equilibrium. Namely, thermal balance of an individual exposed to any given environmental conditions may be assessed according to the following equation:

$$S = M - W \pm R \pm C \pm K - E \pm RES$$

where,
- S = rate of storage of body heat.
- M = rate of metabolic heat production.
- W = rate of energy expenditure for work.
- R = rate of heat exchange via radiation.
- C = rate of heat exchange via convection.
- K = rate of heat exchange by conduction.
- E = rate of heat loss through evaporation of sweat from the skin surface.
- RES = rate of heat exchange in the respiratory tract.

The role of the human thermoregulatory system is therefore to balance the above pathways of heat loss and heat gain in order to maintain a thermal equilibrium ($\Delta S=O$). In the event of heat accumulation or heat dissipation, ΔS will assume a positive or negative value, respectively. Autonomic and behavioral responses are initiated to counteract any displacements of body temperature; the former involving changes in the rate of metabolic heat production, sweating and vasomotor tone, and the latter involving more complex responses ranging from altering the posture of the body to reduce or enhance heat loss to developing complex life support systems. The contribution of each component of the above equation to the overall heat loss and heat gain depends upon the prevailing ambient condition. For individuals immersed in water, as would be the case for divers, the radiative and evaporative pathways of heat exchange may be omitted.

THE REGULATION OF BODY TEMPERATURE

Information regarding the thermal status of the peripheral and core regions is derived from cold and warm sensors, which transduce the thermal energy into neural coded information and convey this information to the hypothalamic region. It has been suggested (Benzinger 1969) that there are two distinct regions within the hypothalamus responsible for the appropriate effector mechanisms to counteract any thermal disturbance. The temperature sensitive pre-optic anterior region of the hypothalamus is said to initiate heat loss mechanisms in response to elevation in body temperature, which it senses by monitoring the temperature of the blood perfusing this region. In contrast, the pre-optic posterior hypothalamus is predominantly concerned with the initiation of heat preservation and heat gain mechanisms in response to the increased cold stimulation of the peripheral and core regions of the body. As a result of the precise mechanism by which body temperature is maintained at about 37°C, the human thermoregulatory control system has been described as a "thermostat" with an internal reference point, this *set-point* or reference temperature being normally maintained at 37°C.

Recent work by Bligh (1988) proposes that it is unnecessary to search the body for an anatomical structure generating this reference point, but that the zone of thermoneutrality (the range of temperatures through which deep body temperature may vary without the initiation of effector mechanisms) may be explained on the basis of the reciprocal inhibition of the neural information emanating from the peripheral and core cold and warm sensors, as depicted in Figure 1. The pattern of activity of the cold and warm sensors is such that the warm sensors are increasingly quiescent below 30°C, and as the temperature is elevated, they increase the frequency of discharge of action potentials, reaching a peak at approximately 40°C and thereafter becoming silent again. In contrast, the cold sensors have a peak of activity in the 20° to 30°C range, becoming increasingly silent as the temperature is either reduced or elevated from this range of peak activity. It is interesting to note that there exists a zone of equal activity, which coincides with the thermoneutral zone. Should the temperature decrease below this region, the increase in cold sensor activity initiates an increase in heat production (HP), but also inhibits the warm sensor activity as indicated in Figure 1. Increasing the temperature above the thermoneutral zone will activate heat lost effector mechanisms, while simultaneously inhibiting the heat production pathway. It is this principle of reciprocal inhibition which establishes a zone of stable body temperature and, as Bligh (1988; see also Mekjavic and Bligh 1987) points out, eliminates the need for an anatomical structure generating the reference temperature. Furthermore, it demonstrates that the set-points or critical core temperatures for shivering and sweating may be established by the relationship between sensor activity and temperature. The neuronal model presented in Figure 1 introduces the concept that other thermoregulatory and non-thermoregulatory excitatory and inhibitory inputs may influence the relationship between the sensors and effectors, which may affect the magnitude of the thermoneutral zone, the critical core temperatures for sweating and shivering, and the gains of the sweating and shivering responses.

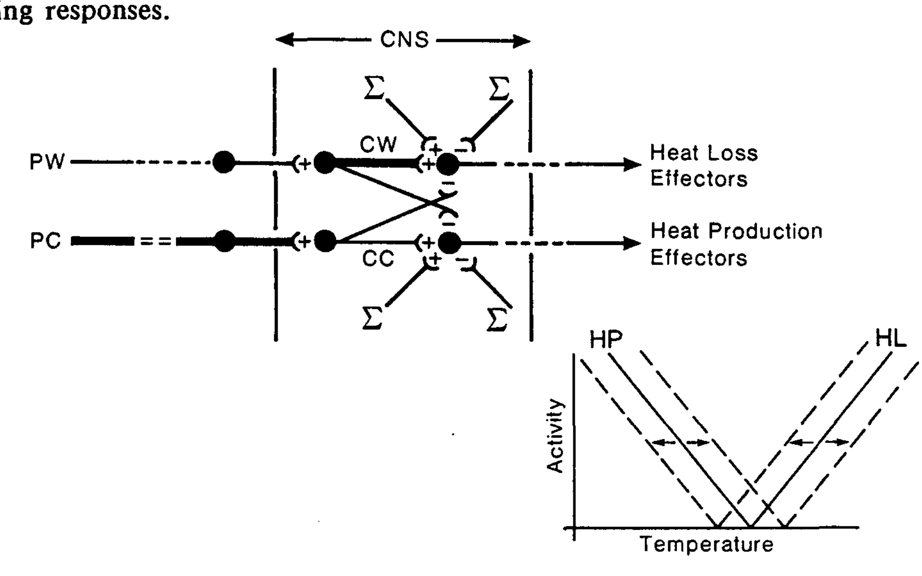

Figure 1. A neuronal model of the human thermoregulatory system. The thermal status of the body is sensed by the peripheral cold (PC) and warm (PW) sensors, as well as similar sensors situated in the core regions (CC and CW, respectively). This thermal afferent information is integrated within the central nervous system, along with other thermoregulatory and non-thermoregulatory factors (represented by $\sum$), to initiate appropriate heat loss and heat production effectors. The range of overlapping activity of the sensors may explain the zone of thermoneutrality, a zone devoid of active HP or HL effectors. Such a theory of reciprocal inhibition of the cold and warm sensor activity may also adequately explain the existence of set-temperature (from Mekjavic and Bligh 1988).

There is, unfortunately, a paucity of information regarding the effect of elevated ambient pressure *per se* and inert gas narcosis on the thermoregulatory control system. It has been shown that during compressed air dives, nitrogen exhibits a narcotic effect by virtue of its lipid solubility and the distribution of the molecules at the water-lipid interfaces in cell membranes, which may explain the detrimental effect on the conduction of action potentials along neural fibers and on the synaptic transmission of action potentials (Bennett 1982, Carpenter 1954). It remains to be proven whether the nitrogen absorbed by the phospholipids of neural membranes while breathing air at high pressures distorts the thermal afferent information from peripheral and core sensors, as well as the subsequent hypothalamic integration of this information. Subjective observations reported in the literature would tend to support this hypothesis (Bennett 1988), as ambient temperatures within hyperbaric chambers need to be maintained at high temperatures, (32°C) and should not deviate more than several degrees in order to maintain the thermal comfort of divers. Thus, in comparison to normobaric conditions, the thermal comfort zone appears to be narrower and elevated towards higher levels in hyperbaric ambients. To what degree the respective contributions of pressure and nitrogen narcosis are responsible for these observations remains to be elucidated.

HEAT PRODUCTION

Displacement of skin and core temperature from the set-zone elicits a proportionate thermogenic response as indicated in Figure 2. Some controversy has existed with regards to the true nature of the relationship between core temperature and metabolic heat production at any given skin temperature (for example, the results of Craig and Dvorak (1966) suggest a different gain of the response than do those of Benzinger (1969) for similar skin and core temperature conditions).

Mekjavic (1983) has suggested that, in part, the discrepancy may be due to the different rates of cooling in core temperature as his results indicate a substantial effect of core cooling rate on the shivering response. However, in most cases, the cooling rate is quite different for a range of subjects and seldom reported in the literature. Thus, a level of heat production observed for a combination of skin and core temperatures in the same subject may be quite different if the rate of cooling of the core or skin is different. Furthermore, Mekjavic *et al.* (1986b) have demonstrated that the thermogenic response is subject dependent and appears not to be a function of morphology (Mittleman and Mekjavic 1988). Previously, studies have suggested a strong influence of morphology on the magnitude of thermogenesis (Tikusis *et al.* 1988); however, when similar cold stimuli are applied to the peripheral (Mekjavic *et al.* 1986a) and core regions (Mittleman 1987) for a range of physiques, no apparent relationship between shivering thermogenesis and morphology is observed.

Again, information regarding the effect of hyperbaric ambients on shivering thermogenesis is scant. There is some evidence, however (Piantodosi and Thalmann 1980, Piantodosi *et al.* 1981), of an inhibitory effect, but the mechanism for this inhibition is yet to be determined.

HEAT LOSS

The main pathways of heat loss which contribute to the overall progressive cooling of the body during cold water diving are: 1) heat loss from the surface of the skin mmmm mmmm

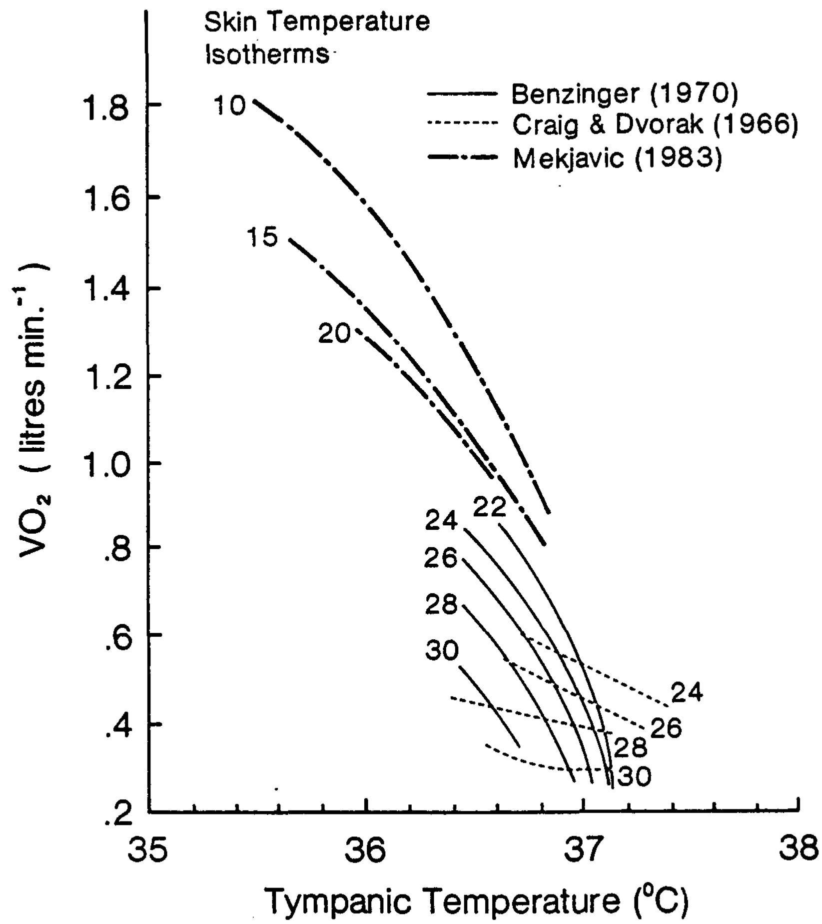

Figure 2. The relationship between the rate of metabolic heat production and tympanic temperature obtained by several investigators for a range of water temperatures. The discrepancy observed between the relationships of Benzinger and those of Craig and Dvorak for the same combinations of Tty and Tsk may be due to different cooling rates of the core region and differential thermal responsiveness of the subjects (from Mekjavic 1983).

through conduction/convention; and b) evaporative and conductive/convective heat loss from the respiratory tract.

a) **Heat Flux from the Skin Surface.** In a normobaric and thermoneutral environment, the mean heat flux from the skin surface in a resting individual may range from 50 to 70 $W.m^{-2}$. Sudden immersion in cold water will increase the magnitude of heat flux 25-fold due to the greater thermal conductivity of the water. Such a high rate of heat loss would precipitate hypothermia very rapidly; however, as the vasoconstrictor tone increases and consequently decreases the diameter of the cutaneous blood vessels and thus blood perfusion of this region, heat flux decreases towards a stable level usually 4- to 6-fold greater than that observed in air (Figure 3).

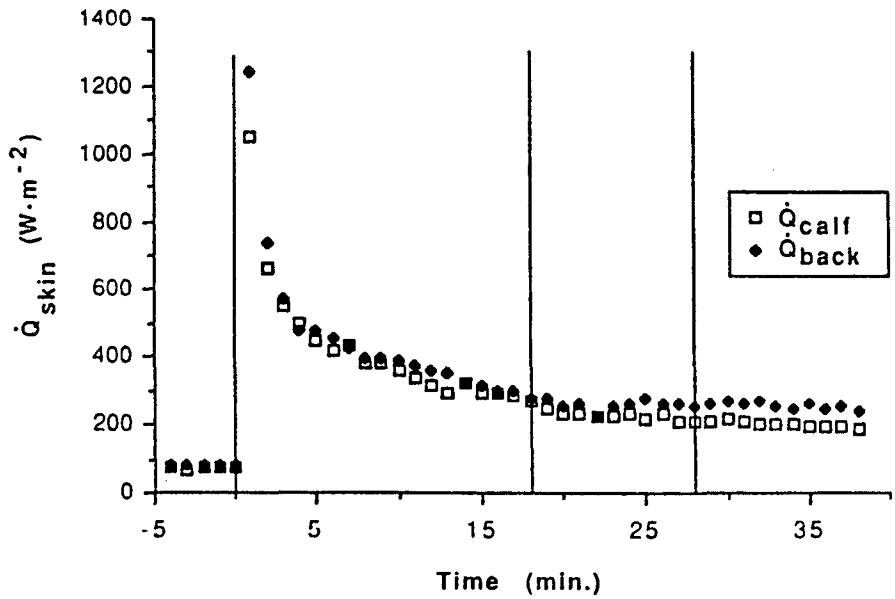

Figure 3. Heat flux from the skin surface (mean ± s.d. for four sites). There is a transient elevation in heat flux immediately upon immersion in cold water, whereupon it decreases toward a level only 4 to 6 fold greater than pre-immersion values (from Mittleman 1987).

The magnitude of heat flux from the skin surface depends upon the thickness of the insulative layer, specifically the skin and subcutaneous adipose layers. Heat loss is further reduced with the addition of an insulative layer of neoprene, as would be the case for divers wearing either drysuits or wetsuits. The obvious advantage of drysuits is their ability to trap a layer of air within the microenvironment of the suit, thus enhancing the insulative capacity of the suit. In contrast, wetsuits allow water to penetrate into the microenvironment of the suits, but decrease the heat flux from the skin surface by elevating the temperature of the water and, thus minimizing the temperature gradient.

Heat loss by convection in nude individuals immersed in water is proportional to the temperature gradient between the skin surface and the water and the convective heat transfer coefficient. Boutelier *et al.* (1977) have shown that, in stirred water the convective heat transfer coefficient can be defined as a power function of the water velocity. Similar adjustments to the calculation of convective heat transfer need to be made for the clothed diver, with the exception that the thermal gradient between the skin and water will be less as a result of the diving suit. However, the reduction in the thickness of the neoprene layer with increased ambient pressure will diminish the thermal resistance of the suit and further enhance heat loss (Warkander *et al.* 1985). For 3/16 inch thick wetsuit, Rawlins and Tauber (1971) observed that the thickness decreases to 55-55% of its initial thickness up to a pressure of 4 atmosphere absolute (ATA), but thereafter remains virtually unchanged.

b) **Respiratory Heat Loss.** Heat is lost from the respiratory tract via conduction/convection and by evaporation of water from the mucous lining which requires thermal energy for the latent heat of vaporization. Thus the colder and/or drier the inspired air, the greater the total respiratory heat loss. At normobaria, the major pathway for respiratory heat loss is through the evaporation of the water lining the respiratory tract. Although the specific heat of air does not vary significantly with pressure, its density will increase with increasing pressure and decreasing temperature. Thus, in cold hyperbaric environments, the conductive/convective pathways for respiratory heat loss become dominant. Indeed, research by Hoke *et al.* (1975), Piantadosi (1980), and Piantadosi and co-workers (1980, 1981) demonstrated that while exercising in a warm high pressure environment, breathing a cold heliox gas mixture will induce a progressive cooling of the core region. In addition to emphasizing the significance of respiratory heat loss at high ambient pressures, it also indicated that the core cooling was not sensed by the core cold sensors as there appeared to be a blunted thermogenic response to the core cooling.

The analysis of the respiratory heat exchange is based upon our knowledge of the thermal gradients in the respiratory tract obtained at sea level conditions. Webb (1982) suggests that with depth, there is a greater penetration of the cold gas in the lungs; thus, the thermal gradients may be substantially different and may, in this manner, enhance the respiratory heat loss from the core. Cold gas breathing may also cause bronchoconstriction (Guleria *et al.* 1969) and stimulate the secretion of mucus which may result in respiratory distress in divers (Goodmann *et al.* 1971, Hoke *et al.* 1975). To avoid excessive cooling and other problems associated with cold air breathing, Piantadosi (1980) has constructed a nomogram for the determination of the lowest recommended breathing gas temperature as a function of depth shown in Figure 4.

With increasing depth, the ability to warm the diver's breathing gas becomes imperative. Unfortunately in most cases, divers have to resort to breathing air at a temperature equivalent to the surrounding water which enhances the risk of core cooling in cold water diving.

THE EFFECT OF MORPHOLOGY ON SHIVERING THERMOGENESIS AND COOLING RATE

It has often been reported that the core cooling rate is inversely proportional to the thickness of the subcutaneous adipose layer. However, Mekjavic *et al.* (1986b) suggest that this relationship does not account for the shivering response and may, therefore, be a gross generalization. They report similar core cooling rates in two subjects differing immensely in their adipose content. Their results show that the subject with minimal adiposity had a very high rate of metabolic heat production, whereas the highly adipose individual had a very small elevation in shivering thermogenesis. The result was that both individuals had identical core cooling rates. Further work by Mittleman (1987) revealed that there was no significant relationship between the thermogenic response to a standardized cold stimulus to the core and peripheral regions and subject morphology, thus supporting the notion that in the range of the normal population (in terms of body composition), it cannot be assumed that core cooling rate will be proportional to the subcutaneous adipose layer thickness since the rate of metabolic heat production is unrelated to morphology and counteracts the cooling process.

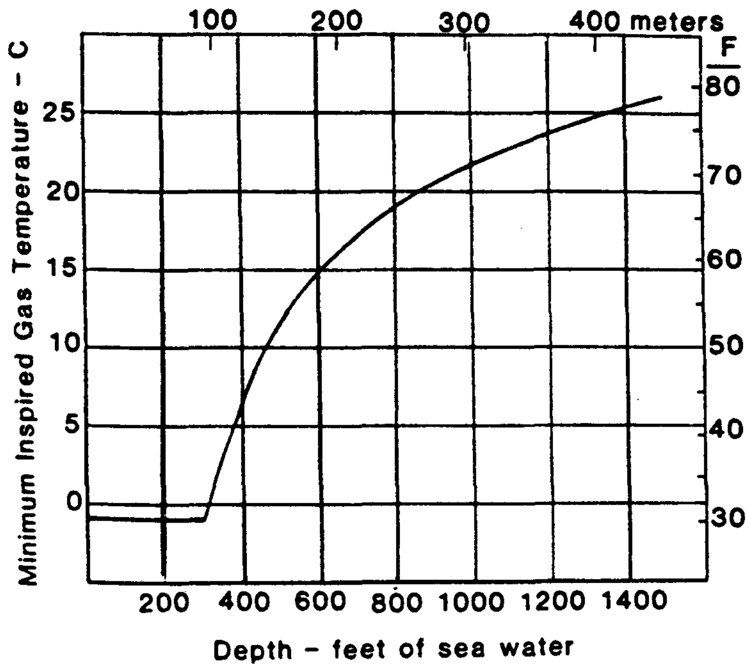

Figure 4. The lowest recommended temperature of a diver's breathing mixture as a function of depth (from Webb 1982; originally adapted from Piantadosi *et al.* 1980).

Her work also suggests that repeated cold water immersion may decrease the magnitude of the thermogenic drive which will tend to potentiate the cooling effect of the cold water (Skreslet and Aareflord 1968).

HYPOTHERMIA

Hypothermia is defined as the condition of a temperature regulator when the core temperature is below its set-range specified for the normal active state of the species (Cabanac 1987), and is a consequence of a temporary or permanent imbalance in the rate of heat production and the rate of heat loss. In the absence of physiological monitoring equipment in the field, it is very likely that a diver is suffering from hypothermia if the following symptoms are evident: violent shivering, loss of coordination, impaired judgement, and stupor. If the cooling process is not arrested, the continued reduction of the body core temperature will result in loss of consciousness and ultimately heart and respiratory failure (Maclean and Emslie-Smith 1977).

Accidental cold water immersion hypothermia is usually associated with rapid cooling of the core region. In contrast, divers conducting repeated cold water dives or exposed to a cold hyperbaric air environment may experience an insidious cooling process which may induce hypothermia with little warning. Divers trapped in a "lost" diving bell, one which has had its umbilical severed, experience this type of insidious cooling (Hope *et al.* 1987). As soon as power to the diving bell is lost, the wall and air temperature decreases to the level of the surrounding water. Unless the divers have well insulated parkas and sleeping bags available with a self-heated breathing device, they may die of hypothermia within 12 hours. Such thermal protective aids appear to extend the survival time to at least 24 hours (Tonjum *et al.* 1980).

PERFORMANCE

In addition to the effects of nitrogen narcosis and pressure on performance, divers exposed to cold water may suffer detriments in performance due to the effect of cold *per se*. Davis *et al.* (1975) suggest three main effects of cold: 1) cooling of the peripheral tissue will impair tactile sensitivity and decrease muscle power; b) cooling of the inner core of the body, and thus the central nervous system, may impair mental performance; and c) the cold may impose a "distraction effect", whereby the perceived threat of the cold may distract the diver and interfere with performance.

Davis *et al.* (1975) compared the performance of divers wearing 3/16 inch neoprene wetsuits in 5°C water with that observed in 20°C water (at a depth of 30 ft in fresh water). Their results indicate a marked decrease in manual dexterity (17%), word recall (37%), word recognition (11%), logical reasoning (13%), and arithmetic test scores (13%). Their findings are in general agreement with other studies evaluating performance of divers during cold exposure (Bowen 1968, Clark 1961, Stang and Weiner 1970) and emphasize the need to not only prevent core cooling of divers in cold water, but also to provide sufficient heat to maintain the temperature of the peripheral tissues and thus allow unhindered performance.

VENOUS GAS EMBOLI

The formation of venous gas emboli ("bubbles") or nucleation results primarily from an excessive decrease in ambient pressure, thus leading to the symptoms of decompression sickness. However, any factors which will affect the rate of elimination of inert gas from the tissues and its subsequent transfer to the pulmonary capillaries, may also effect bubble formation. It is well established that the tissue, blood, and plasma solubility of nitrogen decreases with increasing temperature, thus with increasing temperatures, less nitrogen will be dissolved in these compartments. Furthermore, the elimination of inert gas through the respiratory tract relies on an adequate perfusion of the tissue compartments. Any alterations in blood perfusion of the tissue may result in a decreased rate of nitrogen elimination and enhance the formation of a gas phase in the circulation. There is a dichotomy of opinion with regards to the optimal body temperature during decompression and immediately following a dive. The practice of Kalymnian sponge divers in Greece (Bernard 1967) of placing victims of decompression sickness in hot sand is in conflict with the suggestions of Simmons *et al.* (1982) of placing afflicted limbs in ice. The former would decrease the nitrogen tissue solubility but enhance the peripheral perfusion, whereas the latter would increase the nitrogen tissue solubility but reduce the perfusion of the tissues due to the vasoconstriction. Recent findings of Mack and Lin (1986) in rats indicate a significantly decreased rate of nitrogen elimination if the rats were hypothermic, and do not reveal any advantage of hyperthermia when compared to the euthermic state in enhancing nitrogen elimination. Mekjavic and Katitsuba (unpubl. results) exposed divers to either a hot (40°C) or cold (10°C) air environment following a

12-hour dive to 30 fsw, and found greater VGE scores (as determined with Doppler ultrasonic monitoring) during the cold air exposure. Much more surprising were their observations of skin itching and pruritus in four divers immediately following a hot shower upon completion of the cold air exposure. These symptoms which were not present during the 3-hour cold air exposure, were undoubtedly instigated by the sudden dramatic change in the peripheral tissue temperatures. Much more work is required to elucidate the significance of peripheral tissue and inner core temperature in VGE formation and onset of decompression sickness. Presently, it appears that hypothermia is detrimental to N_2 elimination and that any sudden rapid rewarming of the periphery may enhance nucleation.

SUMMARY

The nature of heat exchange and heat production in humans working in normobaric conditions is well understood. However, to date most of the observations regarding heat exchange at depth have been discussed in terms of the physical principles of heat exchange, with disregard of the effect of pressure and inert gas narcosis, respective, on the physiological mechanisms responsible for heat production (shivering thermogenesis) and heat loss (vasomotor tone). Subjective observations suggest that there is a general shift in the thermoneutral zone to higher temperatures and a decrease in its width.

With the technology available today, we are able to sustain unhindered human performance in a wide range of environments. Thus, hypothermia is a technological impossibility and should only occur in instances of equipment malfunction or of an overburdening of the physiological regulatory process (Mekjavic and Bligh 1987). In the event that hypothermia is induced, proper management of the hypothermic victims will ensure a safe and uneventful recovery (Harnett *et al.* 1983a, b).

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TRAINING SCIENTIFIC DIVERS FOR WORK IN COLD WATER AND POLAR ENVIRONMENTS

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INTRODUCTION

Cold water and polar environments place exceptional stress on both divers and their equipment. Safe and efficient diving operations can only be conducted by dive teams who are specially trained and equipped for these environments. Scientific divers have been successfully working in cold water and the polar environment for more than three decades. However, the diver's working efficiency and, in some cases, safety has been compromised by the fact that much of the learning process has taken place in the field, often under severe environmental conditions. Divers trained in southern California or Florida often have their first cold water experience in polar waters. They simply learned techniques from fellow divers with prior cold water experience and adapted to the new environment.

The record of accomplishments for these divers has been excellent. Thousands of dives have been conducted with only a few unfortunate incidences of injury or death. However, as we enter the last decade of this century, we are faced with the necessity of re-evaluating our polar research programs for the following reasons:

1. There has been an increased emphasis on polar research in the Arctic because of oil exploration in a very fragile environment and a need for a better understanding of the ecosystem. Antarctica will receive increasing attention at the international level and the need for a strong American research presence ranks high with funding agencies. Simply expressed, there will be a significant increase in the requirements for scientific diving in cold water and polar regions.

2. The cost of research will continue to rise. Consequently, funding agencies will have to take a close look at operational efficiency as well as scientific productivity in order to sponsor cost-effective research. Polar scientists will have to perform efficiently under severe environmental conditions as well as intensified agency scrutiny.

3. New technologies have extended the working capability of the scientific diver. However, the same technologies have also increased the complexity of diving. The diver can now remain underwater for longer periods of time to perform more complex tasks. However, to perform these tasks safely and efficiently, a higher level of training and preparation is required.

4. Federal scrutiny of the scientific diving community and the ever present possibility of regulatory intervention at state and federal levels make it necessary for our community to set the highest possible standards to insure safety in the work place -- especially under 5 meters of polar ice.

Most scientific divers are trained in recreational-oriented scuba diving courses. Ice diving specialty courses presented by recreational diving instructors are inadequate for preparing a scientist to perform research in polar regions and under the ice [5]. For these and other reasons the scientific community must assume leadership in training its divers for working in cold water and polar environments.

There is a considerable volume of literature on the physiology of cold stress. However, there is only a limited number of publications on the techniques and procedures of cold water [8], under ice [4,7], and polar diving operations [2]. The U.S. Navy is currently preparing an updated manual on polar diving.

The recommendations presented below are based on the author's personal views, research, and experience. They by far do not represent a complete overview of training requirements. In some cases they may appear excessive and in others inadequate. These recommendations are intended to provide a "starting point" for a responsible committee of scientific polar divers, diving instructors, diving safety officers, and funding agency representatives to develop a National Polar Scientific Diver Training Program.

ACADEMIC TRAINING

The academic portion of the training program can be conducted concurrently with confined water and open water training, as a separate workshop program or, in part, as a self-study correspondence course. Ideally, such topics as polar survival should also include practice exercises in the field.

The details of the academic training program are included in the following discussion and a course syllabus is presented in Appendix I.

TRAINING SITES AND ENVIRONMENTAL CONSIDERATIONS

Confined Water Training

Experienced scuba divers are sometimes reluctant to participate in confined water training exercises. For example, the majority of cold water divers purchasing dry suits use them for the first time in cold open water rather than going through a learning phase in a controlled environment. It is imperative that divers and tenders learn to handle equipment, suits, and themselves under controlled, warm water conditions before submitting to an actual cold water dive. Every item of equipment to be used by the diver in open water should be first used in the controlled environment. This is especially true of suits and special scuba/buoyancy control items.

Under-ice training can be simulated in a large swimming pool by covering the surface of the pool with plastic tarps and establishing an entry opening at a corner. Divers can simulate entry and under-ice swimming on a tether. This is an excellent way to familiarize divers and tenders with line handling and line signals. Both tenders and divers must wear the same gloves or mitts that they will wear on the actual diving operation. The tarp may be supported by placement of small floats on the surface of the water and the entry opening can be reinforced with wood as required. This is also an excellent time to test sampling apparatus and measurement techniques.

The number and duration of confined water training sessions depend on the type of diving operation for which the team is being prepared, the prior dry suit diving experience of the divers, and other special training requirements. Persons with no prior dry suit diving experience should have at least six controlled warm water training sessions prior to open water exposure.

Cold Water Training

I can train a diver to use a dry suit and manage a tether any place including the warm temperate waters of southern California or tropical waters of the Caribbean. However, I am reluctant to train a cold water or polar diver in any place but a cold environment. Ideally, the divers, tenders, and support personnel should complete the final phase of their training in a cold climate with cold water and ice cover.

If one were looking for the most ideal situation, it would be found in our northern states and Canada. A cold water dry suit diver could receive theory and confined water training in the spring or early summer followed by open water training in the summer. The diver could acquire experience dressing under pleasant conditions, master diving techniques in moderate temperature surface waters, and slip below the thermocline to become familiar with colder water. The diver would continue to dive into the fall and early winter in open water with progressively colder surface conditions. By mid-winter the diver could complete under-ice training and acquire under-ice experience during late winter. I would recommend this progression to any diver planning to work in polar environments. A diver must be an experienced open water dry suit diver before venturing under ice cover. Working proficiency should be gained in 25 to 50 dives, depending on the individual.

Unfortunately, this sequence of progressive experience dives would not be possible for a one- or two-week polar diving training program. However, a condensed version could be presented during the training program and divers encouraged to gain additional open water diving experience before committing to under-ice working dives.

If I were asked to recommend a location within the continental United States for conducting a polar diver training program, I would have to select a Great Lakes state, such as Michigan, Minnesota, or Wisconsin. Northern Michigan winters can approximate polar conditions. A program could be conducted at a university with classrooms, pools, living quarters, and nearby lakes in the months of January or February. Transportation and overall training cost would be lower than operating in a remote area.

Ideally, the training should be conducted in two phases. Phase One would include classroom, confined water, and open water training under milder climatic conditions. Phase Two would be conducted in a cold environment with under-ice training capabilities. The divers should be allowed a period of time between Phase One and Two in order to acquire open water dry suit diving experience.

PREREQUISITES FOR POLAR DIVER TRAINING

Applicants for Polar and Cold Water Diver Training must complete the following prerequisites prior to acceptance into the training program:

1. Hold a Scientific Diver Certificate in accordance with the standards of the American Academy of Underwater Sciences (AAUS) or equivalent;
2. Successfully pass a Diving Medical Examination in accordance with the standards of the AAUS or equivalent within nine months of the course starting date;
3. Demonstrate physical fitness and watermanship by completing the Cooper 12-Minute Swimming Test in Fitness Category III or higher;
4. Hold current American Red Cross or equivalent certifications in Cardiopulmonary Resuscitation and Standard First Aid;
5. Submit a record of no less than 50 open water scuba dives;
6. Hold a 60 Foot Depth Certification or deeper in accord with the standards of the AAUS; and
7. Submit a letter of recommendation from the sponsoring university or research organization attesting to the need for special training in cold water diving procedures.

Prior Training and Experience

Prior to entry into a Cold Water Diver Training Program an individual must be a skilled warm/temperate water scuba diver. Basic requirements for sport diver certification often lack the skill proficiency and knowledge level demanded of a working scientific diver. Thus, the AAUS Scientific Diver Certificate or an equivalency is recommended. Furthermore, the adversities encountered in cold water diving dictate that a diver must be completely comfortable with his/her equipment and the environment. Prior experience of 50 open water scuba dives and a 60-foot depth certification are considered as a minimum. There is no substitute for prior diving experience when training a diver to work under adverse conditions.

Since cold water scientific divers may be working in remote locations with minimum support, all members of the dive team must be qualified in basic/advanced first aid and cardiopulmonary resuscitation. Special training in the management of cold-related injuries will be included in the training program. However, time will not permit for training in basic first aid/CPR procedures.

Medical Fitness

The physical and thermal stress associated with cold water diving can be extremely high. All applicants for training must have completed a Diving Medical Examination within no more than nine months prior to the beginning of the training program. The examination shall also be in accord with the standards recommended by the AAUS.

Physical Fitness

Scuba diving in cold water, 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. Experience suggests that a person in reasonably good physical condition is a "better learner" in a training program and is more apt to be a safe and comfortable diver. Scuba diving will generally be a "higher quality" and safer experience for the individual in good physical condition. In my opinion, physical fitness and the ability to deal with physical and emotional stress are of paramount importance to the cold water diver.

In order to assist divers in evaluating their personal physical fitness level, I recommend the Cooper Aerobic 12-Minute Swimming Test. This test is age and sex adjusted and designed for the average swimmer, not a competitive swimmer. Ideally, a cold water diver should maintain a fitness level of Category III (Fair) or higher. This means that an individual 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 [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 30 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. Ideally, all persons should have a medical examination prior to testing. Furthermore, if you feel extreme fatigue, shortness of breath, lightheaded, or nausea during the fitness test, stop immediately. Do not repeat the test until your fitness level has been gradually improved through regular exercise.

I am often asked by divers claiming to be poor swimmers if the Cooper 12-Minute Running Test can be substituted for the swimming test as a measure of physical fitness. Most people can run or jog. Jogging is an excellent way to build physical condition. However, the diver is most likely to encounter physically demanding situations **in the water**, not on land. The ability to perform physically in a water environment is vital. Therefore, I am reluctant to substitute the running test for divers.

Watermanship

Equipment cannot be a substitute for poor watermanship or physical fitness. A scuba diver must be capable of handling any situation which might involve the loss or malfunction of any or all components of the diving system.

It is my opinion that all scuba divers must be good swimmers who are comfortable in the water. In general, good swimmers are comfortable and poor swimmers are uncomfortable in the water. Furthermore, the more comfortable that a diver is in the water, the safer that diver will be in the water. And the more comfortable the diver, the better the quality-of-the-experience. **The cold water diver must be completely at ease in the water, especially when working under ice cover!**

How can you determine if a diver is comfortable in the water? Such determinations are both subjective and objective. First, only the diver can actually assess his/her emotional comfort level. If the trainee exhibits signs of emotional stress or anxiety when swimming away from the security of the side of the pool without mask, fins, and a buoyancy compensator or "struggles" to stay afloat and move in the water, that diver is obviously not comfortable and, in my opinion, is a poor candidate for cold water diver training. I personally feel that a person who can swim at least 400 yards without exhibiting signs of significant fatigue or serious emotional/physical stress is more likely to be a better and safer diver.

SUPPORT PERSONNEL TRAINING

Cold water diver training programs must also be designed for training non-diving support personnel. I recommend that all support personnel who will be assigned responsibility for working directly with divers should participate in all aspects of the training program except actually diving. They should attend all lectures and participate in confined and open water training sessions in order to gain greater insight into the management of diving operations, assisting divers in the field, and providing emergency assistance. All support perons must have current CPR and first aid certifications.

ORIENTATION TO COLD WEATHER AND POLAR ENVIRONMENTS

All dive team members must receive a complete orientation to cold weather climates and polar regions. It is necessary for persons planning to work in these environments to understand atmospheric and water temperature ranges, wind, snow, white-out conditions, weather patterns, and weather forecast interpretation in order to safely and effectively plan diving operations. They must be familiar with ice thicknesses and bearing strength, sea ice movements, tidal influences on nearshore ice floes, iceberg movements and fracturing, and so on. Only through awareness of potential risk factors can a principal investigator, diving supervisor, and dive team safely plan and execute cold water and under-ice dives.

Polar Logistics

Working in remote and polar areas requires a complete understanding of transportation by aircraft and ground vehicles. Persons who have never visited a polar region often fail to comprehend the logistics of simply getting from one place to another. The successful coordination of scientific and support personnel with transportation services and weather conditions can make the difference between successful research or the loss of a week of valuable time. Furthermore, the safety of all personnel depends upon understanding the complexity and risk of operating in polar regions.

Clothing and Thermal Protection

All persons working in the polar environment must have a working knowledge of thermal protection both on the surface and underwater. In addition to an in-depth presentation of diving suits and undergarments, the polar scientist must be instructed in selection and use of proper clothing. This includes emphasis on thermal regulation, prevention of cold injury through proper use of clothing, care of clothing, and personal hygiene.

Dive Site Preparation and Management

Diving under environmentally harsh conditions requires more than a casual approach to selecting, preparing, and managing a dive site. In many cases shelters must be erected, heaters installed, and ice holes cut. Divers must be prepared to work from various land, ice shelf, and vessel platforms. An emergency plan must be prepared for each diving operation.

Polar/Cold Climate Survival

As we approach the twenty-first century many of us have become accustomed to living in a very controlled and relatively risk-free environment. Most of us live, work, and play in locations where professional emergency services are only a few minutes away. By dialing 911, we can solve most of our survival problems. Unless a scientist is somewhat of an outdoor adventurer or has prior military schooling, he/she may have little or no knowledge of survival under adverse conditions.

Our lifestyles have shifted our natural survival skills from those associated with wilderness to those of an urban culture. We may be able to survive on the street, but can we survive hundreds of miles from our support station in temperatures that may exceed -75°C (-100°F) and winds that have been measured at more than 320 kilometer (about 200 miles) per hour? Even those who work at stations like McMurdo tend to become complacent because life seems so normal that they forget the potential dangers of Antarctica.

Whether working on a northern Michigan lake in winter, in the Canadian Northwest Territories, or on the Ross ice shelf, one must have a working knowledge of the risks, skills, and equipment associated with polar survival. This must be included in the formal training program for polar divers.

HUMAN FACTORS IN COLD WATER DIVING

The human body is designed to function within a relatively limited temperature range. Deviation of core temperature can cause serious physiological and psychological responses.

Cold Stress Physiology

Divers and support personnel must have a working knowledge of hypothermia and cold-related injuries. They must understand principles of heat loss and prevention of heat loss. They must be able to recognize the signs and symptoms of both classic hypothermia and "silent" hypothermia. Divers must learn to assess themselves for performance degradation. Tenders and other support persons must learn to recognize signs of thermal stress and performance degradation in divers as well as other support persons.

In addition to hypothermia, persons working in cold environments must take special measures to prevent and recognize signs and symptoms of frostbite and snowblindness. Carelessness can lead to cold injury in a matter of minutes. All team members must be prepared to administer first aid for hypothermia, frostbite, and snowblindness.

Special precautions must also be considered in the prevention of decompression sickness. The U.S. Navy has long recognized the need for decompression schedule adjustment when working in cold water. Such precautions become critical when working in remote locations with limited availability of decompression chambers.

Psychological Stress in Polar Diving

All members of the dive team must be familiar with psychological factors associated with polar operations. In the polar environment individuals must adjust to long periods of daylight, darkness, immobility and/or isolation. Groups of individuals must co-exist in potentially stressful situations for extended periods of time. The emotional aspects of polar living can adversely affect operational efficiency and safety of some divers.

In addition, the diver working under ice is faced with the temporary emotional stress of isolation from the surface by ice cover and mental degradation from thermal stress. In addition, the long and complex requirements associated with preparing for a polar dive and simply working in extreme cold can heighten pre-dive emotional stress. The diver must understand and be prepared to prevent and cope with these stresses.

EQUIPMENT FOR POLAR DIVING

Most cold water and polar divers will use selected conventional open-circuit scuba and dry suits. Divers must be trained in the handling and management of this equipment in cold environments and the effects of thermal stress on the equipment. Techniques and equipment alternatives for dealing with air supply malfunction or loss must be included in the training program. Comprehensive training and practice in using dry suits will be a training priority. In addition, the use of alternate diving modes (i.e. tethered scuba and surface-supplied diving) may expand diver capability and safety.

To my knowledge, the use of special mixed-gas underwater breathing apparatus in polar environments has had only limited success. This equipment requires special training for use and extensive maintenance procedures. Subjectively, I feel that this higher degree of complexity and additional maintenance requirements associated with mixed-gas scuba places the user at higher risk than when using simpler open-circuit scuba. If anything can go wrong, it will go wrong in the polar environment. Although the potential benefits of technological advancements can not be overlooked, objective evaluation for performance under adverse conditions is required. Furthermore, will the added cost of the equipment, higher complexity, and personnel time to maintain it yield significantly higher returns in diver performance and safety. A large number of $500 SCUBA units can be purchased for the $25,000 cost of a single mixed-gas rebreather.

In preparing for polar diving operations one must also consider the desirability of including duplicate items of equipment. Equipment loss and malfunction can be high under environmental extremes.

Dry Suit Training

All divers being trained for cold water diving operations must have special training in the use of dry suits. The divers should train in the same suits that they will use for the actual diving operation. Both theory and practical training sessions must be included. Special training courses have been prepared by Diving Unlimited International (San Diego, California) and Viking-America (Solon, Ohio). Dry suit training must include, but not necessarily be limited to, the following:

- Selection of suits and undergarments;
- Care and repair of suits and undergarments;
- Inlet and exhaust valve operation and maintenance;
- Special procedures/precautions for polar climates;
- Weighting requirements and buoyancy control;
- Dressing and undressing the diver;
- Underwater swimming with suits;
- Control of air in suits;
- Swimming in a flooded suit; and
- Dealing with an out-of-control ascent (blow-up).

Ideally, all divers, regardless of experience, should participate in dry suit training. Most experienced dry suit divers have never flooded their suits to determine swimming and buoyancy characteristics. Nor have they practiced how to deal with over-inflation of the suit and blow-up management.

Although divers will experience some overheating, the actual diving suit and undergarments to be used in the field should be worn during at least some of the confined water training sessions. There should be no surprises under the ice!

Tenders and divers must master dressing and undressing techniques in a warm, controlled environment before committing to a cold weather experience. I require my students to go through complete dressing procedures in a classroom setting the first time. Ideally, everything possible should be done to duplicate actual field conditions. For example, if divers will be required to dress in a small shelter/tent on the ice or in a support vehicle, do it during training.

Tethered Scuba Diving

Deployment of a single tethered scuba diver is a reasonable and safe alternative to conventional free-swimming buddy team diving. The tethered scuba diver is equipped with a full-face mask with communications, high capacity scuba air supply, and a separate emergency air source. A combination safety line-communications cable is secured to a body harness. The diver's tether is handled by a tender on the surface who is in constant voice communication with the diver. A standby diver is available. The deployment of a single diver is cost and personnel effective and, in some situations such as near zero visibility, safer than conventional diving. For additional information, consult Tethered Scuba Diving [6].

Surface-Supplied Diving

University of Michigan researchers have used the surface-supplied diving mode for more than two decades [3, 9]. A lightweight umbilical assembly supplies the diver with air, depth measurement, voice communications, and a safety line. A hot water hose may also be included in the umbilical assembly. The diver can wear either a lightweight helmet or a full-face mask and an emergency scuba. As with tethered scuba diving, a single diver is deployed and tended from the surface. In addition to the advantages of single diver deployment mentioned above, the surface-supplied diver has a virtually unlimited air supply available.

Other Equipment Considerations

Each dive team must be equipped with the necessary equipment to provide emergency first aid for injured divers or hypothermic individuals. First aid supplies, extra thermal protection items, and an oxygen delivery system must be available in the field. A hypothermia management kit should be considered.

All research and diver support equipment must be properly prepared for polar environments. Diver and support personnel must be instructed in requirements and procedures so that they may properly prepare their equipment. Photographic equipment is very important to some scientific projects and may require modification or special care for use in polar regions.

Equipment selection and maintenance must be given a high priority. In some cases the loss or malfunction of a single item of equipment can result in the loss of a considerable amount of time and, possibly, the inability to complete a project.

POLAR DIVING OPERATIONS

Conducting a diving operation in a polar environment requires more extensive planning and preparation than most warm water operations. There are simply more things that must be considered for the safety of both surface personnel and divers. Simply getting to the dive site may be a major effort.

A key person in the operation is the diving supervisor who must take responsibility for designating personnel assignments, site evaluation, equipment evaluation, dive management, and general safety. The efficiency of an operation often depends upon the skill of this individual. Supervisors are experienced divers who have demonstrated leadership capability and have been specially trained in dive operation management.

During training the divers must participate in polar dive simulations in order to appreciate the requirements and complexities associated with working in that environment. Simulations and training dives are the keys to safe, efficient diving in the field.

SUMMARY

Proper preparation of scientific divers for research in cold water and under ice cover is important to the nation's polar studies programs. Divers and support personnel must have a complete understanding of the polar environment, cold climate physiology, psychological stress factors in polar diving, survival, and logistics. Divers must be trained in the use of special equipment and dry suits. In addition, these divers must gain experience in the use of dry suits under moderate temperature conditions prior to polar diving.

The dive team must be capable of establishing and maintaining a diving station on the ice and be prepared to deal with any diving related emergency situation that might arise. Training must involve cold water and under-ice dives.

The key to safe and efficient cold water diving is a trained, skilled diver who is properly equipped to operate under the most severe diving conditions on earth. This diver must be supported by an equally capable surface team.

ACKNOWLEDGEMENT

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APPENDIX I

TRAINING PROGRAM FOR COLD ENVIRONMENT DIVING

Orientation 3 Hours

Staff and student introductions; completion of administrative requirements; distribution instructional materials; inspection of student equipment; overview of cold weather, polar, and under ice diving; overview of training program; orientation to training facilities, lodging, meal service, and local area.

Student Entry Evaluation 3 Hours

Review training and diving records; administer basic/advanced diving theory examination; swimming and fitness evaluation.

Cold Weather/Polar Environments 3 Hours

Cold region/polar climatology; temperature; precipitation; surface visibility and white-outs; cloud cover; weather conditions and forecast interpretation for operations planning; storms; wind chill; snow and ice conditions; water clarity; daylight and darkness; polar marine life; environmental and marine life hazards.

Cold Climate Physiology 4 Hours

Classic and silent hypothermia; frostbite; snowblindness; sunburn; dehydration; carbon monoxide; personal hygiene and sanitation; health hazards; cold environment performance degradation; individual cold tolerances; diet; physical conditioning for cold environment work; prevention of cold injuries; recognition of cold injuries; first aid for cold injuries.

Cold Climate Psychological Stress 2 Hours

Isolation; long periods of light and darkness; immobility; group compatibility; group and individual motivation; work accomplishment; short-term and long-term operations; personal preparation; ice cover diving; psychological profiles.

Polar/Cold Climate Survival 4 Hours

Individual and group survival; travel/survival kits; emergency shelters; fire making/emergency heat; navigation; overland travel procedures and precautions; crevasses; emergency signals; aircraft emergency landing/crash survival; survival on sea ice; survival at sea; fire safety, procedures, and fighting; rescue procedures and operations; field exercises.

Logistics 2 Hours

Ground transportation by wheeled and tracked vehicles; snowmobiles; sleds; transportation by fixed wing aircraft and helicopters; shipping/cargo regulations; travel on foot; personnel lodging and meal service; communications; operational costs.

Clothing and Thermal Protection 2 Hours

Selecting outer and under garments; head protection; facial protection; hand protection; wind protection; layering; vapor barrier principles; foot wear; clothing care; personal hygiene in polar environments.

Diving Equipment 6 Hours

Thermal protection garments; scuba; scuba malfunction/regulator freezing; special precautions for handling and using scuba; backpacks; buoyancy compensators; face mask (standard and full); weight belts/ankle weights; fins; knives; diver's safety harness; depth gauges; compasses; decompression microprocessors; battery selection and use; underwater lights (hand held battery and cable powered); underwater loudspeakers; tending lines; air compressor selection, use, and maintenance; mixed-gas scuba; photography equipment; practical exercises.

Dive Site Preparation and Management 3 Hours

Shelters; site preparation; shelter layout; heating systems; fire and carbon monoxide poisoning risk and management; entry hole preparation and maintenance; hole cutting tools and techniques; mobile operations; fixed station operations; diving from icebreakers and open vessels; diving from/around ice floes; beach entry and diving through slush ice; emergency evacuation.

Dive Planning and Execution 3 Hours

Personnel selection; tenders; stand-by divers; diving supervisor; pre-deployment breathing; dive plan review; pre-dive briefing; dressing divers; transporting divers and support personnel; time limits; decompression tables/devices; decompression diving; temperature/environment assessment; recognition of thermal stress; diver recall; dive termination criteria; rewarming divers; repetitive dives.

Management of Diving Related Emergencies 2 Hours

Accidental emersion in normal clothing; diving suit flooding; buoyancy system malfunction (loss of buoyancy or over-inflation); uncontrolled ascent; breathing system malfunction; lost diver; managing a distressed diver; recovery of an unconscious diver.

Polar Underwater Research Methods 3 Hours

Data acquisition and recording; sampling techniques; installation of sampling/measuring apparatus; site location, relocation, and mapping; scientific dive planning; flora and fauna identification; safety precautions; significant historical aspects of underwater polar research.

Confined Water Training Exercises 8 Hours

Thermal protection garment dressing/undressing; buoyancy adjustment and weighting; underwater swimming with all equipment; recovery of an unconscious diver; suit flooding; simulation emergencies procedure for suit inflator/BC malfunction, uncontrolled ascent, suit flooding, and breathing system failure; diving under simulated ice cover; tending divers and line management; full-face scuba; loss-of-air supply emergency simulation; familiarization with special equipment.

Cold/Open Water Exercise 10 Hours

Dive operation planning and management; dive site selection, evaluation, and preparation; thermal protection garment dressing/undressing; weighting and buoyancy adjustment; underwater and surface swimming with all equipment; underwater navigation; loss-of-air supply emergency simulation; recovery of an unconscious diver; simulated research activities.

Under Ice Exercises 10 Hours

Dive operation planning and management; site selection, evaluation, preparation, and management; shelter erection; personnel assignments; hole cutting; dressing and management of diving outfit on the surface; entry; tether diving; suit and buoyancy system operation; under ice navigation; prevention of regulator freezing; regulator freezing emergency simulation; lost diver simulation; loss-of-air supply simulation; recovery of an unconscious diver; surface procedures; simulated research activities including data collection, sampling, and equipment installation; personnel protection and safety.

Tethered Scuba Diving: Academic and Practical* 5 Hours

Applications; procedures and special requirements; full-face mask; tethers; scuba system; practice dives in confined water, open water, and under ice.

Surface-Supplied Diving: Academic and Practical* 10 Hours

Applications; procedures and special requirements; air supply and air control console; umbilical assemblies; helmets and masks; communications systems; diver tending; stand-by diver; practice dives in confined, open-water, and under ice.

TOTAL HOURS: 65**

* Optional activities; time not included in above total.

** The time requirement assigned to each activity is approximate and may be adjusted to the satisfaction of committees and training directors.

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EXPOSURE PROTECTION: DRY SUITS AND THERMAL INSULATION

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INTRODUCTION

First let me set the stage with some recommended definitions. We feel that water above 70°F is considered temperate water. We feel that anything between 70°F and 40°F is cold water, and that is primarily where we are focusing most of our efforts. Below 40°F is ice diving because even though you may not have ice on the surface of the water, you'll often have air temperatures down below freezing under those conditions and you can certainly get icing conditions in your regulators. Any time you go into ice diving conditions (air or water temperatures below 40°F), you need to take very special precautions and I think all the rules change. What we are looking for is to make divers who are both efficient and reliable.

Efficiency we describe as having good diver strength, dexterity, endurance, sense of feel and ability to use all of your normal faculties to the same extent a person would on dry land under favorable conditions and that the same performance is repeatable day after day, so that the diver has not become incapacitated by cold.

Reliability refers to the diver being able to make sound mental decisions on both safety and operation and being able to make accurate observations and follow multi-task procedures.

We're looking for 100% in those two areas. In order to accomplish that, we must start off with divers who are in good physical shape, good mental shape, and properly trained in their task and equipment they're going to use. Their training must be current, which often is not the case, and lastly they must have the proper equipment to do the job with. The equipment they have for that job should be proper for the task, properly maintained and in good repair. The divers should have dived that specific equipment prior to the deployment they're being sent out on.

I recommend that no foam rubber dry suits be used. This is outmoded technology. The suits compress with depth, have less insulation with depth, resulting in a loss of buoyancy and thermal productivity. They require more lead to compensate for the positive buoyancy. They're also unreliable because of seepage. It was good technology at the time, we have now gone past that. Dr. DeLaca has written an excellent paper on the use of foam rubber dry suits in Antarctica. I recommend you read it, to see what their increased performance was after changing suits.

FUNCTION

Any dry suit's function is to keep the diver dry and it must give them the most freedom of movement. I know of no system that gives you the same 100% range of motion in the water with your diving gear on as you have out of the water. In fact, just putting on a pair of trousers does limit your range of motion. So therefore, all of your equipment you put on has an encumberance factor and you need to take that into consideration. We feel it must be easy to put on and take off, it must interface well with the rest of your equipment and it must resist abrasion and puncture. It should be easy to repair and maintain and give watertight performance. There have been a lot of improvements in dry suit diving technology in the last few years.

EXPOSURE PROTECTION: WET SUIT VERSUS DRY SUIT

INSULATION THEORY AND OPERATION - WET AND DRY APPROACHES

All insulation is nothing more than trapped air. The more stable air you can maintain around you the more effective its ability to insulate or protect you from the cold.

WET SUITS

The wet suit was first introduced in the early 1950s when tight-fitting suits of a closed-cell, foam rubber were developed. These suits were designed to permit a film of water between the suit and the diver's skin. The insulation in a wet suit consists of air bubbles trapped in the foam rubber material which the wet suit is made from. The wet suit itself acts as a thermos bottle, insulating the film of water next to the body.

WET SUIT VERSUS DRY SUIT

Wet suits have been the traditional solution to diving. But today's dry suits offer superior protection for the cold water diver.

Foam Neoprene

Wet suits are made of foam rubber. This rubber has within it trapped air bubbles. These are added to the suit chemically or by infusing it with a gas, usually nitrogen, under pressure.

Maximum insulation determined by thickness of suit

The maximum insulation of a wet suit, i.e. of the fabric, is determined by the thickness of the material and the amount of trapped air within it. The thicker the suit and the less dense the foam rubber, the more insulation it will provide.

Insulation decrease with increasing depth

The air in a wet suit is compressed with increasing depth. Thus, as you descend, the amount of insulation decreases. Also, the water is colder in greater depths, so when you need insulation the most, you have it the least. For example, at the surface the insulation loss is minimal. At 33 feet, the air bubbles have compressed to one half their original volume, so you get one half of your original insulation. At 66 feet, the air bubbles have been compressed to one third, giving you one third of your original insulation. At 99 feet, the insulation you have left is the same as solid rubber. This reduction in insulation coupled with cold water is inadequate for a safe and enjoyable dive.

Some other factors to consider with wet suits

When diving in strong current, conduction through the wet suit is increased. Currents also increase water infiltration and flushing which can substantially degrade the wet suit's performance.

Waist high pants will reduce the suit's efficiency, as will arm and leg zippers. Open neck hoods allow water to circulate through the suit, further reducing their effectiveness. A combination of these factors can reduce the thermal protective capacity by as much as 50 to 70 percent. As previously stated, the U.S. Navy does not recommend the use of wet suits below 60°F.

Buoyancy decrease with increasing depth

As you descend, the small insulating bubbles trapped within your wet suit decrease in volume according to the pressure volume relationships explained by Boyle's Law. As these bubbles compress, they take up less space and therefore provide less buoyancy. You become more negative as you descend. In fact, once on the bottom, you have experienced enough suit compression that you probably don't even need a weight belt anymore. To overcome this decrease in buoyancy you must constantly add air to your BC descending. Likewise he must vent off the air in the BC upon ascending. Wet suit divers lose both insulation and buoyancy at depth.

Requires perfect fit.

Degradation of performance with use.

Drying time requirements before repair.

Cold water against skin - uncomfortable.

No one likes that shock you experience when cold water rushes into your wet suit upon entry. Sometimes that's all it takes to discourage new divers before they even get started.

Increased air consumption

As you get cold your air consumption goes up dramatically. This has been a concern to military and commercial divers for some time. In fact, one of the ways scientists monitor the degree to which a diver has chilled is by monitoring his increase in air consumption. Medical personnel will force a diver to discontinue diving when his consumption has increased to a predetermined unsafe level.

Wet suit performance degradation-prediction from the Personal Insulation Guide

Refer to your DUI Personal Insulation Guide to show how you can expect a wet suit to perform for you as an individual. This Guide was developed so you can make sound decisions when planning any dive. Proper application will allow you to dive warmly and comfortably, without regard to water temperature or exercise rate. It will also let you know just how uncomfortable or unsafe you can be when improperly equipped.

All the diver needs to know is water temperature on the bottom where they plan to dive and what the planned exercise rate will be. As the exercise rates get heavier, they generate more heat. Therefore, the same insulation will keep you comfortable in colder water because of the higher heat being generated.

There are three basic exercise rates. Light exercise rate would be like taking pictures. Moderate rate relates to swimming at a steady speed. Heavy rate is equal to dragging something across the bottom.

Listed under each of the exercise rates is the water temperatures at which your wet suit should keep you in thermal equilibrium (not gaining or losing temperature). The water temperatures are given for each exercise rate at the surface, 33 feet, 66 feet, and 99 feet. You will note that depth has a greater degrading effect on your suit than does the water getting colder.

DRY SUITS - (misnomer - most leak a little)

The concepts of a dry suit for divers has been around for some time. Rubberized canvas dry suits were used with hard hat diving for years. Combat swimmers during WWII used dry suits of various styles. Latex dry suits were used by both military and civilian divers including Cousteau. However, they were never popular because they were too fragile, too difficult to put on, and they leaked a lot. Squeeze was also a severe problem in the first dry suits because there were no inflate or deflate valves available at the time. Divers had to accept and suffer through the squeeze they experienced on each dive. Dry suits in use today rely on the insulation provided by the clothing or undergarments worn under the suit.

Rugged outer shell, longer life, more durable

The outer shells of today's dry suits are constructed of very durable waterproof fabrics. These suits resist tearing and abrasions and are virtually unaffected by salt or fresh water. Yet, at the same time, they provide comfort and flexibility when properly designed and constructed. Generally, a rinse in fresh water and a little maintenance and storage away from direct sunlight are all that is needed to allow a suit to last for many diving seasons.

Variable insulation

A superior feature of the dry suit system is the ability to vary the amount of insulation to your dive requirement. Just as you vary the amount of clothing you wear in winter and the summer. This means when the water is cold you can add more insulation by simply adding or changing the undergarments worn and when the water is warm you can reduce the insulation by simply wearing less. No longer do you need to suffer through the same insulation becoming chilled when the water is cold or overheating when the water is warm.

Long: *Exposure protection: dry suits and thermal insulation.*

Insulation constant regardless of depth

Whereas the wet suit compresses with depth reducing its effectiveness, the dry suit system maintains the same insulation throughout regardless of depth. With a dry suit you can stay as warm on the bottom as you were on the surface. Insulation remains constant because the volume of the trapped air (that is, the volume in the suit) remains constant with depth. As you descend, the increasing pressure will cause the volume to change and the suit begins to squeeze against your body. You relieve the squeeze by adding enough air from your scuba tank to the suit through the inlet valve to keep the volume constant. As you ascend and the volume of air in the suit begins to expand, you simply allow the expanding air to vent through the exhaust valve either manually or automatically.

Buoyancy constant regardless of depth

Since the volume of the suit remains constant, the buoyancy provided by the suit also remains constant. With a wet suit, you add air to the BC to compensate for decrease in wet suit volume. In the dry suit, you keep the suit at the same volume. Hence, the dry suit is generally all you deal with to maintain neutral buoyancy throughout a dive. In most cases, you will only utilize the BC for surface flotation and swimming. We highly recommend you wear the BC as a means of gaining additional buoyancy or surface flotation.

Does not require perfect fit

To have good results with a wet suit, the fit has to be perfect requiring in most cases a custom made suit. If your size changes, the quality of the fit changes. With a dry suit, the fit is not as critical. The outer garment must provide you with enough room to move around and provide a waterproof barrier. If you get a little larger or a little smaller, no problem.

Performance does not change with use

Wet suit material breaks down and the insulation capability decreases with use. Dry suits retain the same insulating capability with use. With the wet suit, the trapped air bubbles tend to break down from repeated contraction and re-expansion impact. The dry suit will be as effective on the last dive as it was on the first dive.

Can be dried and field repaired quickly

Since dry suit fabrics have no pores to trap water, they dry very quickly. This means they can be air dried in a few minutes and quickly repaired in the field. No need to make a dive in a damaged suit or wait hours for the suit to dry while everyone else dives.

No cold water against the skin - comfortable

I'm sure that you have all entered cold water and experienced that uncomfortable feeling when the cold water hits your skin.

No increase in air consumption

With a properly insulated dry suit, your air will last longer. Since you don't get cold you won't experience the increase in air consumption you had before. In fact, your air consumption can be cut as much as 5-20%. That means more dive time.

Dry suit performance constant regardless of depth

Warmth predictable by using the Personal Insulation Guide

DRY SUIT STYLES AND CONSTRUCTION

STYLES AND MATERIALS

First attempt - canvas and latex. Commercial and military.

Old style sport

Foam neoprene. The next step in the evolution of dry suits was making one from wet suit rubber. Pile underwear was added to increase the amount of air trapped inside the suit. Waterproof zippers and advancements in sealing made them more or less waterproof. Valves were fitted to put air into the suit while descending and to vent off air during ascent. However, foam air dry suits suffer from the same insulation and buoyancy loss as wet suits and very little real insulation is provided at depth from the rubber. Also, this system requires about 15 pounds of extra lead to be added to the suit and still compensate for the compression of the neoprene foam. The shortcoming of the neoprene foam dry suit is the "neoprene cement" with which the suit is made - eventually becomes brittle and cracks, causing pinholes. "Weeping" occurs because the air cells rupture into one another, there is no way to stop the leaks. "The technology of this type of suit is rapidly disappearing."

There are residual effects from the compression and loss of insulation as the material itself breaks down.

Pack Cloth. One of the first generation of dry suits was made of a thin pack cloth material lined with urethane. The zipper is located across the back of the shoulders and wrist and neck seals as well as boots are made of latex. The advantages to this suit are that it does not compress with depth, it is easily repaired, and is more reliable. Shortcomings: the zipper across the back limited arm mobility and the long torso, which was necessary to enter the suit, restricted leg movement. Also, the latex boots deteriorate rapidly, are slippery, can be punctured easily and they require a wet suit boot to be worn over them for protection. However, these suits were very effective in allowing the diver to vary the amount of insulation according to his or her specific needs.

Modern Style. The modern suits keep the insulation dry and effective and allow the amount of insulation to be varied according to water temperature and individual preference. Constant insulation and buoyancy are maintained regardless of depth. The modern day dry suits are four times warmer than any wet suit made. With the proper training, dry suits are easier to use than wet suits and they have a lower operating cost per dive and are therefore a better investment than the wet suit.

The modern dry suit with front zipper is much thinner and softer but tougher and longer lasting that its predecessor. The front zipper location has several advantages. First, the zipper itself lasts much longer. Secondly, this location allows for freer movement of the arms. Lastly, the neck seal can be conveniently adjusted. The modern day dry suit has a telescoping torso, allowing for unencumbered leg movement and ease of arm mobility. This suit is also equipped with a strong boot which insures protection, long wear and firm footing.

Rubber Coated. This fabric is coated with rubber on the outside. The material makes a good dry suit because the seams can be vulcanized after construction. One important shortcoming: the fact that the waterproof barrier is on the outside of the suit. Rubbing up against something can cause the waterproof barrier to be chafed away or be easily punctured. This type of suit is a bit stiff and difficult to modify once constructed. However, these suits are easy to patch and are quite durable overall.

PVC. Some dry suits are made of vinyls. Vinyl suits are very inexpensive to build and are easy to identify by the welded seams. Vinyl is very soft and pliable. Vinyl materials have poor resistance to abrasion and low structural strength. They wear out in a very short period of time. Thus, vinyl is not a suitable material for dry suits.

Woven Fabric. There have been some vinyls that have been applied to a woven fabric. However, these also are unsuitable for diving as again, the vinyl does not have good adhesion characteristics and wears out in a very short period of time.

Trilaminate. Trilaminate is the most popular material today. It is made of two layers of tightly woven nylon fabric with a thin layer of butyl rubber between them. This is the same rubber that is used for car tires. But when used in such a thin layer, it is very soft and flexible. It is resistant to punctures and has a long lifespan. In fact, the material used today was originally developed for use by NATO in gas and germ warfare so it has a proven history.

Modern Day Polyurethane Laminate. Today we see a number of lightweight nylon fabrics with polyurethane laminate to them. These materials have proven worthy of confidence of the diver and are seen in a number of the less expensive dry suits. It is quite durable and is easily patched.

CF200 Material. The CF200 material was developed for the off-shore oil industry. Ordinary wet suit material was not strong enough for them. The CF200 has a high density neoprene sandwiched between heavy duty nylon on the outside and lightweight knit material on the inside. This makes it easy to dress in and out of the suit. CF200 is the only material that has true four way stretch. As a result, the suits constructed of CF200 material fit snug and tight making it the best dry suit available on the market today.

SEALS

Wrist Seals

Foam Neoprene. Made with lycra on the outside for strength and ease in taking them off. This material expands only 100% which makes them more difficult to take on and off but they are strong, resist puncture and will last up to 2 years.

Cone Seals. The cone foam seal is easier to put on when first lubricated with warm soapy water or talcum powder. To don the seal, run your hand down the sleeve until you can see your fingers protruding at the end. Grabbing the sleeve just above the seal, force your hand through and place the seal just above your wristbone. Be sure to check that the undergarment or the loops to the underwear are not under the seal. To take off the foam seal, pull the seal up your arm about an inch and invert the sleeve all the way down over the seal so the lycra is next to your skin. Grab the sleeve where the seal joins the suit and pull it off your hand.

Fold Under Seals. The fold under seal is one of the older wrist seal designs. To put it on, slide your hand in until the open end of the seal is on the heel of your hand leaving the rubber skin facing your wrist. Fold the edges under all the way around the seal. To remove this seal, insert your fingers under the seal and unfold the seal all the way around. Grab the open end of the seal and pull it up over the wrist and off your hand.

Latex. Latex seals expand about 400% thus are easy to put on but only last nine months to one year. The seal should be replaced when it cracks or feels gummy.

Cone Seals. The wrist cone seal has ridges which allow it to be trimmed to fit different sizes. To put it on, use talc or soapy water. Extend your hand down into the seal until the fingers stick out of the end. Take the first two fingers of the other hand and push them up inside the seal. Force the seal over the hand and onto your wrist. This usually causes the seal to roll up. Just pinch the seal directly behind the roll and pull straight out. This causes the seal to unroll and seat properly. To take it off, run the first two fingers down inside the seal, grab the suit cuff between the fingers and the thumb and pull your hand out.

Bell Seals. This seal is called a bell seal because of its shape. The shortcoming of this seal is that it must be exactly the right size for a proper fit. To remove this seal, take two fingers and run them up under the seal. Grab the seal and pull it off.

Neck Seals

Foam Neoprene. The 1/8 inch fold under foam neck seal is popular because it is strong, lasts approximately two years and is the best seal for holding air in the suit. A couple of disadvantages include the difficulty in donning and that it is tighter around the neck than a latex seal. To put this neck seal on, place the seal over the head and with the palms of the hands, pull the seal down until your head pops through and comes down to chin level. Grab the seal under the chin with the thumbs and forefingers, pull out and press downward with your fingers to fold the seal under. Reach inside from the zipper in front to readjust. To remove the seal, put your fingers inside the seal, pull it open and up onto your chin. Then put the back of the seal up onto the back of your head. Grab the front of the seal with both hands and pull it over the nose and up off your head.

Latex Neck Seals. Like the latex wrist seals, latex neck seals have ridges that can be trimmed to the appropriate size. This seal is also easy to put on and take off. The disadvantages are that it is more prone to punctures and tears and has a shorter lifespan than the foam seals. To put on a latex neck seal, put the seal above your head. Put the palms of both hands into the seal and pull outward, making a very large hole. Pull the seal over your head and place on neck. To straighten, just grab hold of the middle of the neck seal and pull straight out. The seal will automatically unroll and seat properly. Make sure the seal is down below your hairline. To remove the latex neck seal, put the palms of your hands down into the seal. Pull outward keeping the seal wide and flat against your hands. Make a large hole, then pull the seal up and over your head.

VALVES

The inflate valve is necessary when using a dry suit in order to add air to the suit when descending to relieve squeeze and to maintain buoyancy. An exhaust valve is necessary to let air out or vent air when ascending in order to maintain buoyancy and control the rate of ascent. There are many valves on the market today.

Inflate

There are many different and specific features of inlet valves you should consider when selecting the valves for your suit. It should be easy for you to connect and disconnect the low pressure hose to the valve. Some are more difficult than others to attach, especially with gloved hands. Also, the fitting should be somewhat universal in the event that you need to replace a hose. The most common fittings are the same used by most manufacturers for their power inflators. These hoses are readily available and easy to attach and remove. In addition, it is a fitting that you and your buddy will be most familiar with. In the event of an emergency situation, a rescuer will be more likely to be familiar with it than another type of fitting. Next, check the ease with which you can activate the valve. Some valves have very stiff and hard to depress springs and rather small buttons to push. On the other hand, some valves are very easy to operate and are generally referred to as "soft touch" valves. Also, you should look closely at the valve stem where you will attach the low pressure hose and determine its likelihood of causing a suit puncture during transportation or storage. There should be no sharp edges.

Deflate, Exhaust

There are two types of exhaust valves: the "press to deflate" also referred to as the "push to dump" variety where one must physically depress the valve to vent the air and the "adjustable exhaust" variety, which you can set to automatically vent at a pre-set pressure.

Push to Dump - Manual. With the press to deflate valve you merely depress the button in the center of the valve and the air vents out. When you stop pushing, the valve closes and the venting stops.

Adjustable - Automatic. When using an adjustable exhaust valve you are able to adjust the pressure at which the valve will activate. This overpressure can be set generally between one inch and ten inches of water pressure. In most cases, this exhaust valve is set to the minimum pressure to prevent accidental overinflation. However, if you use the suit for buoyancy compensation you may adjust the valve to a higher overpressure in order to maintain the desired amount of air in your suit. Caution: this should only be minimal.

Smaller bodied people may not have the strength to overcome spring resistance with the exhaust valve located in the upper arm. An easy to operate valve with a large area to push over is a tremendous advantage for a small person especially in cold water where finger strength and dexterity may be reduced.

You should also check the silhouette of the valve to determine that your tank harness, BC or other equipment will not foul or get caught on the valve when putting the equipment on or taking it off.

Power Exhaust Valve. The idea behind this valve is when manually activated, it can either inflate the suit or deflate the suit. It is called a power exhaust valve because it can literally suck the air out of the suit without the necessity of insuring that the valve be at the highest part of the suit. It would also allow you to easily remove all of the air from your suit before entering the water. It does not eliminate the need for a separate adjustable exhaust valve.

Placement

Virtually all inlet valves are placed in the center of the chest as high as humanly possible on the suit itself. However, the exhaust valves can be located in one of three places:

Chest. Early exhaust valves were mounted in the chest but this required the diver to come to a flare-up position, or chest-up position, in order to vent air out of the suit. This is normally not done anymore.

Upper Arm. The most common place to put the exhaust valve is in the upper left shoulder. This has a minor shortcoming in that it sometimes hangs on the shoulder strap when putting a BC on. But, from the logistics of buoyancy control, this is the best place for location. On some women, they must be careful to insure the fact that when the valve is in this position that they can reach it both for adjustment and to be able to push to dump.

Wrist. There have been some divers who have located the exhaust valve in their wrist so that it makes it very easy for them to dump. However, an automatic exhaust valve in this position cannot be used to control buoyancy because it will adjust, depending on where the location of the arm is rather than the amount of air that is contained inside the suit. With the exception of some special applications, this is not the best location.

Long: *Exposure protection: dry suits and thermal insulation.*

Ease of Use

Again, be sure that wherever the valves are located that it is easy and convenient for the diver to reach them as an individual.

It is important that the person who is going to be using the suit check the interface for themselves and with their equipment that the valve locations are easy for them to use, and that they have the strength necessary to press in on the buttons and work them properly. In the case of some smaller people and certain types of valves which have very strong springs in them, it is very difficult for them to depress the buttons, particularly those on the shoulders.

Type of Hose Fitting Required

Be sure to check both the length of the hose and the type of the hose fitting on your quick disconnects to be sure they interface with the valves you have chosen for your suit. In particular, check to see that the fittings on the valves are rounded. The most common cause of punctures in dry suits are the sharp edges on the male quick disconnect fitting on the inflation valve.

ZIPPER LOCATION AND EASE OF ENTRY

Wraparound Between the Legs

This zipper was developed for the Norwegian military which allowed them to unzip the zipper and use the toilet without having to take the suit off. Although very effective for that use, it makes the suit extremely difficult to put on and requires the crotch of the suit to hang much lower than the person, thereby making it a little difficult to walk. Also, assistance is required to close the zipper all the way.

Back Mounted Zipper

Many good suits on the market today have back mounted zippers running across the shoulders. The difficulty with this design is it requires assistance to close the zipper. The crotch of the suit has to be longer to allow the suit to come up so the neck and head can be put in. Also, the zipper is located in the most vulnerable part of the suit so whenever the diver is bracing themselves against rocks, or a wreck, or the bottom, they are in fact bracing themselves against their zipper. The zipper also restricts arm movement in a forward position.

Front Diagonal "Self Don"

The front diagonal, self donning zipper offers a number of advantages. First, this zipper location means full freedom of movement for the arms and shoulders. The design also improves zipper reliability and minimizes damage. It also provides easy access to check the neck seal fit. Another benefit to the front location is that stand-by divers can open the zipper and cool off without having to undress. It can also be used as a relief zipper.

Wrap Around the Back and Torso

Another zipper configuration that still remains a bit unproven by time is the wrap around the back torso zipper. The zipper starts on the breast on one side, goes down under the shoulder around the back and up the front to the breast on the opposite side. This design was developed some twenty years ago and then was abandoned because of the high stress it placed on the zipper when the person bent over.

TORSO

Standard

The standard dry suit design has added material in the torso area in order to facilitate putting the neck seal over the head. When the suit is fully donned, extra material hangs below the crotch area. This can impede leg movement in the water and can restrict leg mobility for activities such as ladder climbing, etc.

Telescoping

DUI's telescoping torso design folds to fit all body lengths comfortable. The suit is equipped with suspenders on the inside which hold the crotch firmly in place. This feature provides a far greater freedom of leg movement and is much more comfortable. The added crotch strap keeps the suit in place by holding the top half of the suit down. This allows for greater arm mobility. The telescoping design makes reaching and bending comfortable and provides a snug fit regardless of changes in insulation thicknesses or body weight.

SEAM CONSTRUCTION

Foam Neoprene - Glued and Sewn

This process is very similar to that used in wet suits.

Vulcanized Rubber

This is one of the strongest methods in that the rubber is uncured when the suit is built and then is later vulcanized during the curing process so it makes a very strong seam. However, it is very difficult to repair this type of seam.

Vinyl, Dielectric Welded, Taped, or Combination Welded and Taped

There are a variety of methods of sealing vinyl. They are very easy to identify because of the welding marks left by the machine that makes them. The seams should be as strong as the material itself. However, if not done carefully or if the machine is left on for too long, it can make the material next to the weld weaker because the material is now thinner.

Polyurethane - Mouser Sewing and Heat Tape, Coated or Laminated

An older method of making seams using the polyurethane material was the use of the mouser machine which used seven threads and a heat sealing tape over the seven threads. The shortcoming of this was that the tape can chafe through because the threads are protruding and very strong. The more modern way of doing it is folding the seam much as you find in a pair of blue jeans so that the threads are buried down inside the material and then the seam tape is heat sealed over the top of that.

CF200, Glued, Coated

The CF200 uses a unique method of first sewing and gluing a seam, and then with the material stripped of the inner nylon strip, a special elastomaric coating is put on top of it which binds the material together. It makes a very durable seam. Also, the most common method of seaming trilaminate suits is to use a folded seam much as in your blue jeans and then coat it with the same elastomaric seam coating as is used on the CF200 suit. This also makes a very long lasting, durable seam.

HOODS

The head loses a great deal of heat compared to the rest of the body. Therefore, as the water gets colder, more attention to the protection given by the hood is called for. Many people do wear a standard wet suit hood. However, they will find that if they have a latex neck seal, the use of a warm neck collar will give them increased comfort.

For maximum protection, a hood attached is recommended and although most suits are not, if you get into ice diving conditions, they certainly must be. If you're using latex seals you have to be very careful that you have something which protects the neck. When that cold water gets against that latex seal, this can be the area where the highest heat loss occurs, that seal is going to get very cold.

Furthermore, if the hood is attached it will give them more protection yet. Most of the modern day dry suit hoods have a thinner face seal that reduces the amount of flush of water through the hood itself, and some of them come all the way up and that mask actually seals over the outside of the hood eliminating the cold area around the face. Again, having a hood that has the capacity to vent the air escaping from the mask or neck through the hood without leaking of water in is an advantage. There are some masks that are used in the Arctic or extremely cold weather in which a full face mask is used and it in turn also seals onto the hood or the hood seals around the outer edges of the mask.

I recommend that when you get into water below 55°F, you need to start paying more attention to the areas around the mouth and cover them up. You can either go to full face mask which will give you thermal protection for your face along with a lot of other advantages, or we have hoods where the face mask seals on the outside of, and covers the lips. The tissues around the lips can suffer frostbite damage by diving repeatedly in very cold water.

Standard

When using a standard hood with a suit that has latex seals, it's the latex that has no insulation effect and therefore, any cold water on them makes them very cold against the neck. The standard hood seals against the outer seal. This is quite satisfactory with a foam fold-under neck seal. Your neck will get cold using a latex seal.

Warm Neck

To compensate for the cold water against the latex, the warm neck hood was developed which essentially has a long foam rubber bib on the hood itself and is tucked in an outer covering on the outside of the suit, thereby keeping the neck warm.

Attached

The warmest hood combination possible is having the hood attached to the suit. This requires extra care and attention when putting the suit on and taking it off, and is normally only used by professional divers or divers who are going to be diving in extremely cold water and who are prepared to take on that extra discipline of seeing to it that it is done properly. Some hoods now come equipped with a self venting feature in which any air that escapes from the mask into the hood or from the inner body of the suit up into the hood is allowed to escape through the top of the hood without allowing water to come in. This is a very convenient feature.

ADDITIONAL FEATURES

Color

Since the diving public has become much more color conscious, the dry suit industry has responded with a wide variety of designer colors and combinations. In the custom made suits, one can now virtually have the accent colors of their choice and of course with the brighter colors, it makes the divers much easier to see from a greater distance on the surface.

Custom Fit or Tailored

The majority of people will be able to fit into standard sizes ranging from extra small to extra large. However, there are those of us who are built a little different. Or, because of the particular type of diving we do, we want something special on our suit. There are a number of dry suits that are available with custom fitting. The largest issue most often is the size of the foot. It would appear that the size of the foot is not always directly proportional to the size of the body. There are also a wide variety of options that can be put on a suit when it is being custom made. As in almost all things, when one goes to custom made, the price is a little higher but for those special people, it is worth the extra effort.

Boots or Socks

The boots must be flexible enough to fit over the insulation, fit close enough for you to have good control of your foot, but it also has to be loose enough to ensure good blood circulation. One of the common things we see is that people don't change fins when they go to more insulation. The result is that more insulation shuts down circulation because it's too tight on the feet and the feet get colder by putting on more insulation. It's very important that you put something on which insures that fins don't come off. When you put on more insulation your heels disappear and there's a greater chance of kicking yourself right out of your fins. I urge those of you moving into the cold water environment to pay particular attention to that sort of interface.

Material - CF200, Molded Sole. The DUI molded sole boot made with CF200 is rugged yet soft and comfortable when walking or wearing fins. It gives you good footing because of the rugged tread and the ankle strap and it eliminates the need for an overboot.

Socks - Latex, Smooth. These are tough to put on, require a protective over boot and are very slick on decks. They puncture easily.

Heavy Boots. These are good for some diving jobs and sport applications. They are difficult to use with fins. It is suggested that you try them out before you buy them to insure overall compatibility with your type of diving.

Suspenders

The suspenders act to hold the crotch in place, thereby allowing full freedom of leg movement. This feature also allows the diver to be partially dressed while waiting for the next dive.

Ankle Restraints

Ankle straps secure the foot in the boot for added comfort and safety. They prevent the boot from filling up with air and slipping off the foot.

Chafing/Wear Protection - Elbow and Knee Pads

Most suits today come with elbow pads and knee pads for extra chafe and puncture protection. By and large, these have proven to be both satisfactory and functional. For those working in very high chafe areas such as on shipwrecks where a lot of swimming is not a requirement, the addition of chafing gear can be worn. However, it must be underlined that formal chafing gear does reduce the diver's ability to swim and should only be used when they have down lines and are tethered to the surface or where the experience of the diver is such that they are quite able to handle it. This chafing gear should not be worn by the amateur.

Pockets - Utility, Knife

There are a wide variety of accessory pockets and knife pockets available for installation on your dry suit. Just check with your dealer and at the time of either having your suit built or for your annual overhaul, you can have these installed.

WHY A DRY SUIT LEAKS

All dry suits leak a little; if from nothing else, then from the hair on your arms. When the suit is closed up, the humidity inside the suit rises to 100%. Even when not perspiring, moisture is constantly coming out of the skin pores. Moisture evaporates because of the heat of the body and moves to the cool surface of the dry suit where it condenses. It is common to find condensation on the inside of your dry suit after a dive. This does not necessarily mean that a leak has occurred in the suit. Remember, "damp is OK, as long as you are warm."

A post-dive check is useful for finding leaks. You will practice post-dive leak checking procedures following your pool and open water dives. Additional practice pool dives are recommended for those having problems with leakage. To locate the area of leakage, unzip the dry suit after leaving the pool, carefully checking for wetness. Then check the neck seal. Check your arms for dampness.

ZIPPERS

Not Fully Closed

The most common cause of perceived leaks in dry suits stems from the zipper not being closed all the way. Check to make sure the zipper is closed prior to entering the water. The zipper must be fully snugged up to the sealing plug at the bottom of the zipper. Water coming through an open zipper is sometimes mistaken for a seam leak in the crotch. A zipper which has been properly closed upon initial dressing can become loosened when donning other pieces of equipment such as the weight belt. It is recommended that another check be made after the weight belt and other waist straps have been attached. Also check to insure that no other clips or other items can snag the zipper pull cord.

Damage, Failure

Zippers can fail because of improper attention to detail when closing or because of damage to the zipper itself.

Not Fully Open When Dressing and Undressing. Failure to fully open the zipper to its end stop could result in too much stress being applied to the upper teeth of the zipper when stretching the opening for donning or doffing the suit. This stress could result in a tear or damage to a tooth. This could result in an expensive repair requiring that the entire zipper be replaced. When storing the suit it is best to leave the zipper fully open.

Sand, Dirt and Salt. The elements can take their toll on a poorly cared for zipper. Foreign matter such as sand, clay, mud, dirt, salt, silt, etc., being caught in the zipper can damage the zipper. These materials get into the zipper seal and cause water to leak. They may also permanently damage the zipper seal necessitating the zipper's replacement. It is important to keep the zipper out of the elements as much as possible. Don't lay the suit down in the dirt or sand. Avoid excessive salt build-up. Rinse the zipper thoroughly after each dive or clean before each dive if necessary. One of the best ways to clean a zipper is to go over it with a clean toothbrush and get dirt out from between the teeth and of the sealing surface.

Improper Lubrication. The zipper must be kept well lubricated. It is recommended that only a single finger in the closing loop be required to comfortably pull the zipper closed across its length. If more force is needed to operate the zipper, it must be lubricated. To lubricate the zipper, use a wax stick such as "zipper ease". Do not use a spray lubricant with silicone or petroleum based products as these will harm the zipper. Lubricate the outside "teeth" of the zipper by moving the wax stick up and down the zipper. It is not necessary to lubricate the inner sealing surface or closure teeth.

Perilous Closing - Undergarment Snag. When closing the zipper avoid catching the undergarments, straps or other items in the zipper. Whenever resistance to closing is felt, immediately stop, back the zipper slide up and check for what is causing the resistance. Correct the problem before proceeding.

Overstress. The zippers used in dry suits are not designed to handle much stress at right angles to the zipper itself. As little as 15 psi at a right angle to the zipper will pull it apart. One of the major considerations in dry suit design is the prevention of stress to the zipper. If you put undue stress on the zipper, it may fail. You should not pull at right angles to a closed zipper to try and adjust the suit. An outer zipper guard as on a TLS suit will help protect the zipper from accidental overstress.

Old Age. Any material gets tired with age. A waterproof zipper properly maintained and cared for should last you several hundred dives. However, as your suit ages, you need to pay the zipper special attention. Be extra careful when opening and closing, lubricate faithfully. But remember, everything wears out with age.

SEALS

Many leaks can occur from your seal being not properly seated, or if too large or in need of replacement.

Insulation Garment Extending Under Seal

A common cause of seal leakage is simply the underwear or insulation garment extending under or through the seal. The wrist, the thumb loops or elastic wrist band may be under the seal and at the neck, a collar may be to blame. Be sure everything is clear of the seal leaving a wide sealing surface area against the body.

Hair Under Seal

Hair under a seal can be another simple reason and very easy to fix. When donning the suit, pay particular attention to the back of the neck especially on people with long hair. Make sure the sealing surface is against the skin below the hairline. People with heavy arm hair may also have some slight seepage at the wrist.

Folds in Seal

Folds in the seal can create small tunnels that allow water to leak into the suit. These can be avoided by smoothing and flattening the sealing surface against the skin. The end of the seal should never be folded under or inside. The only exception is the fold under foam wrist and neck seals.

Improper Adjustment - Tendons

Seals may leak because of wrist tendons that are on the surface of the inside of your wrist. This is unique to each individual. To check for tendon leakage, turn your hand palm up, make a fist and then turn fist inward. If the tendons in your arm stand up and you observe small grooves in your arm at your wrist, this means that any time you grab hold of something to pull on it, those tendons are going to rise and the seals will probably leak a little. About one third of the population has tendons of this nature. This type of tendon leakage can be overcome by pulling the wrist seal further up the arm, above the tendon area or down to the very end of the wrist. You will need to experiment to find the best placement of the seal for you. In the event you pull the seal up the forearm, a good pair of gloves will be needed to protect the forearm and wrist from the cold water. Some women also experience tendon leakage in the neck when turning their head all the way to one side.

Age Cracks, Tears and Snags

The common enemy of all rubber especially latex rubber, regardless of manufacturer, is the ultraviolet light from the sun, petroleum products and ozone coming in contact with the rubber. As the seals age, small cracks appear or it will become gummy. In time, these will extend through the seal. At this time, the seal will need to be replaced.

Besides age cracks, neoprene seals lose their stretch and flexibility making it more difficult to put on and more likely to split or tear from overstretching. The time required before a seal will need to be replaced varies greatly. It is partly dependent upon the seal itself and how the seal has been cared for.

The life expectancy of the latex seal is around nine to eighteen months and for the neoprene seal, about two years. Suits stored in garages around petroleum based products where fumes, oil, etc. come in contact with the seals, will deteriorate more quickly.

Seals on fabric suits or neoprene based suits which have been exposed to petroleum sources may become checkered or develop a soft gummy or oozy type of appearance. They may stretch and tear easily.

Suits stored near gas fired water heaters (the largest manufacturer of ozone around the house) will also encourage seal degradation. In fact, divers who store or dry their equipment near a hot water heater may cause premature deterioration of all their diving gear.

Seals can also tear or snag from coming in contact with sharp objects. This could be your fingernail when donning the suit or something such as a camera control knob, a hook on your equipment, or sharp rocks, coral or shells while diving. The use of gauntlet type gloves should be used to both protect the seal from damage and protect the diver from cold. One could also cut the fingers and thumb from an old pair of 1/8th inch gloves and pull the remaining portion up over the seals to protect them.

It is recommended that your suit be inspected before each dive and the condition of the seals noted so that repairs/replacements can be made at opportune times. In the event of a small tear in the seal, a small piece of tape may be applied to a dry seal. It may last through a couple of dives as an emergency temporary measure. However, most seals can be replaced in the field in fifteen minutes. Do not dive with a deteriorated seal.

Overtrimming. Proper fit of the seals is critical for dry diving. Sizing of your seals is important to your comfort and their function. If the seal is too tight it may interfere with blood circulation. If too loose, it will allow water to enter the suit. Overtrimming or overstretching your seals could allow them to leak. Seals will naturally stretch in time. If, however, you feel the seal is too tight, first try to accelerate the natural stretching process by stretching the foam neck seal over an object about six inches in diameter such as a three pound coffee can or the wrist seals over the neck of a bottle. Apply this stretch for 24 hours. If, after stretching, you feel the seals are still too tight, carefully trim with a sharp pair of scissors or get the next size larger. On latex seals, trim off only one ridge at a time checking the fit after each cut. On neoprene seals, never trim more than 1/8th of an inch at a time.

VALVES

The valves can also be a source of leaks. Leaking valves leave a wet spot at their location.

Dirty Valves

Sand, silt or salt crystals are usually to blame for leaky exhaust valves. However, these valves are easy to disassemble and clean. Valves should be flushed through with fresh water after every dive. They should be disassembled and cleaned on a regular basis especially if the valve does not appear to move freely during a pre-dive check or inspection.

Improper Adjustment of Adjustable Exhaust Valve

All exhaust valves leak a little, particularly in an adjustable exhaust valve when adjusted to the lowest setting, and one does a lot of swimming or thrashing around on the surface. The valve only requires one inch of water to open it up and in the process of closing, usually a couple of drops of water will get in.

Exhaust Valve Stuck Open

Although very rare, an exhaust valve stuck open usually comes from foreign debris caught in the valve. This should be caught in your pre-dive equipment inspection. Should this happen, exit the water and clean or repair the valve.

Minor Leakage Upon Closing of Exhaust Valve

All exhaust valves leak slightly - usually only a few drops of water - in the process of closing. This is normal for all valves.

Valve Not Properly Secured to Suit

Valves which are not securely attached to the suit may leak between the valve and the suit fabric. This could be the result of a loose backing ring, a ring failure, a breakdown or insufficient adhesive between the suit and the valves or the absence of a fabric/rubber washer to increase the thickness of the fabric at the valve attachment location. To check the attachment of the valves, first check to see if the valve backing ring is screwed tightly enough to hold the valve in an maintain waterproof integrity.

If not, tighten the valve assembly. Next, look for adequate adhesive between the valve and the fabric. Look also for a rubber back-up washer, try and gently pull the fabric at the valve and notice if it pulls away from between the valve sections. If any of these tests indicate a possible source of leakage, unscrew the valve from the suit, apply a small amount of silicone type sealant to both sides of the fabric, re-insert the valve and tighten in place. In the case of the inflate valve, check the air nipple alignment while reseating the valve.

Old Age

As valves age, the springs will become weak, the rubber components begin to crack and shrink, or the seats may become old and worn. There will come a time when the valve will need to be overhauled, the spring(s), seat and the rubber components will need to be replaced. Valves, like regulators, must be kept clean and lubricated to give dependable service.

SUIT/FABRIC

Seam Failure or Chafing

The most common cause of seam leaks that we have found have been in the urethane laminate type materials where a heat sealing tape is applied. In particular, where a mouser type sewing machine has been used to make the seam. This uses seven threads to sew the material together. These threads have a very high profile. Because of the high profile and the threads being very strong, you can chafe through the tape causing a leakage. Therefore, it is important to inspect these and test them on a regular basis as part of maintenance.

Tears, Punctures and Splitting

Punctures are the most common cause of actual dry suit leaks.

<u>Inflate Valve, Valve Stem</u>. 75% of all punctures come from the valves. 80% of those are caused by the valve stems on the inlet valve. Many of these have a very sharp corner. If you bend the suit over the valve such as rolling it up and something solid hits it such as

the lens of your facemask, it will knock a hole in your suit. It only requires a tap. There is no dry suit material which can resist this kind of puncture. The remaining 20% of valve punctures are caused by the exhaust valve. To prevent this, keep a stem protector on the valve when not in use and fold up the suit so the valves are on the outside.

Abrasion from Sitting or Scraping Against Sharp Objects. We do see punctures resulting from sitting or scraping against sharp objects. However, it is very rare to see any rips in a modern dry suit, except the seals. We see as many caused out of the water such as on boat decks as we do in the water. So the word of caution is, watch what you sit on - always.

Delamination. Delamination was a real problem with early urethane laminated suits. These problems have been greatly reduced. They are still a problem with the vinyl laminates. Most of the quality manufacturers have adequate delamination warranty to protect the dry suit user.

EQUIPMENT CONSIDERATIONS AND SYSTEM INTEGRATION

WEIGHT SYSTEM

Pay particular attention to your weighting system. Make sure you don't weight yourself heavier than being neutral with an empty tank. That's one of the most common causes of problems we find. Divers will load a lot of lead on, they'll put more air into their suit to compensate for that, and then if they have a problem, they suddenly have a volume of air they have to take care of inside, plus the fact that when they come up, they're sitting much lower in the water because they're carrying all this extra lead. **DON'T OVERWEIGHT YOURSELF.** You want to weight yourself neutrally buoyant and trim yourself out so that you'll stay in a neutral plane. If you're not, you're plowing a lot of water, you're getting very inefficient use of your fins and as the encumberance factor of all the equipment you add on gets greater, these kinds of little things begin to be important.

Waist Belt

Standard Weights. The standard weight system used with wet suits is a belt with solid lead weights on it. Certain weight designs, particularly homemade ones with sharp edges on them, can unduly chafe your dry suit and in particular, in the case of self don zipper, if the hard edge of a homemade weight gets up against the zipper itself, it can put enough of a strain to cause premature parting of the zipper.

Lead Shot. The best system found for use with dry suits has been shot belts. A wide variety of shot belts, some of which have a single pouch in them in which they put the lead, or have individual weight pouches and pockets in the belts in which to put the pouches. This has worked best because as one varies the amount of insulation they are using and/or the air tank, and/or going from fresh water to salt water, they will want to change the amount of weight they are carrying, much more so than they would with the use of a wet suit. It is important that the diver not put on excessive weight with the system. Normally, the most advisable is to weight the diver neutral plus whatever the weight within his air tank is at the beginning. For instance, an eighty cubic foot cylinder has six pounds negative weight of air at the beginning. Therefore, they should start this dive being six pounds negative buoyant. At the end of the dive, the diver will be neutrally buoyant.

Ankle Weights

Ankle weights are used by many divers to keep their legs down. Actually, for many, these are thought of more as training wheels only used during the beginning orientation to dry suit diving. They are necessary in colder waters where maximum insulation is being utilized. An important consideration when using any weight or with ankle weights is the trim the diver is in the water. The ideal situation is for the diver to be neither foot down nor head down, but in fact to be in level trim. The idea is that if the diver is both in trim as well as neutrally buoyant, then all of the power generated by the fins will be used to move the diver in the direction they want to go. It is most common for divers to look like scallops in the water. In other words, they have to kick to get up off the bottom and go where they want to go. As soon as they stop kicking, they plunge back to the bottom again.

Weights Attached to BC

It is acceptable to use weights attached to your BC except that in the case you want to make sure that the weights can easily be dropped and they'll fall completely free from the diver with great ease. It should be pointed out that because of the changing of insulation, the diver will be changing weights much more often and whatever system is utilized should allow for small amounts of weight to be added or subtracted from the weight system with ease and safety. It should also be pointed out that just as with the wet suit, the buoyancy will change in the dry suit between the fresh water and the salt water. A simple formula for calculating that difference is included in the Thermal Guidelines. Again, the major word of caution here is do not overweight yourself when using your dry suit.

The buoyancy compensator is always to be worn when using a dry suit to give the diver surface flotation when on the surface. Any excess weight carried by the diver will reduce that amount of buoyancy available for surface flotation should the diver be required to surface in rough water or have a long swim. The diver should take the tanks he normally uses in diving and all of the potential insulation ensembles they intend to use to a swimming pool. And in that swimming pool check out and test all of the different insulation combinations that the diver might employ and determine what amount of weight it takes to neutralize that buoyancy and properly record it in their dive log. It will save much experimentation and discomfort in trying to do it in the open ocean.

OTHER EQUIPMENT

Style of BC

There are a wide variety of BC's available which seem to be acceptable for use with the dry suit. The only word of caution we have is that whatever BC is being used supply adequate flotation from under the arms. We do discourage the use of any buoyancy compensator that supplies most of its buoyancy from up around the top of the shoulders and the neck. A good way to test the BC is that when in the water, it supports the diver chest high out of the water with the weight belt still on. Again, a word of caution: the dry suit must be used with a BC. Do not attempt to use the dry suit as a BC. It puts too much pressure on the neck, and in the event of a leaky neck seal, it will allow the air to vent out and then the diver has no surface flotation. Also, we strongly recommend against a BC inside the dry suit. See the "Diving Dry" video.

Scuba Harness and Straps - Location and Adjustments

A word of caution: with any dry suit, be sure that the straps from the BC or other harness work does not interfere with the operation of the valves. It is normal to experience some restriction when putting the left arm through the BC and having the shoulder straps hit it on the way through. This is normal. One simply wants to be sure that none of the straps from the harness work go over the top of the valve or can accidentally activate any of the valves.

Regulator LP Ports

Dry suit divers should check to see if he has an adequate number of LP ports on his regulator to take care of his BC, his dry suits, and both his safe second and main regulator. Attachments are available for those models which do not have sufficient number. The location of the ports should be such that the hose is easily reached without putting an excess strain on the hose itself or fitting. Most modern regulators have sufficient ports.

Tanks Commonly Used

Today's diving is done using a wide variety of tanks. However it should be remembered that the tanks will change in buoyancy from the first part of the dive to the last part of the dive. The air in the tank weighs something. It weighs approximately three pounds in the case of a 38 cubic foot cylinder and approximately six pounds in the case of an 80 cubic foot cylinder, and seven pounds in the case of a 100 cubic foot cylinder. The relative negative buoyancy of various different tanks made by different manufacturers need to be checked and included when making the weight computations for use with your dry suit and the insulation packages.

Fin Size and Strap Length

It is quite common when divers move from a wet suit to a dry suit that they are required to move to a size larger fin because of the increased insulation around the foot to keep it warm. It is important not to get too tight around the foot and cut off the blood circulation which can cause cramping and cold feet.

Gloves

As the water gets colder, our capacity to deal with it effectively diminishes. The greatest problem are the hands and the feet. And right now, the hands I feel, is where the industry has done the poorest job, it's the area that gets the least attention, it's the last thing anybody spends money on. People just pick up a pair of gloves and take them with them. Yet when you get on the job site, your eyes are what guide what goes on and your hands do the work. I think it's very important to choose the gloves, tools and equipment fittings that are compatible with one another. Often times your hands will work with the tool involved, but once you put the glove on, it's too big and clumsy.

Standard five finger inexpensive wet suit material gloves usually will not keep the hands warm enough to take full advantage of the capacity of the dry suit for making dives longer and all weather. Therefore, a little more attention is deserving as the gloves protect the hands and the hands are the most valuable tool the diver has.

Most gloves suitable for use with the dry suit have a long gauntlet of some kind on them for two reasons. One, to give protection to the wrist seals of the dry suit. Also, to give added thermal protection for the forearms which is where the muscles that control the hands are located.

There are two theories. One is to have the hand completely dry. In this case, if one can keep the hand completely dry as in the case with the use of ring seals, one can actually use a woolen mitten quite successfully for keeping their fingers warm.

If the water is so cold and the hands become incapacitated because of the cold, then one may want to go to a mitt. The mitt allows the hands to stay warmer by virtue of keeping the fingers in the same place thereby reducing the surface to mass ratio. Normally, three finger mitts are required in water temperatures below 50°F.

The choice for the diver, whether it be a dry glove or a wet glove, or whether it be three finger or five finger, has more to do with the combination of water temperature and the type of work the diver is doing and the amount of care or discipline that the diver is prepared to use during his dive.

THERMAL GUIDELINES

We developed a model called thermal guidelines so you can choose the correct amount of insulation for the kind of diving you're going to do. This model was developed to provide a simple system to choose insulation and the correct amount of insulation for the task at hand, suited for the person who's doing it. It therefore is not exact, due to the simplifications made to make it more user friendly. It was not developed for ice diving, because there, hands and feet play a much greater role than in milder temperatures. It was designed to keep you in thermal equilibrium, where your scientific brains and your physical extremities work the best. Anytime we begin to see an onset of hypothermia in any form, we feel that we have lost the war, it's time to go home and start all over again.

Divers have accepted the cold as something that had to be endured, or as a necessary occupational hazard. The guidelines are based upon the best scientific information available to Diving Unlimited International from laboratory tests, U.S. Navy tests, and field empirical data. DUI has brought together the accumulated knowledge of the medical, scientific and engineering communities to enable divers to be warm and comfortable in the water regardless of the water temperature, body type, depth, sex, exercise rate, or dive profile.

Long: *Exposure protection: dry suits and thermal insulation.*

In the basics, the muscles and the brain develop the heat in the body. The blood system circulates the heat through the body. When men go through puberty, they develop muscles, when women go through puberty, they develop other aspects. So, the result is that men have more muscle mass per body weight, as a rule, than women and therefore, they generate more heat. If women and men eat the same amount of food, the women gain weight because they don't have as many ways to burn it off. We dissipate that heat through the surface of our body and out through our lungs. The surface of our body is the greatest place we can lose it in a diving operation.

Virtually all diving that we do is done in a heat deficit state. We're losing more heat to the water than our bodies are manufacturing. We're wearing equipment that simply slows it down long enough so that we get the job done and out of the water before we die.

Thermal stress, if allowed to continue unchecked, can lead to hypothermia. Hypothermia and/or cold water stress is a factor in most diving accidents. Hypothermia is tolerated in most diving operations, which is a major mistake. Hypothermia is the major limiting factor in diving performance today. However, thermal stress, or hypothermia, is predictable and preventable.

WETSUIT PERFORMANCE PREDICTION

The Wet Suit Performance Prediction Chart (see Figure 1) was created to allow divers to predict the performance of a wet suit given the diver's anticipated work rate, depth of water, temperature of the water and individual characteristics of the diver.

The vertical axis on the left has water depth from the surface to 99 feet and the horizontal axis at the bottom has water temperatures from 30°F to 90°F. The curved lines represent the expected work rate for the dive, and are defined as:

Resting: Decompression

Light: Taking photographs or observing surroundings

Moderate: Normal swimming

Heavy: Strong swimming or dragging an object across the bottom--only in short intervals

Extreme: Heavy work--not possible with Standard Scuba

To read the chart if the dive is to be 33 feet, start at 33 feet and go across until you intersect with the appropriate work rate, then go down to the horizontal axis and see what the water temperature should be. For example, at 33 feet if the work rate was moderate the water should be approximately 72°F. At 66 feet and a moderate work rate, the water would have to be 77°F in order to maintain thermal equilibrium. However, using the same wet suit and work rate at the surface, the diver can stay in 60°F water without incurring thermal debt. As you can see, there is a significant penalty paid by wearing a wet suit at depth. This is caused by the loss of insulation through compression.

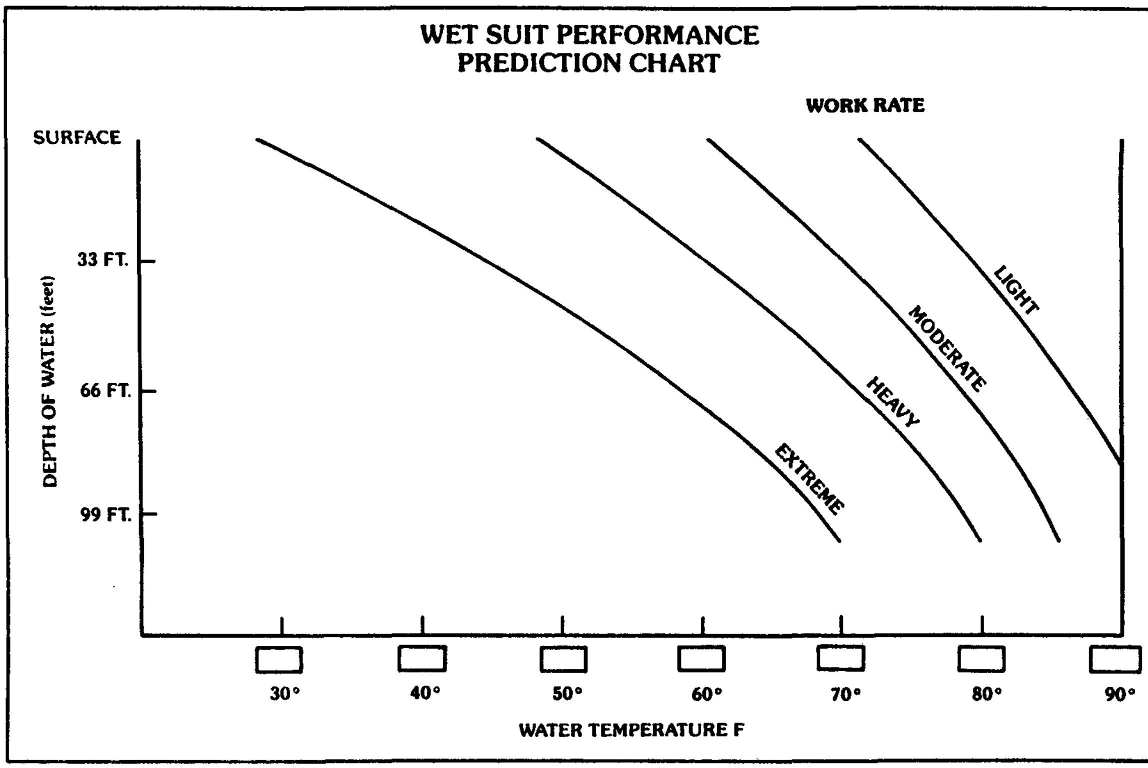

Figure 1. Wet Suit Performance Prediction Chart.

Wet suits are made of foam rubber. The trapped air bubbles in the foam rubber are the insulation. But increased depths compress the air in the wet suit material. At a depth of 33 feet, the air bubbles in your suit have compressed to one-half their original thickness so you have half your insulation. At 66 feet, the bubbles have reduced to one-third, and at 99 feet, to one-fourth. At this depth, all you have left is the solid rubber for insulation which is totally inadequate for a warm and safe dive. This example did not consider the fact water is colder at greater depths. With the wet suit, when you need the insulation the most, you have it the least.

The wet suit chart is rated for a five foot, eight inch, 165 pound male in good physical condition. The suit is a high quality 1/4 inch nylon lined wet suit with attached hood,

Long: *Exposure protection: dry suits and thermal insulation.*

Farmer John pants, a one-zipper jacket, gloves, boots, and in colder temperatures, a 1/8 inch vest.

You will notice that at the bottom of the chart are blank boxes. These are used to modify the chart for individual characteristics. If you are:

• a male over 200 pounds	5°F colder
• over 40 years of age	5°F warmer
• a female 121 to 140 pounds	5°F warmer
• a female under 120 pounds	10°F warmer

Add or subtract the degrees from the temperatures referenced under the boxes. For example, a 200 pound, 40 year old male would be 5° colder for being over 200 pounds and 5° warmer for being over 40 years old so the temperatures would be unchanged. But a 115 pound, 32 year old female would add 10° to the temperature referenced under each box for being under 120 pounds.

These guidelines have been proven to be reasonably accurate. However, to accommodate a wide range of individuals we must deal with averages. Since each individual is unique, once you establish your needs within these guidelines, you should field test the results and adjust accordingly.

It is a common practice for divers to go into colder waters than this chart recommends. Assume a diver makes dives of between 20 minutes and one hour duration and look at what would be expected at colder and colder temperatures.

Dives 5°F colder than chart recommends: The heat loss will be slow and therefore the degradation of diver performance will onset slowly. However, in most cases, the diver will sufficiently rewarm between dives.

Dives 10°F colder than chart recommends: Can be easily accomplished without significant performance degradation, but the outer body shell will accumulate thermal debt with each dive. This can be tolerated in certain types of activities, providing there are not more than two dives made in one day and there is one day's rest between diving days.

Dives 15°F colder: Will degrade the diver's performance during the dive, plus accumulate body shell thermal debt.

Dives 20°F colder: Will show significant in-water performance degradation and poor efficiency. Exposures must be kept short, if at all.

Dives 25°F colder: Will quickly reduce the diver to shivering and misery. This dive should be severely questioned.

Dives 30°F colder: Should not be attempted under any circumstances.

A diving supervisor must be alert and adjust the job requirements. Situations must be monitored closely, as high diver motivation can cloud sound judgement.

Hyperthermia, getting too hot, is more dangerous than hypothermia. Take the same set of circumstances at warmer temperatures than the chart recommends:

Dives 5°F warmer: Can be tolerated. Most divers will take a glove off or ventilate water through their hood. This will create sufficient cooling.

Dives 10°F warmer: The Diver must be careful and be aware. In a wet suit, he can ventilate water easily for cooling. In a dry suit, removal of the hood and gloves will possibly do. The diver must be aware and watch for signs of heat prostration. Examples: (1) Heavy or labored breathing without apparent justification. (2) Feeling tired or weak without cause. This can be followed by feeling sleepy and listless, without energy or ambition. Should these occur, the dive must be terminated.

Dives 15°F warmer: Can cause a substantial build-up of heat in the diver to threaten his capabilities. If unchecked, it can lead to disastrous results. This is particularly dangerous in a diver working hard at a difficult task.

Some other factors to consider with wet suits

When diving in strong current, conduction through the wet suit is increased. Currents also increase water infiltration and flushing which can substantially degrade the wet suit's performance.

Waist high pants will reduce the suit's efficiency, as will arm and leg zippers. Open neck hoods allow water to circulate through the suit, further reducing their effectiveness. A combination of these factors can reduce the thermal protective capacity by as much as 50 to 70 percent.

The U.S. Navy does not recommend the use of wet suits below 60°F.

DRY SUIT PERFORMANCE PREDICTION

With a dry suit, the depth of the dive is not a factor as the insulation remains constant at depth. A dry suit does not suffer from the compression problems of wet suits. Therefore, on the Dry Shell System Performance Chart (see Figure 2), the vertical axis has insulation packages instead of depth. Number 6 is the most insulation and number 1, the least. The insulation packages referenced are:

1. Pile socks, polypropylene expeditionary weight underwear, fabric gloves and no hood.

2. Pile socks, polypropylene expeditionary weight underwear, Plus 5 vest, fabric gloves, 1/8" wet suit gloves, standard hood.

3. Pile socks, polypropylene medium weight underwear, 50-65 Thinsulate divewear, 1/8" wet suit gloves, standard hood.

4. 50-65 Thinsulate boots, polypropylene medium weight underwear, 50-65 Thinsulate divewear, Plus 5 vest, 1/8" wet suit, gloves, standard hood.

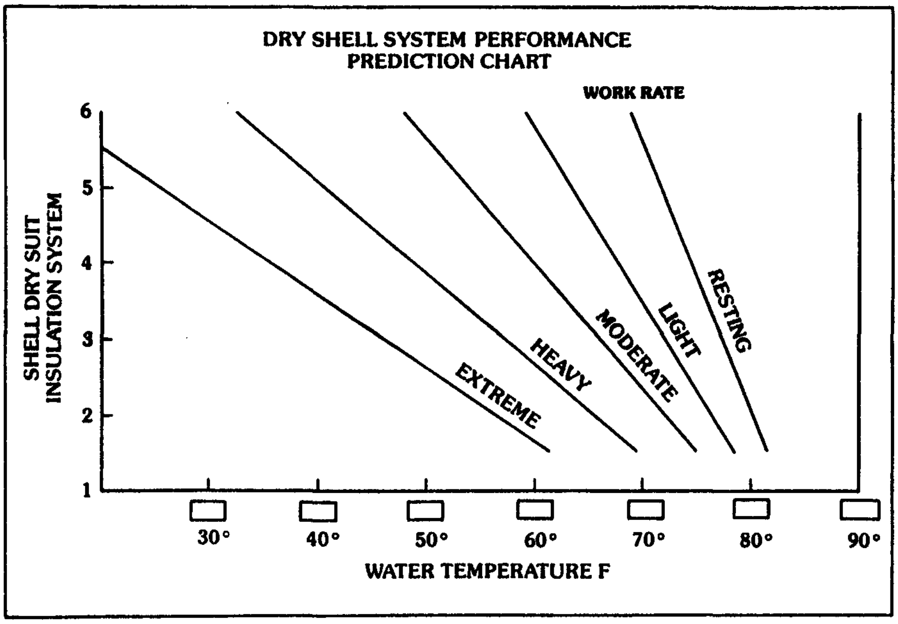

Figure 3. Efficiency and Reliability Prediction Chart.

5. 35-50 Thinsulate boots, polypropylene medium weight underwear, gloves, standard hood.

6. 35-50 Thinsulate boots, polypropylene extra weight underwear, Plus 5 vest, arctic mitts, no nose hood.

These are some examples. You can develop your own chart by using the conversion tables under the Insulation Section for bunting or pile. You can further augment your insulation package with clothes you already own such as jogging suits.

To use this chart, first select the water temperature you plan to dive in, move up until it intersects with the intended work rate, and move to the left to find the right insulation package. In 55°F water at a moderate work rate a number 5 insulation package is recommended to maintain thermal equilibrium.

As before, the chart is based on a male in good condition, 5 feet, 8 inches tall, and 165 pounds. To fine tune the values for your individual dry suit needs, if you are:

• a CF200 suit diver	5°F colder
• a male over 200 pounds	5°F colder
• over 40 years of age	5°F warmer
• a female 121 to 140 pounds	5°F warmer
• a female 120 pounds or below	10°F warmer

Add or subtract your factors and put the new temperatures into the boxes. As before, after establishing your own chart, field test the results to verify the accuracy.

These tables were not developed for the purpose of making life threatening decisions. There are too many unknown variables in a high risk dive profile for these broad based guidelines to cover. Also, because of the many variables on any dive, it was impractical or impossible to cover all aspects. As you have seen, the physical make-up and condition of the diver alone can make a 5 degree difference. Neither DUI nor any DUI dealer can be held responsible for the results of using these guidelines. One does so at their own risk.

DRY SUIT INSULATION

Suit insulation is controlled by how much and what type of undergarments are worn. The amount of insulation needed to stay comfortable can be determined by the Dry Suit Performance Prediction Chart (Figure 2).

Recent technical advances provide for insulation by trapping air and stabilizing it with a fiber structure inside a dry shell. The most common insulations in use are synthetic fibers made of polyester, nylon and polypropylene. These base fibers are selected due to low water absorption qualities. Fabrics made of these fibers are used in piles, buntings and battings. A common benefit of these materials is their resistance to compression. Open cell foams are also used to produce insulative undergarments for use with dry suits. The open cell foams are fairly good insulators but are bulky and adversely affected by water.

Radiant barriers are occasionally considered. This material was designed for use in a vacuum, such as space, where most of the heat is transmitted by radiation. It really has no use in diving insulative undergarments as almost all of the diver's heat is lost through conduction.

To date, the most effect insulation in diving is a microfiber batting made of a special blend of Thinsulate fibers. This product maintains insulation under dry suit diving compression while absorbing suit squeeze. Thinsulate also has a unique property that allows it to maintain most of its insulation and buoyancy when wet. It is the warmest insulation per unit of thickness as of this writing.

HOW TO TEST YOUR OWN INSULATION

We recommend you make control dives using the alternate insulation you might use for diving. Then, noting the water temperature and exercise rate, you can give that particular insulation a rating. Record this on your insulation chart. Knowing this in advance will allow you to make informed decisions and adjustments regarding your insulation when diving in different water temperatures or at different exercise rates.

If you're uncertain as to how an insulation will perform, one method to judge it by is its thickness under compression. Put a sample of material on a flat surface and place a 4" x 4" metal plate on top of the sample. Now place 8 lbs. of weight on the plate. Measure the distance between the plate and the flat surface. This can be done by pushing the tip of an ice pick through the material and marking it. Now do the same with a listed insulation. This is a simple way of comparing compression resistance. This is only one of the characteristics to consider when choosing dry suit insulation. We still recommend Thinsulate Type B.

If you're on a tight budget and diving in all temperatures, you might consider using 50-65 Divewear with an exercise suit or alternative clothing under it. This is suggested so that if the suit leaks, the water will go to the feet and not go through the Thinsulate, unless the leak is large.

The table below was extrapolated from U.S. Navy tests using 2PSI compression and is supplied to give you a relative scale to judge insulation under pressure. Using 30°-50° rated Thinsulate as a base value of one, the other insulations are expressed at a comparative value. You can make rough calculations of your own insulation from this table. Again, we recommend testing to verify the accuracy of these assumptions.

THINSULATE		OPEN CELL FOAM	PILE	SINGLE LAYER BUNTING	DOUBLE LAYER BUNTING
35-50	50-65				
1	0.5	0.5	0.65	0.22	0.55

Remember that there are a lot of different piles and buntings and the numbers will vary from type to type. The insulations used for the comparison were high quality types such as pile plush. Some bunting material has radiant barriers but these barriers do not add enough to raise the comparative number.

Comparing the Insulations:

Insulation Under Pressure	Least Restrictive	Water Tolerance
1. Thinsulate	1. Pile	1. Thinsulate
2. Foam	2. Thinsulate	2. Pile
3. Pile	3. Foam	3. Bunting
4. Bunting	4. Bunting	4. Foam

Overall, the most efficient insulation is Thinsulate.

Zone Insulation

Different dive profiles require different insulation strategies. Example: If a lot of exercise is anticipated, you may wish to lessen the insulation on the arms and increase it on the torso. However, if the diver is going to be very inactive, you may choose to do the opposite. Further, you may even choose to increase insulation on the thighs or directly under a specific piece of equipment. The most common form of this application is the pile vest. The same strategy is employed in modern glove design in which the insulation is thinner over the palm of the hand where natural insulation is provided by calluses, and thicker over the back of the hand where the skin is thin and there is a network of blood vessels. This allows for greater mobility.

CALCULATE YOUR WEIGHT AND BUOYANCY - THE EASY WAY

The amount of lead or ballast you will require with your dry suit will vary greatly depending on the amount of insulation, and thereby the air you are carrying. This could require a lot of valuable diving time to experiment to find the right amount of weight you will need. Therefore, we suggest the following:

First, gather together all the different combinations you might use for insulation under your dry suit.

Take all your normal scuba gear and your dry suit to a swimming pool.

Take a weight belt with lots of extra weights in different denominations. Example: 2,3,4,5 lbs. weights or shot pockets.

Suit up using the different possible insulation packages from the lightest (for warm water) to the heaviest (for cold water).

With each package, weight yourself until you are truly neutral buoyant. If you inhale, you rise; and exhale, you sink.

Note in your log book the underwear combination and the amount of weight it took to neutralize it (be sure you have totally purged all the air out of your suit and swam around to verify there were no air pockets left in the suit).

To convert from freshwater to salt, you add for the body weight of:

125 lbs.	--	add 4 lbs.
155 lbs.	--	add 5 lbs.
186 lbs.	--	add 6 lbs.
217 lbs.	--	add 7 lbs.

Now make the corrections for your scuba tank. Example: 80 cubic foot tank-- add 6 lbs. to allow for the increase in buoyancy as the air in the tank is used up. Also, an 80 cubic foot tank is about 1 lb. more negative in a pool than in salt water.

Now you are ready for the ocean with the knowledge of just how much you will need in your weight system. It is reasonable to need to make a few pound adjustments one way or the other once you start diving in salt water.

Once you have established neutral buoyancy, locate your weights to be in trim. Ideal trim is a horizontal plane when not moving at all. Depending on how your gear fits, this will determine how the weight is distributed. If your legs are much lower than your torso, swimming will be very inefficient. You should perfect this balance in a pool first.

EFFICIENCY AND RELIABILITY COMPARISON

Assuming the diver makes three dives to depths of 50 feet, the Efficiency and Reliability

Prediction Chart (see Figure 3) compares the previously mentioned wet suit and a modern dry suit with variable insulation and accessories.

	WETSUIT			DRYSUIT		
	1st	2nd	3rd	1st	2nd	3rd
70°F	100%	100%	100%	100%	100%	100%
60°F	100%	90%	80%	100%	100%	100%
50°F	80%	70%	50%	100%	100%	100%
40°F	50%	25%	*	100%	85%	75%
32°F	*	*	*	100%	75%	55%

*Not recommended unless involved in a life saving rescue.

Figure 2. Dry Suit Performance Prediction Chart.

Efficiency is defined as good diver strength, endurance, dexterity, sense of feel, and ability to use all his normal physical facilities to the same extent as he could on dry land under favorable conditions, and that the performance be repeatable on the next dive, and the diver has not been incapacitated by cold.

Reliability refers to the diver being able to make sound mental deductions for both safety and operations. He will be able to make accurate observations and follow multi-task memory procedures.

As you can see, the wet suit begins to fall off on the second dive at 60°F, at 50°F it is poor at best, and at 40°F is totally unacceptable. This is one of the reasons the U.S. Navy does not recommend wet suits in water below 60°F. The dry suit is still at 100% in 50°F water and starts to fall off on the second dive at 40°F.

TRICKS OF THE TRADE

One way to avoid overheating the diver prior to a dive is to put him into a cold insulation diving suit. The suit system will absorb a certain amount of heat from the diver.

For divers with a lot of hair on their head, use an old nylon stocking with a knot in it as a hair net. This will make a smooth surface for the neoprene neck seal to slide over.

It is easier to put on fins and take them off in very cold water by attaching 1-1/2" soft nylon with a loop in it to your fin strap in the back. Hook your finger in the loop to pull it up and stand on the loop to pull your heel out of the fin. It works great.

Rewarming Operations

The method of rewarming preferred by doctors is to allow the diver's own biological process to rewarm his body over time with plenty of rest. However, if aggressive rewarming is **REQUIRED** (for example, if you must make another dive to save a life), then use a tub of hot circulating water. Do not remove the diver as soon as he says he feels all right. Keep him in the water until sweat appears on his forehead. Showers are not adequate for rewarming nor are still bath tubs. The water must be circulating around the body for maximum heat transfer. It is the diving supervisor's responsibility to provide proper equipment and dive site management to prevent divers from getting into thermal trouble. It is generally better to dive with a warm, rested, less qualified diver than to put a cold, tired diver in the water.

Determining Performance Degradation

To tell if a diver is thermally degrading, have him sign his name on a clipboard prior to entering the water. Have him sign under it when he comes out of the water after his first dive. Then have him sign again before entering and after exiting the water on each successive dive. If the signature shows a continual degradation, it indicates lack of blood flow to the muscles in the lower arm area and, therefore, the accumulation of a thermal debt.

Testicles. As the body cools, the testicles will rise to keep warm. One indication that the diver is completely rewarmed is when the testicles descend again.

The above occurrences are only symptoms and are not reliable indicators by themselves. The dive master can also use an oral thermometer to check for heat stress. However, this method is not as useful for recognizing cold stress.

Urinating in Your Wet Suit

This practice causes the surface blood vessels to dilate, and actually accelerates the cooling of the diver's body. Therefore, it should be avoided when cold stress is a factor in a dive.

Support of Stand-By Divers

On a cold windy day, the divers must be protected from wind chill, particularly if they are in wet suits. Dry suits can be inflated to reduce the conductance of cool air through the suit skin. Wraps, parkas or blankets along with a windbreaker, worn over the wet suit, will protect the diver from heat loss prior to water entry, between dives, or after dives during transit back to shore.

Heat stress is also an important concern. Wet suit or dry suit divers in a stand-by mode are subject to severe heat gain on a hot day, particularly if they are sitting in the sun. Pouring cool water down the neck and arms of the wet suit diver is quite effective. Putting hands in ice water also helps divers stay cool, as does putting an air line inside the dry suit. Wet towels and running water over the head are also effective. Monitoring the internal temperature with an oral thermometer is reliable.

Long: *Exposure protection: dry suits and thermal insulation.*

CONCLUSION

As far as association is concerned, I certainly know that I speak for most of the manufacturers in that we will help you any way we can to gather together the information to make your people safer and more reliable on a continuous basis. I think we must be very, very careful when we come to newcomers. In the liability issues that we have today, which includes public entities, if we were to have a high visibility accident in which much publicity is made, we could set back scientific diving a long way. And let's face it, diving is not without risks, it never has been and never will be. All we can do is mitigate the risks as best as we can and we're going to do that with knowledge and skill.

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COLD WATER DIVING WITH VULCANIZED RUBBER DRY SUITS

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INTRODUCTION

Dry suits are the best technology currently available for keeping divers warm under the logistical constraints of typical polar scientific diving operations. An Antarctic operation with the greatest logistical support in the world will collect little or no accurate data if its divers can't be kept warm underwater.

Vulcanized Rubber Dry Suits

While there are many different types of dry suits available, this paper will concern itself strictly with vulcanized rubber dry suits. These suits are sealed under heat and pressure to produce dry suits which are free of seams and far more reliable than most other designs. In the event a vulcanized rubber dry suit is punctured, this material can be permanently repaired in five minutes (Figure 1).

To ensure long life, vulcanized rubber suits should be manufactured from a combination of natural and synthetic rubber to resist deterioration from ozone. Although this is obviously not a consideration under Antarctic conditions, it is an important factor when suits spend most of their time in storage in areas with heavy air pollution.

Another important consideration in the design of vulcanized rubber dry suits is to control the stretch modulus of the suit to ensure a balance between optimum stretch and abrasion resistance. A suit made from all natural rubber has tremendous stretch, but its surface is easily torn and gouged. Conversely, a suit made entirely from synthetics will be very rugged, but will have so little stretch that dressing into the suit becomes all but impossible. Very few manufacturers have the technical knowledge or resources which enable them to manufacture dry suits which achieve a balance of the best characteristics of both types of material.

Dry Suit Features

Beyond the suit material itself, there are certain essential features which should be a part of any dry suit designed for use under cold water conditions. Included among these features are attached boots, an automatic exhaust valve, and a dry hood with a thermal liner. The dry hood is especially important since fifty percent of the diver's body heat can be lost through the head. Dry hoods are available in either latex material, or in a "turbo" design, with an inner latex hood and an outer hood of vulcanized rubber.

If at all possible, the optimal situation is to equip the diver with a surface supplied diving helmet which mates directly to the diver's suit (Figure 2). This approach has been used with excellent results by people like Bruce Townsend from Canadian Fisheries, Lee

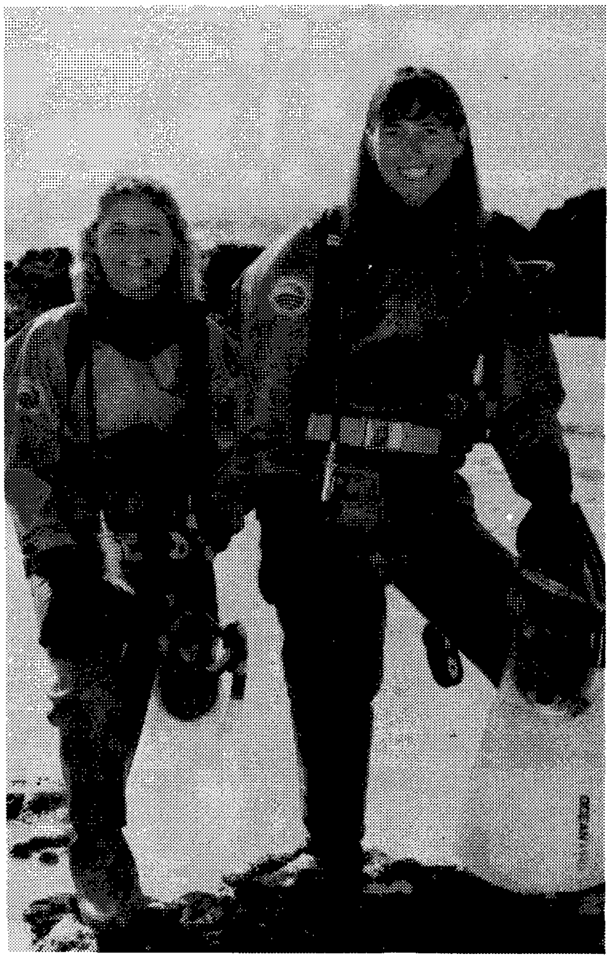

Figure 1. Vulcanized rubber dry suit.

Figure 2. If the option is available, a surface supplied helmet which mates directly to the dry suit is the best choice for under ice diving.

Somers at the University of Michigan, the U.S. National Park Service's Submerged Cultural Resources Unit, and the Australian Antarctic Division.

Dry Suit Underwear

It is important to remember that the only function of a dry suit is to keep the diver dry. The efficiency of the underwear is what keeps the diver warm. With this in mind, it becomes very obvious that there really are no thermal limitations to dry suits themselves. While there are a variety of formulas and calculations we can go through to estimate the amount of insulation we might require under a particular scenario, there is tremendous variability in individual physiological tolerances. Ultimately, each diver must determine his personal requirements.

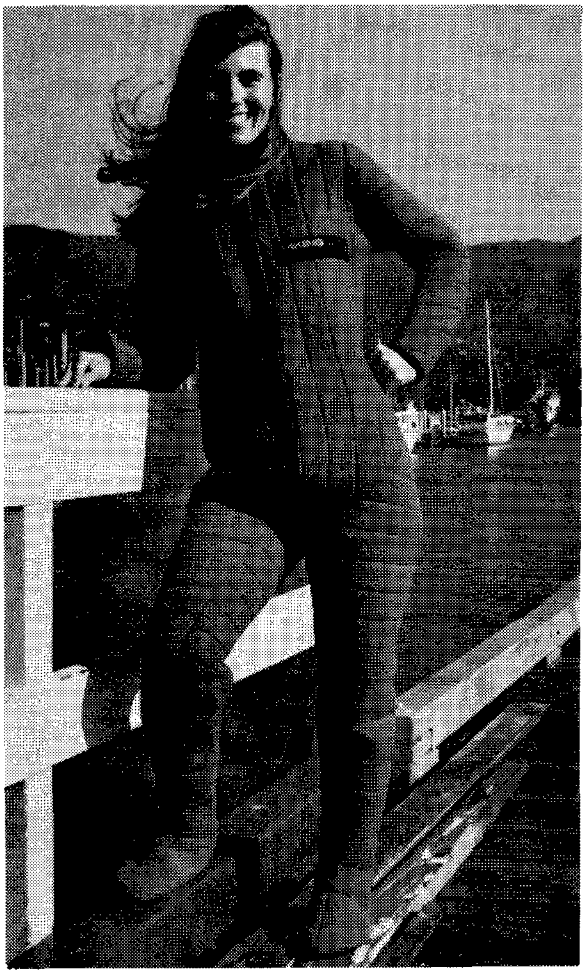

Figure 3. One popular type of dry suit underwear is open cell foam.

The most popular types of material used to manufacture dry suit underwear are Thinsulate, open cell foam, and radiant insulating material. Thinsulate is a very expensive, but efficient insulator which retains a large percentage of its insulation value even when wet. Open cell foam is a more economical material for dry suit underwear. It retains good insulation values when damp, but loses all capabilities in the rare instances when a dry suit completely floods. Radiant insulating material is manufactured from a combination of layered mylar and synthetic pile. It is an efficient insulator when both wet and dry. Like Thinsulate, it must be carefully laundered or its insulating capacity can be impaired.

Gloves and Mittens

The diver's hands are another major source of heat loss. Of course, any time the hands are sheathed there will be a certain trade-off between dexterity and warmth.

A good dry glove system consists of an inner ring and an outer ring which snap together and capture the suit sleeve. A thermal liner is worn against the skin and the mitten or glove attaches to the outer ring with a compression fit.

Training Is Essential

Virtually all of the dry suit accidents which have occurred in the last year can all be related back to a distinct lack of training. It is unreasonable to take a diver with little or no dry suit experience and place that person in an environment as hostile as the Antarctic, and expect them to be able to perform efficiently. Dry suit training should progress like all other diver training, from relatively benign environments to situations which are increasingly more hostile.

For example, the initial dry suit experience should be in confined water (i.e. a swimming pool) or, at the most, confined open water, such as a calm inlet or bay, at relatively mild temperatures. Only when the dry suit skills are mastered in an open water situation should the diver progress to an overhead environment, such as ice diving.

Dry suit skill training should deal with every conceivable emergency situation which might arise while using a dry suit. Most important among these are valve failures and sudden rapid buoyancy changes. The ability to recover from an inverted position is also critical.

CONCLUSION

While dry suits are probably not the ultimate diving technology for thermal protection, they do represent the best option available at the present time for operations in remote locations or where economics are a factor. Someday, there may be a spray-on, diver heating system, but for now, dry suits are the state-of-the-art choice.

REFERENCE

For specific information on dry suit diver training, consult the following reference:

Barsky, S. 1987. Dry Suit Diving Specialty Course. NAUI News, Montclair, CA. Sept-Oct:38-44.

COLD WATER DIVING LOGISTICS

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INTRODUCTION

Theoretically, I'm speaking on logistics and diving safety in cold environments. I'd like to start by asking, how many of you are divers? How many of you have been diving for more than twenty years? How many of you have ever forgotten your weightbelt? Facemask? Regulator? That comes under the heading of logistics. I think the greatest thing to have come along is called the goody bag, in which you theoretically have all of your equipment before you leave on a dive. How many of you have ever put together a cruise? How many of you have ever been responsible for more than two or three people going diving some place? You've all done it and it's just a matter of where. I don't think there's really any difference in the logistics of an Arctic/Antarctic trip, over a seagoing trip. If you ain't got it, you won't have it. There are very few manufacturer's representatives when you're sitting on a ship in the middle of the ocean. The same is true in these cold environments in which we work. What are logistics?

The Antarctic

In looking at things we find in the colder regions, and I've spent time in both Alaska and Antarctica, I find the Antarctic a much more hostile environment. How many of you have ever thought about what it takes to get a drink of water in the Antarctic? Somebody said I've dived the North and South Poles. That's very difficult to do. At the North Pole you walk out to the middle of the ocean, bore a hole, and it's about 12,000 feet deep. The South Pole is 9,300 feet in elevation. 8,800 feet of that is fresh water ice. I think that if you look at the continents you'll find it has not melted in millions of years. It's the second driest desert in the world. Now how do you get a drink of water? It takes so much energy to melt the amount of ice necessary to supply water to the little camp of McMurdo, that it's cheaper to convert salt water. If you are out in those kinds of environments, you better take it with you. How do you keep water from freezing? You put it in your refrigerator to keep it from freezing, if that makes sense. Those are things you need to think about.

This is the Antarctic continent. The panhandle up there is the tip of South America and across from it is the Palmer Peninsula. It's a pretty hostile environment, not a very pleasant place. There are no trees, very few plants and animals away from the ice edge. There is now one native Antarctican. I believe it was Argentina who took a very pregnant lady down there and let her give birth on the ice. It's the only continent on which there were no native people.

Palmer Station is supplied by ship from South America. You have an entirely different kind of logistical operation there. When the ship is leaving, you can physically look aboard that ship and be sure that all of your hardware is there. Then you have your diving operations which Bill Hamner will describe to you later on. There you're working from the ship off a small boat and have all the kinds of problems associated with getting people in and out of the water, the problems of cooling of individuals, what kinds of suits are best, which we'll hear a lot about in a little while.

This little dot is McMurdo Station and this whole area is a large shelf of ice called the Ross Ice Shelf. When the Scott expedition didn't return from the Pole in 1912, they erected a cross on the top of Observation Hill, which is about 1200 feet high. The cross was 20 feet high, made with 12 x 12 lumber. In 1974 that cross was blown down. A wind blew through there that pegged all the anemometers. Those are the kinds of things you face in this environment.

We also have a station at the Pole, and just for some realism, the average temperature at the South Pole during winter is 110°F below. It's a much more hostile environment because this whole polar continent has the highest average elevation of any continent in the world: 6,000 feet, 5,000 feet of which is ice. It gets pretty chilly down there. The dry valleys are areas where there is so little moisture in the snow, that when the wind blows through, it simply sublimates and it's all gone. The Commonwealth Glacier just simply comes out and stops. It attaches to the Polar Plateau a few miles away.

Christchurch, New Zealand, 2100 miles away, is where most of the supplies and equipment come from, normally by air. The sun goes down about the 18th of April and comes up about the 18th of August. We send an airplane or group of planes in around the 1st of September, called the winter fly-in. The next airplane is not for six weeks. So, if you get involved in that kind of an operation, you have to have it with you. It's encumbent upon you to make sure that all your equipment is there.

The Preparatory Stage

We have something called dive planning. It's the same thing as putting together any cruise. You sit down and figure out what you're going to do. Then you get a whole bunch of your friends to say yes, we'd like to do that with you, then you write a proposal. That is then reviewed by a bunch of friends you didn't invite who say no dice! After all that is sorted out, you go or maybe you postpone it until next year, then you get these other friends involved who say, sure it's a good idea. Now you have the funding, you've decided what you want to do, now you need to decide on the best tool with which to do that. Those of you who have worked in a marine environment know that most of the tools we use here on dry land or in space aren't worth much in salt water. Those are things you need to think about, based upon the environment in which you are going to work. What's out there to do your job? You always buy or build two, preferably three of anything. The first one is going to flood, the second one is not going to work and in the third one, the manufacturer forgot to install the o-ring. Maybe out of these three, you'll find bits and pieces to make one work and collect useable data.

When one heads for the Antarctic and you've gotten all your equipment, you get together with the housekeeping contractor that supports the operation, you put all your equipment in great boxes and take them some place and load them aboard the aircraft. They fly them to either Barber's Point and then to Pago Pago and on to Christchurch, New Zealand, from there to the Antarctic. If you've ever flown on a C-130 aircraft, it's about 9.5 hours on each leg of the flight. Hopefully, when you get there, your equipment will be there. Because if it's not, it's going to be a long time before it gets to you (about 6 weeks after the winter fly-in).

Field Logistics

You have to think about logistics and what is going to work best and you'd better consult your friends who have been there. Hopefully, what this document will do is give us a little perspective. If any of you have input with me, let me know.

What else do you need in the way of logistics? Once you get there, you need transportation to a worksite, unless you're working right here near McMurdo. You need protective cover, a tent or hut of some kind, a means to keep you personally out of the environment. You need communications. Each party is assigned a radio or two. You check in every time you leave the base, you check in when you get there, when divers go into the water, when divers get out, and check in before you start back home. We may work out of a pickup truck, a trackmaster, tent, Jamesway hut or other cover. You have to have food, water, communications, and a means of staying warm. You carry all of these with you at all times. Because if things get bad down there, you'd better be prepared.

Sometimes one needs to cook outside. At 57°F below zero, we took a case of steaks with us which we had to chip out with an ice axe. We had a Coleman stove, and in those days the Navy, in its infinite wisdom, wouldn't allow us to use Coleman fuel, we had to use white gas. I tell you that in a cast iron skillet, on a Coleman stove with white gas, a steak will never get warm enough to thaw, let alone cook. Those are the kinds of things you have to look into before you go to Antarctica or any similar environment.

Transportation

If your car stops, it's not going to start. If you stay in a metal vehicle, metal cools down in an awful hurry, so you get out, put up your tent, crawl in your sleeping bag and you stay alive until it gets better or somebody can come and get you. We have lots of days where you flag the road every 1/10th of a mile and can see the 6 foot high flag but not the ice due to upward blowing snow. Somebody has to physically get out of the vehicle and walk in the tracks you made coming in. The driver puts the bumper against your back and follows you. You alternate every five minutes so somebody doesn't freeze. In the Antarctic you don't see it snow as you know it here, it's more like standing in a sand storm. You can brush it off.

Sometimes in outback places you put everything on a banana sled and tow it across the ice. The trucks have very large low pressure sand tires. There are track vehicles of various kinds, ski-doos, dog sleds, helicopters, and a number of different types of aircraft. In our case we have a couple of aircraft. The C-130 is most common for setting up our outback camps, then we fly people around in helicopters. The C-130 has a number of advantages. You know you can back the plane up by reversing the thrust. You can also jump-start this plane. That's an advantage if you're stuck out there.

This rough ice is your road. You have to pick your road and flag it so you can find it again. It's really tough to drive over that stuff.

The whole town of McMurdo requires logistics support. Way out on the ice is the annual ice runway. It's about 6 feet thick ice. There is an ice freeway into town and no parking problem once you get there.

Protective Cover

The early Antarctic houses were all insulated with cork. This is an early pre-fab house that had about 10"-13" of cork insulation, so you're really quite comfortable. Everything in there is designed to keep you alive. You have water from melted ice, and food, and though it's a nice warm day, it's 55° or 60°F below and if the wind blows, you're in trouble because the chill factor drops and you have to have a place to get out of the weather.

There are fish huts, 16 feet long, 8 feet wide, 8 feet high and made of plywood. There's a hole in the bottom over the hole in the ice. This is one of the ways to make your dive.

The Jamesway hut is one of the insulated fabric kinds of houses. You can add on to these. They have insulated floors and with an oil heater, are quite comfortable. In addition, you can dive through a hole in the floor.

In this case we were living in mountain tents. There are also three squad tents, one of which has a porta-potty, one of which has a Coleman stove, and the other in which we have our compressor. Sometimes it's safer and more convenient to use a surface supplied Kirby Morgan Band Mask and line tenders. They've found a blue-green algae in this area. It uses the same kind of chemosynthesis that the hydrothermal vent animals use, because obviously, it's dark for six months.

The Under Ice Dive

The diving is really incidental. Once you get there, you've got the equipment, you've all got several types of suits, dry suits or wet suits. It's interesting to note that once you've completed your dive, you get out of the water and it's cold. The colder it is, the faster you freeze, the warmer you stay. Because you get a glaze of ice on the outside of your suit and the wind doesn't get you. Of course you don't want to walk very far. I don't know if any of you have ever broken a wetsuit, but I have.

What are the hazards? What looks like a graded road is in fact a tidal crack. Masses of ice come together and these tidal cracks are formed. One of the great hazards as you're diving along is finding a tidal crack that forms a triangle, and you get out on the apex of that triangle, it goes tweak and you're gone. In the blink of an eye. That really scares me. One of the ways we get under the ice is through the tidal crack, since it's mushy down the middle. A few feet on either side of the crack, the ice is 6 feet thick. We're putting in stations at 45, 85 and 130 feet. There's that tidal crack and we've taken our bars and since the tidal crack is hemispherical, we've chipped out a hole through the crack itself. There are a number of ways to get in. We bored some holes, took a chainsaw and sawed it out. If you don't like that one, you make a larger one. This is probably the best way to create a hole in thin ice.

You can also use explosives. Ice is so resilient that it takes a lot of powder to blow it. You have to do it sequentially because you don't want to disturb the bottom you want to study. You bore a hole and put in a whole bunch of charges so that they go off sequentially and ultimately everything blows up rather than down. Go and find yourself a good powder monkey.

My favorite way is a 43" auger which you tow out and bore a hole with. We have drilled in the hardest ice you'll ever see. If you don't like one hole, you bore two overlapping holes. Next, you back up your camper with its gasoline powered heater, get in, suit up and jump in the water. Always have someone on watch to keep a 36" diameter seal out of a 43" diameter hole. Seals are breathhold animals. They go to a couple of thousand feet and stay there for a while. When they come back into a hole to hyperventilate and if you've only got one hole, you're in trouble. So you've got to have some bailout holes.

In some cases it wasn't convenient to blow or drill a hole, so we took a heater and coils of copper tubing through which we pumped glycol or prestone. You heat that, set it on the ice and it melts its way down through. It was about four or five feet of ice and took a few hours, but we got a nice clean hole.

The coldest dive we've made was about 61°F below zero. The o-rings at that temperature turn to glass. I don't care what you do, you can't get them to work. We tried to warm that o-ring with a match and that didn't work either. We use double hose regulators, because of in spite of what the manufacturers say, we haven't found a single hose yet that will not freeze.

The Antarctic water visibility at this time of year is like distilled water. The water we're working in is about 28.5°F. It freezes at 27°F. That's one of the reasons the single hose regulator won't work because you get an approximate 5°F drop. As the air expands in your second stage, the temperature drops 5°F and you're putting moisture in on that second stage. It gets exciting when that quits.

Diving Safety

Diving Safety. Most of you are out in cold water at some time. You can't afford to make a mistake. I think that's what it boils down to. We live in such benign environments that it's really tough for someone from anyplace where it's not really cold to go down and know what they're getting in to. We can train people to dive. Anyone who's comfortable in diving, and who's trained in the proper use of cold water equipment, can be a very successful diver. We always give people check-out dives in a hole in very shallow water right at the base camp to shake them down. You never take them out and put them in a hole out there. There is a recompression chamber facility down there. Over the roughly thirty years we've had diving down there, we've had some near misses and those near misses have been people dropping their weightbelts using Unisuits and popping up under the ice. Some of you saw the presentation where there was a line coming down that had anchor ice attached to it. We've had anchor ice develop on these lines and you can put a line out there in the water and see it at different times of the year without seeing it. I might also say that with this clear water, when you make a night dive and there's so little particulate matter in the water, it's so clean that you can't see the beam of light. You don't see it like a projector light, you see what the beam hits. The anchor ice, when you get up in the overhead in many spots, will form a layer under the hard ice that is maybe three or four feet thick. If you drop your weightbelt and plaster yourself up in that, you've really got your work cut out for you. You've got to get yourself in a head down position and walk back to your hole. It's like walking upside down on a roof. Those are the things you have to think about. Regulator freezing. Take lots of things with you. If you take two, take two more. Finstraps, maskstraps, o-rings. When you get out in a place like that, you're usually using small compressors. They get cold, you've got to keep them warm. You can use electric or gas, it makes no difference, but you have to understand that once that block of steel cools down, it's going to take a while for it to warm up. You never shut the engine off in a car or one of the generators. They stay running all the time. You have to carry fuel with you.

Diving Safety! Here it's a benign environment, when you go down there, you need specialized training. We all believe in diving safety. It is nonetheless difficult for anyone to teach a person to be a safe and competent diver in a cold environment when that person is in San Diego. All we can do is ensure that they are comfortable and proficient in the kinds of equipment that they will be using and insist that check-out dives will be made in the environment in which they will work. The logistics are easy, just get a large cold water diving gear bag!

THE UNDER ICE DIVE

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INTRODUCTION

Ice diving is certainly not without some added risk factor in comparison to conventional open water scuba diving. The inherent complications associated with extreme surface exposures, thermal stress on the divers, equipment function/malfunction under extreme cold conditions, ice cover, cold climate logistical support, and so on place unusual demands on the dive team.

Naturally, the specific procedures for planning and conducting an under ice dive will very considerably with geographic location, dive objectives, support personnel and facilities, and ice conditions. An ocean dive in Antarctica will differ extensively from a dive in a Michigan lake. However, the same general concepts of organization, planning, equipment selection, personnel selection, and dive execution can be applied. Persons seeking information on diving in the Great Lake region are encourage to consult Somers [21, 23, 27]. In addition to these publications, polar divers are encouraged to read Andersen [1] and Jenkins [14].

The selection and training of research personnel for under ice diving has been discussed elsewhere in these proceedings. This paper will address the specifics of planning and organizing under ice diving operations. The selection and use of equipment will be discussed in detail with emphasis on equipment information not normally addressed in conventional diving manuals. Under ice diving emergencies and first aid for thermal injuries will also be addressed.

ORGANIZING AND PLANNING AN ICE DIVING OPERATION

The diving supervisor coordinates the establishment of the shore facility, selection of the hole site, cutting of the hole, erection of the ice shelter, and all other pre-dive activities. Generally, these tasks have been 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. For 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.

Instruction in dive organization and planning is frequently "minimal" in sport diver training programs. Since ice 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 of an ice diving operation. For additional information consult Somers [21, 23, 27] and Jenkins [14].

Personnel

Someone must take charge of the ice diving operation - a diving supervisor. 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. 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 surface tenders, stand-by divers, and other 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, tending, timekeeping, and so on. The supervisor will direct tenders and diver aides and inspect each diver before he/she enters the water.

Tenders, one for each safety line, must be qualified to independently tend divers and operate surface support equipment. He/she must be a qualified ice diver or a diver specifically trained in the theory and operational aspects of ice diving. Some teams use non-divers who have been specifically trained as tenders. These individuals must have a complete working knowledge of scuba diving, diving equipment, and ice diving. Keep in mind that the knowledgeable tender can be the final and most significant "link" in the chain of dive safety "checks and balances." The alert tender is often the first to detect silent hypothermia; emotional, physical, or cold stress; improperly fitted equipment; and so on. Avoid the temptation to let untrained support personnel serve as tenders!

A stand-by diver team is required for all under ice operations. The diver must be fully dressed for diving with the exception of scuba, weights, fins, and mask. This equipment must be "laid out" in a fashion which will facilitate rapid donning and deployment. The stand-by diver's tender remains immediately adjacent to that diver with the safety line in a "ready" position. With practice a good tender-diver team can generally deploy within one minute. Some teams actually place the diver on site completely equipped with the safety line attached. In this case the diver can be in the water within a few seconds. This practice, however, can be awkward and cold and is often abandoned in reality.

It is the responsibility of the individual diver to present himself/herself at the dive site fully equipped and prepared to dive at the discretion of the diving supervisor. Any individual who is experiencing the adverse effects of thermal stress, illness, emotional stress, excessive fatigue, alcohol, drugs or other disorders that may influence their safety must notify the diving supervisor immediately and withdraw from the dive operation.

Dive Site Selection

The diving supervisor 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, distance from shore, bottom type, and ice thickness. Charts of many inland lakes and quarries are available from various state agencies.

Ice thickness and condition should be evaluated several days in advance, especially during early winter and spring months. The ice should be at least 4 inches thick for even small groups and no less than 5 to 6 inches thick for larger groups and snowmobiles. Do not take vehicles onto the ice unless it is more than 8 inches thick (preferably 12 inches).

You can check the ice thickness by measuring through a small hole cut with an ice chipper (spud) or auger. Be especially careful early in the season. Approach new ice and snow or slush covered ice with extreme caution. I recommend that a team of two or more individuals conduct the ice "reconnaissance." One person dressed in a dry suit and equipped with a safety harness/line can proceed on to the ice 50 to 75 feet ahead of a safety person. Ideally, the safety person should also be dressed in a dry suit and the safety line secured to an object on shore. If the ice starts to crack or appears "weak" the advance person can retreat. If the advance person falls through the ice, he/she can be pulled from the water by the safety person.

The advance person may also wish to carry two "ice picks" to facilitate recovery. The ice picks can be constructed from ordinary ice picks by cutting the pick portion to a length of 2-inches and re-pointing. Protect each pick with a cork pushed securely onto the pick point. A line approximately 4 feet long should be strung between the two pick handles so that the user can carry the picks around his/her neck for immediate availability. For further information on ice thickness, formation, strength and rescue techniques consult Linton and Rust [16].

The advance person will prepare the measurement hole at the anticipated dive location and check the ice thickness using a measuring rod. This rod can be constructed from a piece of light steel or aluminum stock approximately 3 feet long. The lower 2 inches of the rod is bent 90° to form a hook that can catch on the underside of the ice when the rod is inserted through the test hole. The rod is marked in inches. A wood handle can be placed on the other end of the rod to facilitate handling and reduce the possibility of accidentally dropping it through the test hole. Knowledge of ice thickness is extremely valuable for determining hole cutting procedures.

Under ice visibility can be estimated by lowering a "secchi" disc through the hole. This is a small disc approximately 4 inches in diameter (smaller than the one used by scientists in order to use through a hole cut with a small auger). The disc can be constructed of metal or weighted plastic. The disc is divided into quarter pie shaped sections and the sections are painted alternately black and white. An eye is placed in the center of the disc for attachment of a measured line marked in feet. The disc is lowered into the water until it "disappears" and then pulled upward until the observer can again see it. The distance to the disc is a measure of visibility. If not previously known, the depth under the hole should be determined with a sounding line. A sounding line is simply a line marked in feet with a 2- or 3-pound weight secured to one end. The weight is lowered until it makes contact with the bottom.

Several test holes may be used in order to select the best possible dive location(s). The "recon" team should mark each hole with a flag in order to facilitate relocation on the day of the dive. Ideally, someone should check the site the day before or early in the morning of the dive day to assure that the markers are still in place.

Upon arrival at the dive site most groups will establish a shore base. 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, pick-up mounted camper, van, or a large tent. For example, Jutland buildings are large internal frame tents that can withstand the rigors of the polar environment and may be used on shore or on the ice. 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.

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 exhibit signs of cold injury.

It may be difficult, if not impossible, to establish an adequate shore base at some dive sites. Some teams select structures, or even use motel rooms, that are some distance from the dive site for dive preparation. Divers and support personnel are transported to the dive site in special vehicles or aircraft. Only necessary personnel remain at the actual dive site at any given time and transportation capability is always available to transport injured or cold individuals to base. Radio communication is maintained between base and personnel on the ice.

Dive Site Preparation

Once the shore base has been established, the dive site is prepared. Whenever possible, the ice hole should be cut in advance by support personnel rather than the divers. The personnel cutting the hole should be dressed in waterproof clothing and boots since they will generally be exposed to considerable splashing during the latter stages of cutting. Many individuals wear divers' dry suits. The ice hole should be as close to the shore base as possible.

Triangular shaped holes are the most popular among ice divers. They are easier to cut and have the advantage of being much easier to exit. Although seldom used, a specially constructed ladder secured to the ice with lines tied to ice pitons can be very advantageous for entering and exiting the water.

Cutting ice holes has always been a problem. Northern lakes may be covered with more than a foot of ice and polar ice cover can exceed 6 feet in thickness. For cutting holes in ice less than 18 inches thick, you can use ice augers, ice saws, or chainsaws. Ice chippers (spuds) can be used; however, this method is very time consuming and fatiguing. I find the "axe" to be least satisfactory of all tools and discourage its use because of the potential danger in the hands of an unskilled person. For cutting a triangular hole with an ice saw, simply drill the points of the triangle with an ice auger and cut the sides of the triangle with the saw. The method can, however, be difficult and time consuming.

Langerman prefers the use of gasoline powered chainsaws [15]. Keep in mind that water entering the carburetor can cause malfunction and require a complete field overhaul of the engine. In order to reduce or avoid splashing many experienced ice divers will use the chainsaw to cut through about 90% of the thickness of the ice and then complete the hole with a hand ice saw. If you cut through the ice at the beginning of your cutting procedure, you will always be cutting in water and splashing water on yourself and the chainsaw.

Chainsaws can be hazards, especially for the inexperienced user. When selecting a chainsaw, consider a direct drive model. Clutch models get wet and can malfunction. Always read the instructions and safety precautions provided with the saw and/or acquire instruction from the seller or renter. Many divers elect to rent both power augers and chainsaws.

The hole size is a matter of team/diver preference. It should be large enough to comfortably accommodate two divers with equipment. Many teams use a hole that is 4 to 5 feet on a side. The ice block is stored under the ice during the dive and placed back in the hole at the end of the dive. Some divers fear the possibility of the block of ice being accidentally pushed back into the hole while they are underwater. This is unlikely and, in the event that it does happen, the tenders and stand-by diver can immediately correct the situation. Remember that ice is extremely heavy and that it would be difficult, if not impossible, to pull a large block of ice on to the surface.

Some divers are concerned about catching a diver's safety line on the ice block, especially in the event that a circle search pattern might be used to search for a lost diver. Relatively large blocks of ice can be removed from holes and placed on top of the ice during diving operations. Ice block removal is facilitated by attaching a line to an ice piton that has been screwed into the ice before the hole is cut. The ice block is tilted by pushing down on one side and pulling from the other; several persons may be required to pull the block from the hole.

Ice auger may be used to drill a series of holes about one inch apart. After the holes have been drilled, the matrix of ice can be chipped away and the center plug removed or pushed under the ice. In thick ice a chainsaw may be used to cut a series of ice blocks that can be broken loose with a heavy duty chipper and removed with ice tongs. The ice should be cut and removed in a step fashion to facilitate systematic removal by layers.

Special thermal ice cutters and blasting techniques have also been used for hole cutting. The requirement for special thermal equipment and risk associated with explosives handling and use limit these techniques to select dive groups. For additional information on cutting holes in extremely thick ice consult Somers [21, 23] or Jenkins [14].

Except under relatively warm, windless conditions, some sort of shelter should be set up over or immediately adjacent to the hole in order to provide protection for tenders and support persons. A variety of huts and self-supporting frame tents have been used for this purpose. The shelter must be large enough to comfortably accommodate a supervisor, two divers, one or two tenders, and aides. Benches add to comfort and convenience. Because of availability, low cost, portability and relative ease of erection, many divers use large tents similar to those used for family camping with part or all of the floor removed. The interior of the tent can be warmed to some degree with a catalytic tent heater. The tent can be protected from high wind damage by securing guy lines to large ice pitons. Snow can be placed around the bottom to provide added protection.

For long exposures under extreme conditions and at highly used training sites, a heavy-duty double walled tent or insulated plywood or metal hut with a heater is required. The floor of the shelter may be decked with sheets of styrofoam insulation and covered with plywood for added insulation. Prefabricated modular structures can be either assembled on shore or on the ice. Properly designed structures can be erected and stabilized in one to two hours; some self-supporting tents in a matter of minutes. The interior of the structure should be furnished with benches and a storage rack (or hooks) for clothing and support equipment. In solid walled shelters, a substantial ring should be securely mounted on the wall for attachment of safety lines. Andersen and Jenkins discuss the selection of shelters for polar diving operations [1, 14].

Whenever a stove or heater is used indoors, the danger of carbon monoxide accumulation always exists. Even tent heaters that are designed to produce little or no carbon monoxide under optimum conditions may produce high levels of contamination if they malfunction or if there is incomplete combustion of fuels. Always use and maintain heaters in accord with manufacturer instructions and safety recommendations. It is always best to provide adequate fresh air ventilation. Deadly carbon monoxide is odorless and can render a person unconscious with little or no warning.

Fire is another hazard associated with the use of tent heaters. Be certain to place the heater in a location where it will not be tipped or accidentally come into contact with the shelter material or support personnel clothing. The use of flame retardant tents is highly recommended.

As an added safety precaution when diving under snow covered ice, a diver orientation pattern can be shovelled in the snow. A standard procedure is to shovel 8 to 10 lines radiating outward from the hole for a distance of 100 to 150 feet. A circular path connects the ends of these lines to form a large wheel-like symbol. Arrows pointing toward the hole are shaped at 10 to 20 foot intervals along the radiating lines. This pattern can generally be seen quite well by the divers under the ice. A lost diver could, in this case, easily find his way back to the hole. However, this procedure should not supersede the use of diver safety lines and a stand-by diver.

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 lines and equipment, long period of inactivity on the ice, 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 a 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 recommended for persons who are highly active or for use at temperatures above freezing. The system appears to be most effective for sub-zero temperatures and sedate activities.

Tenders 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. Line and equipment handling is extremely difficult and uncomfortable with cold, wet hands. Most tenders 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. Tenders should always include one or two pairs of extra gloves/mittens in their pockets. Pocket-type hand warmer heating units are also valuable.

When working on exposed ice surfaces in the winter, air temperatures will frequently be below 0°F and wind can exceed 20 miles per hour. This combination can produce an equivalent chill temperature of -35°F. 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.

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 loss can be considerable, especially in a wind, and pre-dive/post-dive chilling can result in significantly increased risk of injury or mishap.

For additional information on clothing for polar environments consult Somers [21, 23], Jenkins [14], and the National Science Foundations booklet titled, "Survival in Antarctica" [3] (or most recent edition).

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 in the 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.

EQUIPMENT FOR POLAR AND ICE DIVING

Most divers and dive teams will be equipped with conventional open water scuba diving equipment. This equipment can also be used for ice diving; however, there are some special requirements and additional items that must be considered for diving under ice and working in cold environments.

Basic Equipment

The selection of mask and fins 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 committing to the ice 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.

Although most sport divers continue to wear a snorkel attached to their mask strap for all diving, I personally discourage this practice for ice diving. The risk of entangling the snorkel in a safety line and dislodging the diver's mask is of great concern. Some divers advocate that a flexible hose snorkel can be inserted through a small hole cut through the ice with a knife and used in an emergency to draw air from the surface. This procedure is difficult and limited by physiological capability because of the water pressure on the submerged diver's chest. If you elect to include a snorkel in your ice diving outfit, I recommend that it be secured elsewhere on the diver such as on the underside of the buoyancy compensator (BC), in a BC pocket, under the knife straps, etc.

All ice divers should carry a sharp knife secured to the leg, BC, scuba harness, or arm. Some divers carry large sheath knives on the inside of their leg in order to minimize the possibility of snagging on the safety line. 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. Some divers who frequently work in limited visibility carry two knives at different locations on the body. I personally secure a sharp, compact knife to the front portion of my BC or scuba harness [22].

I must again emphasize that surface temperatures may be sub-zero, thus complicating equipment adjustments and donning. Keep in mind that some rubber products become stiffer and have slightly less stretch under sub-zero conditions than at room temperature. Weight belts must have the appropriate amount of weight for a given dive; adjustments on the ice or in the water can be very difficult. Attempting to adjust or "fix" equipment by cold divers or surface personnel on site increases the possibility of "life-threatening" mistakes!

Self-Contained Underwater Breathing Apparatus

Most research divers will use the same scuba for all diving, both open water and under ice. 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 "octopus" and a pressure gauge; and a backpack/BC combination unit. A decade ago, the use of double-hose regulators was recommended by most ice diving authorities because single-hose regulator malfunction was relatively common under ice diving conditions [21]. U. S. Navy Oceanography Office personnel experienced a 48.6% single-hose regulator "icing" malfunction rate during one series of dives [8]. Even today the old style double-hose regulator is still the regulator of choice for many polar divers. However, repair parts and replacement regulators are becoming increasing difficult to acquire. The experiences of various ice diving groups and the mechanism of regulator icing is discussed in detail by Somers [21,23,27], Fullerton [11], and Morson [5,19].

Over the past decade the single-hose regulator has almost completely replaced the double-hose regulator for all diving, including under the ice. Although regulator icing 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 may also have been significant in reducing the frequency of regulator "icing. 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 silicone or an anti-freeze 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. The exact mechanism causing regulator icing is unclear.

Some authorities suggest that many, if not most, regulator icing 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 has designed a regulator with Teflon coated components and a heat retention unit in the second-stage assembly in an attempt to reduce the potential of regulator icing.

On the other hand, one noted diving equipment engineer suggests that the major cause of regulator free flow resulting from icing is the deformation of the diaphragm in the first-stage assembly. Under extreme cold conditions 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, anti-freeze compounds, special coatings, and other freeze prevention systems may or may not play a significant role in reducing regulator icing.

Regardless of the exact mechanism causing a regulator to ice, I must emphasize that the potential for regulator icing still exists in all scuba regulators available on the market today. Fortunately, the icing almost always 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 continued cooling of the regulator assembly, freezing of water inside and outside of the regulator housing, and a subsequent increase the rate of air flow.

Proper pre-dive management of the regulator appears to be the most important factor in prevention of regulator icing. Common precautions used by cold weather/ice divers to reduce the possibility of regulator icing include: (1) keeping the interior of the second-stage completely dry before entering the water; (2) not breathing from the regulator until underwater; (3) allowing little or no water to enter the second-stage chamber during or between dives; (4) not depressing the purge button for more than 5 seconds prior to or during the dive; (5) avoiding heavy work loads that would significantly increase the breathing rate and volume of air moved through the valve with each breathing cycle; (6) assuring that the scuba air is moisture-free; and (7) keep the regulator in warm surroundings prior to the dive, if possible.

Langerman has 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 [15]. 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.

Langerman [15] also suggests that "the single most important factor which correlates with under ice free-flow problems appears to be surface temperature. When the air temperature is well below zero, we experience many problems; when the air temperature is above 15°F, the problem seems to disappear."

The use of an "octopus" is becoming a "standard" in the scuba diving community today. Although I feel that there are better emergency air alternatives for ice divers, general public acceptance of the "octopus" has made it the "system of choice" of most ice 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 the first-stage might increase the possibility of first-stage freezing. Langerman finds that the removal of the "octopus" reduces the incidence of free-flows ("regulator icing") underwater [15]. 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. Some under ice divers use two separate and complete scubas mounted in a double cylinder backpack.

Either of these systems allows 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.

Do keep in mind that the independent "controlled emergency swimming ascent" option is still available to the ice diver in the event of complete loss of air supply. It is a common practice to limit under ice penetrations to less than 100 feet by controlling the amount of safety line fed to the diver(s). A skilled, experienced diver should be able to successfully complete such an emergency ascent to the hole on a diagonal path. This ascent, to be used as a last resort alternative, can be tested and practiced in a confined water situation by having the diver make an exhaling emergency ascent following his/her safety line from the deep end of the pool to a "simulated" hole at the shallow end of the pool. All emergency ascent alternatives should be practiced under controlled training conditions.

The use of a buoyancy compensator (BC) with a dry suit is becoming a standard practice, especially with the increasing popularity of the "thin fabric" dry suit. Many foamed-neoprene dry suit (i.e. air suit) divers used their suits for "buoyancy compensation" and thus did not wear a separate BC. However, an increasing number of divers and instructors are concluding that the dry suit should not be used as a substitute for a BC. 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 BC current in use at present is the jacket style in contrast to the collar style of earlier years. However, some divers still prefer and use the collar style BCs. The pros and cons of BC styles are beyond the scope of this paper. Regardless of individual preference, select a BC and/or position the dry suit inflation/deflation valve(s) so that the BC will not interfere with the operation of these valves.

Buoyancy compensator and dry suit inflation/deflation valves are subject to potential malfunctions. These may be induced thermally or otherwise. I am familiar with at least one incident where the malfunction of a BC inflation unit resulted in an "uncontrolled, full BC inflation" ascent. Inspection of both BC and dry suit exhaust valves following separate diving accidents revealed that the valves malfunctioned in an "open" position. Consequently, the divers apparently could not maintain air in the BC or dry suit for compensation or emergency flotation. There is the significant likelihood that poor or inadequate maintenance was a factor in these alleged malfunctions.

Andersen reports on "suit blow-ups" resulting from dry suit 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 for Divers

Selecting and learning to use a comfortable, versatile, and adequate thermal protection system is not an easy task. Although some research divers still advocate use of the foamed-neoprene wet suit, some authorities suggest that its use should be limited to water temperatures above 60°F. Air suits are still in use, but the popularity of thin fabric suits has increasing significantly. Divers are encouraged to complete a dry suit training course.

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 polar and under ice diving 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.

Thermal protection outer and undergarments and dry suit training programs are addressed in detail elsewhere in these proceedings and in Somers [23, 24, 27].

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 foam-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 [20]:

> "Tests 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 foam-neoprene suits) and the amount of insulation worn under the outer suit. As with wet suits the weight requirements for a foam-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 weights are generally lead pellet filled nylon or 1/8 inch neoprene tubes or pouches fitted with a quick-lock buckle. NOAA researchers [14] 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; 1.75 to 3 pounds is more reasonable.

In order to test buoyancy, enter the water with all equipment that will be used 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. Over-inflation can cause "control" problems and compromise your safety.

Safety Harness

A lightweight, adjustable chest harness constructed of nylon webbing and secured with a locking D-carabiner is used to attach the safety line to the diver. This harness provides a more secure attachment than the scuba harness or BC. The harness is worn over the suit and under other equipment.

Safety Lines

Depending on the water visibility, a safety line may be the diver's only dependable link with the surface. Under ice, Antarctic visibility may approximate several hundred feet, whereas under ice conditions in inland lakes may limit the divers view to only a few feet or inches. Relocating the entry hole from under the ice is difficult, if not impossible, without this safety line. Most ice diving fatalities have involved situations where safety lines were not used. Based on accident reports, accepted procedures, and **common sense** one can only arrive at one conclusion: "a safety line is mandatory for ice divers."

Unfortunately, some ice divers will simply select the nearest and most convenient rope available to use as a safety line. This practice should be avoided. A variety of synthetic ropes are used by ice divers. The rope should be of relatively high tensile strength (over 2,000 lbs.) and large enough for the tender and divers to conveniently handle. Manila rope is less desirable for cold weather work. Manila rope that is allowed to freeze after being water soaked is readily broken and, therefore, cannot be trusted for ice diving.

I have selected a 7 mm water rescue rope constructed of a polypropylene core with a nylon sheath for ice diving. The rope is lightweight, brightly colored (greenish-yellow), and has a tensile strength of 2600 lbs. The multifilament polypropylene core provides a low specific gravity and zero water absorption, enabling the rope to float. The outer sheath increases the strength and abrasion resistance. This rope is flexible under cold temperature conditions to facilitate knot tying and handling.

I use approximately 350 feet of line "stuffed" into a double-end rope bag. The bag and rope can be secured at the surface with an ice piton or other security device. A loop is tied in the diver's end of the rope using a figure-8 loop knot. This loop is secured to the diver's safety harness with a locking mountain climber's carabiner or a screw link. When using a single rope/two-diver system, a second loop is tied about 8 feet from the first one for the second diver. The rope is marked at 10 to 25 foot intervals with self-laminating, write-on rope markers so that the tender will be able to determine how far the diver is from the hole.

The other end of this long rope is for the safety diver and is prepared in the same fashion. Approximately 100 to 150 feet of line is available for the diver and the remainder is reserved for the safety diver. Consequently, the safety diver is equipped with a rope that is approximately twice the length of the primary diver's line. The entire rope/safety line system can be carried and stored in a single bag.

Rope bags are recommended for easy storage and quick drying of rope. The rope is "stuffed" into the bag, not coiled. This facilitates rope deployment and handling.

Another excellent method of handling ropes is to "stuff" (not coil) the rope in a bucket or similar plastic container. The container can be placed on the ice in front of the tender or secured to the tender on a belt. The rope is fed to the diver as needed and placed back in the container as it is retrieved. This avoids the accumulation of a pile of tangled rope at the tender's feet. Small holes in the bottom of the bucket facilitate drainage.

There are several different ice diving safety line configurations used throughout the country. Some instructors/ice divers prefer to use a separate safety line and tender for each diver under the ice. This is certainly a "safe" procedure; however, it can involve some rope tangling if the tenders and/or divers cross lines several times. The single line-two diver configuration has gained in popularity over recent years. Some dive teams use a single safety line securely attached to a large heavy-duty aluminum or stainless steel ring approximately 10 inches in diameter (sometimes referred to as a "bridle" system). Two lines approximately 6 feet in length are attached to the large ring at one end and the diver's safety harness at the other. Each diver holds the large ring in one hand. This enables the divers to stay close together and both feel signals from the surface.

Ropes used for ice diving safety lines should be reserved specifically for that purpose. Keep the ropes clean and free from chemicals. Never overload the rope by using it for towing a car out of the snow, etc. Check the ropes frequently and guard against abrasion. Avoid direct exposure to hot objects such as shelter stoves or placing in the trunk of a car directly over the exhaust system. Synthetic rope fibers may break down or even melt when exposed to excessive heat, thus reducing the strength of the rope significantly. Dry and stow ropes in a cool, well-ventilated place. Examine ropes, carabiners, and other components of the safety line system frequently and replace if they show signs of excessive wear or damage.

Communications/Safety Line System

Many dive teams deploy only a single diver under the ice at a time. This procedure is gaining popularity and is considered "safe" by many authorities. A unique diver communications system has recently been introduced that makes the single diver technique significantly safer. This system includes a combination safety/communications line, a diver-to-tender electronic communications unit, and a diver's transducer.

The combination safety/communications line is constructed of nylon static kernmantle rope with a tensile strength of 3000 lbs or more. Two or four communications wires are woven inside the rope. This rope is fitted with electrical connectors at each end. It has the strength and handling characteristics of ordinary safety rope. Tying knots in the rope apparently has no adverse effects on the communications wires.

The topside communications unit is a small, lightweight metal box which may be hung from the tender's neck and conveniently positioned on his/her chest. The tender wears a headset with earphones and a boom microphone and presses a "speak" button located on the front of the unit to talk to the diver. In two-wire units the line from the diver is always open except when the tender is pressing the speak button. Four-wire units provide open communications similar to a conventional telephone.

The diver is equipped with earphones and a microphone in a full-face mask. Several full-face masks that are compatible with scuba have been used to significantly improve diver to tender communications.

The combination communications/safety line adds a new dimension of safety to ice diving. I recommend that all divers and teams seriously consider this system as a replacement for conventional safety lines.

Some divers are concerned that the use of full-face masks will complicate or eliminate the possibility of using an alternate air source. Andersen recommends that the divers back-up system consist of a secondary air cylinder/regulator and that the diver wearing a full-face mask carry a spare standard mask that can be used with the back-up regulator [1]. Several very compact models that can be carried in the BC pocket or a small "pouch" attached to the scuba harness are available.

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. 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 or entanglement in a safety line. 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.

Do not encumber the diver with equipment that is unnecessary for safety or task accomplishment. For example, if I am working a dive team under the ice in a relatively shallow, constant depth lake, I will often measure the depth by lowering a marked line through the ice hole and checking survey charts to determine if any significant depth variations occur in the area. Dive time is monitored by the tender or a timekeeper at the surface. Dive termination is designated by line signal or voice communication. Consequently, the divers need not be required to wear the timing and depth monitoring devices.

The use of electronic decompression/dive status monitoring devices is increasing in popularity for all diving activities. Be certain to read the manufacturers' instruction booklets for these instruments and pay particular attention to information relative to cold environment diving. Battery performance and power drain have resulted in significant reduction in "battery life" under extremely cold diving conditions.

Cold Weather Clothing and Other Personal Equipment

Each diver and support person is responsible for providing a complete outfit of cold weather clothing. The selection of cold weather clothing will be discussed later. In addition to thermal protection equipment, it is desirable for each person to use "ice creepers" attached to the bottom of their boots. The ice surface can be very slippery and falls, especially with diving equipment, can cause serious injury.

All persons working on the ice must have a pair of high quality sunglasses. 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 ultra-violet and infra-red 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.

Dive 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:

- Safety lines in bags;
- Ice pitons (a sufficient number for securing safety lines and shelter) and an ice hammer for placing pitons;
- Shore shelter and ice shelter;
- Snow shovel;
- Chainsaw, hand-type ice saw, and auger;
- Ice thickness measuring rod;
- Weighted descent line and a sounding line;
- Heaters for both shore and ice shelter;
- 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).

DIVING UNDER THE ICE

Final Preparation

The divers proceed to dress with the assistance of their aides. The tenders may proceed to the hole site/ice shelter for any final placement or check of safety lines. The divers are escorted to the hole by their aides with all equipment in place except for mask and fins. If the distance from the shore base 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 and the tender secures the safety line to the diver's harness. The tenders, 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 is done for the diver by an aide or tender once the diver is on the ice. Just before entering the water, warm water is injected into wet suits. If a dry suit diver is wearing unattached gloves, hot water is injected into the gloves.

Entry and Diving Procedures

Generally, most divers prefer to sit on the ice and slip slowly into the water. This is much better for purging air from dry suits. As previously mentioned, some authorities suggest that the diver not draw a breath from the regulator until submerged in order to reduce the potential for icing. The diver or aide can hold the regulator clear until just before the diver submerges, insert the regulator into the diver's mouth, and the diver then submerges and draws the first breath. Langerman recommends that the diver not breathe from a cold regulator until just before entering the water. He also recommends pouring hot water over the regulator housing just before the diver leaves the surface [15].

As the diver submerges he/she holds on to the descent line, adjusts suit air level, adjusts buoyancy, and quickly checks the buddy diver's equipment and status. When both are satisfied, they signal the surface to give them slack by pulling twice on the safety line, and they descend. Breathing slow and easy will minimize the potential for regulator freezing.

Some divers prefer to use a weighted vertical line to facilitate descent and buoyancy adjustment. They proceed down the line to "swimming depth" and then swim laterally. Once they have reached the extent of their safety line allowance or underwater objective they can swim arc or circle patterns. Some divers are concerned about the possibility of tangling their safety lines with the descent line. This is a minimal probability for a good dive team and tender. In the event that the lines do tangle, surface personnel can quickly retrieve the descent line and release the safety line. Or the descent line can be easily removed from the water once the divers have started their swim. Keep in mind that most ice divers do not use the descent line. However, I find it to be a significant aid, especially for trainees.

Each diver is responsible for maintaining the buddy system. Even in good visibility I prefer to see divers no more than 8 feet apart. The divers should keep a light but steady strain on the safety line. If there appears to be a significant amount of "slack", signal the tender to take in the slack by pulling three times on the line. Excess line under the ice increases the possibility of entanglement. A good tender will "feel" the diver's movement and allot the appropriate amount of line. Ideally, the tender will maintain enough strain on the line to "feel" the diver but not restrict his/her movement. The tender will occasionally tug once on the line, a signal which asks if the diver is "OK"; the diver will respond with a single pull to indicate that he/she is "OK." Although the line is secured to the safety harness, the diver should also keep one hand on the line at all times.

Divers should avoid rapid and excessive movements that tend to confuse the tender. 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. Either the divers or the tenders will monitor time and depth in accord with the designated dive plan.

Most lakes and quarries have a thick layer of silt 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 to the entrance hole.

In some situations it is possible to encounter currents under the ice. 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 flow under and/or move large units of ice. Tide-induced currents must also be considered in ocean diving. The diver should avoid diving under the ice in currents, if at all possible.

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/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/BC valves.

Generally, the divers will be required to terminate their dive when they experience a regulator freeze-up, begin to shiver, reach the specific time limit established for the dive, or reduce their air supply to approximately one-third of full cylinder pressure. Some teams are more conservative and others more liberal regarding termination cylinder pressure, depending on the dive site and conditions.

The diver should plan to terminate the dive with approximately 30% 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. I always plan to complete my observations, task, or practice near or directly under the hole when my air supply reaches the 40% to 50% level.

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 [13]. 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). At present several new decompression tables and devices are being marketed. Divers are encouraged to monitor diving safety literature for the most current information.

Tending the Diver

Tending is an art! As previously mentioned, tenders should be qualified divers or persons specially trained in tending ice divers. The most effective assistance can only be given by a tender who is familiar with the equipment, procedures, safety precautions, environmental conditions, and difficulties that are inherent in ice diving. It is the tender's responsibility to see that the diver receives proper care while both top side and underwater. The tender must check all equipment and the status of the diver before sending him/her down. While the diver is submerged, the tender handles the safety line and maintains communications with the diver.

Tenders and divers must memorize and practice basic line-pull signals so that they can be used easily and safely. The following line-pull signals are used by the U.S. Navy [2]:

Tender to Diver

1 pull............	Are your all right? (When the diver is descending, 1 pull means stop.)
2 pulls...........	Go down! (During ascent, you have come up too far. Go back down until I stop you.)
3 pulls...........	Stand-by to come up!
4 pulls...........	Come up!

Diver to Tender

1 pull............	I am all right!
2 pulls...........	Give me slack!
3 pulls...........	Take in my slack!
4 pulls...........	Haul me up!

Emergency Signals: Diver to Tender

2-2-2 pull series..	I am fouled and need the assistance of another diver!
3-3-3 pull series..	I am fouled but can clear myself.

These signals have been selected from the U.S. Navy's standard signals for surface-supplied divers. Additional signals are discussed in the section on searching for a lost diver. Additional and special signals may be designated to meet team requirements. Many research divers find the U.S. Navy system complex and objectionable. Regardless of the system used, it is the responsibility of the diving supervisor to designate the system and review it in the pre-dive briefing.

When tending a diver do not hold the line so taut as to interfere with the diver's movements. The diver should be given 3 or 4 feet of slack, but not so much that he/she can not be felt from time to time. Signals can neither be received or given on a slack line. Consequently, the diver's line must be kept in hand with proper tension at all times.

Line pulls consist of a series of sharp, distinct pulls, strong enough for gives the amount of line required for various depths and a lateral distance of 100 feet:

Depth (D)	Line Requirement
30 feet	104 feet
60 feet	117 feet
90 feet	135 feet

The tender should also monitor the diver's underwater time and signal the diver when the designated time limit is reached. If the diver is equipped with a communications unit, the tender may also maintain voice communications with the diver. In some cases the diving supervisor or a designated "communicator" will manage the communications system and a timekeeper will be designated.

The above water end of the safety line must be secured to a metal stake, ice piton, or other secure object to insure that it is never pulled under the ice. When the diver is submerged, the tender must never let go of the safety line. The tender skillfully feeds the line to the diver and pulls in slack. The line may be neatly laid in a "figure-8" on the ice surface. Never allow the lines to become tangled.

Rewarming the Diver

When the diver surfaces, remove breathing apparatus, BC, 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; do not remove the mittens or hood in cold air on the ice. 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. In some cases divers have experienced severe blistering and peeling of the skin following the application of "too hot" of water. The diver apparently did not realize that he was being scalded.

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 [17].

DEALING WITH UNDER ICE EMERGENCIES

Ice divers and support personnel must be prepared to resolve under ice emergencies such as breathing system malfunction, suit or BC inflator malfunction, suit flooding, uncontrolled ascent, loss of the safety line 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 ice diver must "discipline" every move that he/she makes both on the surface and underwater. Many fatal and non-fatal 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 ice 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 macho-ette)" 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 under the ice. 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 things 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 have already been discussed. In the event that the regulator malfunctions, the diver(s) should immediately return to the hole. 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 malfunctioning regulator. Naturally, both divers in a buddy team will return to the hole. At the hole, air is turned off and the regulator first- and second-stages are thawed with warm water. If sufficient air remains in the scuba, the divers may descend directly below the hole 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.

Blow-up

A diver may lose his/her weight belt, accidentally over-inflate a BC or suit, or experience a suit/BC inflation valve free-flow malfunction. Any of these conditions can result in an uncontrolled ascent or "blow-up". 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 BC.

If the suit or BC valve is free-flowing, the diver must disconnect the hose. If possible, place one hand over head in order to break the impact with the underside of the ice. Above all, remain calm and exhale. Unless the malfunction is corrected immediately, anticipate impact within a few seconds. Even if you resolve the situation, signal the tender to "pull you in" and terminate the dive. The diver must be observed for signs of pulmonary barotrauma.

Many divers fear blow-ups, either in a head-up or feet-up (inverted) position, if they accidentally lose their weight belt. The following information on blow-up was summarized from a NOAA study [20]:

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 blow-up were successful within 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 possibility 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 difficult for divers wearing the heavy mittens common to ice 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 [20]:

1. Emergency blow-up 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 blow-ups 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 BCs 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 foam-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. If the diver feels 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 blow-up: the forward roll, where the diver curls inward, and the back roll, where the diver extends and arches his/her back [20]. 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.

The diver can practice blow-up 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 starts 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 blow-up recoveries must be practiced.

Lost Under the Ice

There is simply no reason for a diver to ever become lost under the ice. Through the use of proper equipment, procedures, and safety precautions the diver always has a "link" with the surface. A strong and securely attached safety line is mandatory even under high visibility conditions. However, all ice divers do agree that there must also be an emergency procedure for such situations. This procedure involves the deployment of a stand-by diver and specific actions by the lost diver.

Let's assume that the diver has become separated from his/her safety line. Once the diver realizes that he/she is no longer attached to the safety line, he/she should stop swimming, listen, and watch for the buddy. Above all, do not panic and start swimming wildly around the bottom! This only increases air consumption and will probably complicate rescue. If the buddy, safety line, or hole are not in sight, the diver should immediately ascend to the underside of the ice. If the ice is thin enough, break through and call for help; do not attempt to climb out. When the ice is too thick to easily break through, it is best to not waste time, energy, or air trying to break through. Simply stay put and relax!

Once the tender realizes that the life line is no longer attached to the diver or that the line is apparently entangled underwater and signals are not being acknowledged by the diver, he/she will immediately notify the diving supervisor and the stand-by team. The tender should immediately note the amount of line that is under the ice and the direction of the diver at last contact and report this information to the supervisor. This is another advantage of using a measured safety line. The supervisor will quickly analyze the situation and brief and deploy the stand-by team.

Although the situation is critical, the surface group must be maintained under strict control and panicky, irrational actions avoided. The supervisor is in command! The stand-by diver is advised to swim in a direction of about 30° behind the location of last contact and known swimming direction of the ice diver. A compass is necessary for the stand-by diver. The tender is advised to let out enough line to allow the stand-by diver to swim approximately 25 feet beyond the last known distance of the distressed diver from the hole.

The stand-by diver enters the water, stretches out his/her safety line to the designated distance, and starts a clockwise sweep just below the underside of the ice, visually scanning to both sides. Visual scanning is important since an unconscious diver floating under the ice might not be snagged by the rope. The diver and tender must coordinate to keep the line relatively taut at all times. When a full 360° sweep has been completed the tender will signal the diver with two pulls (in this situation meaning, "stop search and go out until I stop you"). The tender will let out more line, the length of which is determined by the diving supervisor based on visibility, and the stand-by diver will make another sweep. Additional sweeps can be made at the supervisor's discretion.

In the meantime, the lost diver must remain calm and hang directly under the surface of the ice in a vertical position. The search line will come across the body or, if a floating line is used, it will pass on the underside of the ice. Keep your hand on the underside of the ice at all times to catch the line and look down in case a non-floating slack line passes below your fins. The divers should be briefed prior to the dive regarding the type of line that will be used for emergency searches. As soon as you have the safety line in hand, secure it to your safety harness or make a loop around your wrist and signal the diver and tender with three pulls (meaning "take in my slack/stand-by to haul me in"). Upon receiving the three pulls, in a search situation, the stand-by diver should move to the distressed diver. Once they are united, the divers will signal the tender to haul them in by giving four sharp pulls on the line.

If the lost diver is not located under the surface of the ice after two or more sweeps, the supervisor must assume that the diver is unconscious on the bottom. The rescue diver is signaled back to the hole in order to assess his/her physical status and air supply. If these conditions are satisfactory, the diver is directed to start circular sweeps at a distance above the bottom that allows him/her to see the widest area for a given visibility condition. The supervisor and tender will control the sweep pattern through line signals as above.

In the meantime, additional dive teams are assembled from among the better divers and tenders at the site, briefed, and readied for deployment. The local dive rescue squad should be called to the scene immediately and, upon arrival, will generally assume responsibility for continuing the rescue search. Keep in mind that an unconscious diver may survive extended cold water immersion and rescue attempts should continue for at least one hour after the anticipated time of air supply depletion.

Keep in mind that the stand-by diver will have a long swim if he/she has to complete an entire circle. If the diver is swimming a circle sweep with a radius of 50 feet, the actual swimming distance will be 138 yards (50 feet out, 314 feet circumference, and 50 feet back). One hundred and 200 foot radius searches require 276 and 552 yard swims, respectfully.

Entanglement

The stand-by diver may also be deployed if the tender suspects that the diver's safety line is entangled. If the line appears to be "held firm" and signals are not answered, the tender must immediately report the situation to the supervisor. At that point the stand-by diver-tender team will prepare for deployment. If the tender is unable to pull the safety line in with a modest amount of tension and no signals are received, the supervisor will deploy the stand-by diver. This diver will swim down the line and take whatever action is necessary to free the line and diver(s). All divers will then return to the surface and terminate the dive.

If a diver finds his/her line entangled, but is still in a position to signal the surface, he/she should use a series of line pulls to indicate status. Pulling on the line with a 3-3-3 series indicates "I am fouled (entangled), however, I can free myself!" A 2-2-2 series of pulls indicates "I am fouled and need the assistance of another diver!" If entangled, do not panic! Relax, remain calm, and gain control of breathing. If possible, signal your status to the surface. Slowly and carefully feel back along your line and systematically try to untangle it. Do not cut the safety line! If you are entangled in another line, attempt to work the line free with your hands. If you cannot free the line and can definitely identify that the line holding you is not your safety line, carefully cut away the entanglement.

Tethered scuba divers working alone under the ice may find themselves in this type of situation at some time. A few hours spent in a pool or "safe" water practicing solving simulated problems of "entanglement" in fish line, fish nets, wire, and rope with a "black-out" mask could be very worthwhile. The advantages of diver-to-surface communications become very obvious when you consider the possibility of having to resolve an entanglement situation.

Diving Under Partial Ice Cover

The number of fatal ice diving accidents is relatively small. 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 same potential risk must be considered when diving from, or adjacent to, ice shelves and ice floes.

A scuba diving team may enter a partially ice covered body of water intending to swim only in the open water portion. They may 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 in open water; use a heavy line.

THERMAL STRESS IN POLAR AND UNDER ICE DIVING

The human body is homeothermic, or warm blooded, and must constantly interact with its external environment in a 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. 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. Polar and under ice divers must have a complete working knowledge of thermal stress in order to maintain proper operational safety.

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 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 (98.6° F). At 36°C (97°F) 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 [28]. By this time the dive should have been terminated and rewarming procedures initiated.

When the core temperature drops to 35°C (95°F), 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 (95°F) causes loss of memory, poor articulation, sensory and motor degradation, and amnesia [28]. Many investigators believe that cold creates a distraction in the diver that interferes with his or her work, and indeed, safety [6]. 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" [9].

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 [10].

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 [10]. 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" [28]. The amount of continual heat loss can be quite substantial if the head is not properly protected [25].

Silent Hypothermia

Divers have only recently developed an awareness of "silent" or "undetected" hypothermia resulting from long, slow body cooling. Field experience has showed that after several days of work in cold water temperatures scientific divers often neglected to complete their research task and, in some cases, forgot what they were doing underwater. In most cases the divers generally would not indicate that they were cold, just fatigued or unwilling to dive again.

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" [18, 29].

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" [18].

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 (82.5 to 91.5°F) water or dives in a wet or dry suit in 15°C (59°F) or colder water, the mean skin temperature can remain close to the usual comfort zone (33°C or 91.5°F). 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 (2 to 4.5°F) and shivering supervenes [18, 29].

Bachrach considers "silent" or "progressive" hypothermia as "perhaps the major hazard to the diver in cold water" [6]. 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 [9,12].

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 be observed to sleep on the way back from the dive site. This "thermal debt" may continue to accumulate over successive diving days. It takes time, rest, food, and, sometimes, aggressive rewarming procedures to replace lost heat energy [25].

Determining Performance Degradation and Diver Status

One simple method of determining performance degradation is by monitoring the diver's hand writing [17]. 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 [17]. This may or may not be a reliable indicator of thermal recovery.

RECOGNITION AND MANAGEMENT OF HYPOTHERMIA AND COLD INJURIES

Cold stress and hypothermia have already been discussed. 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. 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/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 difficulties
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
- Depersonalization

I cannot 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, remove 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 [7].

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. Attempt at 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. For additional information consult "State of Alaska Hypothermia and Cold Water Near-Drowning Guidelines" [4], Bangs and Hamlet [7], and Somers [26].

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 cells in the skin and capillaries freeze 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 your 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 [7].

Immerse the affected part in warm water at approximately 42°C (108°F). To measure the temperature accurately a thermometer should be available. Too hot water can cause extreme discomfort and damage the tissue. If a thermometer is not available the temperature can be tested with an "un-frostbitten" finger; it should be comfortable to touch and not burn the finger. If the affected area cannot 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 [7].

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 evacuation 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 ever present. 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 re-breathe 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 monoxide is 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 poisoning and know appropriate first aid procedures. The symptoms include:

- Headache
- Dizziness
- Weariness
- Nausea
- Yawning
- Ringing in the ears
- Heart beat abnormalities
- 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 resuscitation. Immediately transport to a medical facility for treatment and/or observation.

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UNDERWATER RESEARCH IN THE SOUTHERN OCEAN ON THE ANTARCTIC KRILL EUPHAUSIA SUPERBA AND ON BALEEN WHALES

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INTRODUCTION

My research group from the University of California at Los Angeles has conducted underwater research in Antarctica for five austral summers, from 1980 to 1986. Our project, funded by the National Science Foundation Division of Polar Programs, was to study the behavior and ecology of the Antarctic krill, *Euphausia superba*. This small shrimp, growing to a length of 6-7 cm, occurs in enormous aggregations and is of central importance in the Antarctic food chain (Hamner 1984b). The Southern Ocean around the Antarctic continent is the summer feeding ground for baleen whales and the breeding site for penguins and other seabirds, all of which feed on the Antarctic krill. Although the importance of krill in the Antarctic food chain has been recognized for many years, little was known about its natural behavior until *in situ* observations were made possible by the development of blue-water diving techniques and the design of diving equipment appropriate to underwater work in water temperatures of -1°C to +2°C.

ANTARCTIC DIVING TECHNIQUES

We operated out of Palmer Station on Anvers Island and from the research vessels *Hero* and *Polar Duke* in coastal waters along the western side of the Antarctic Peninsula. In order to observe krill underwater at sea we used scuba or snorkeled, diving in a typical blue-water situation, with a surface-support boat and boatman, and with all the divers tethered to safety lines attached to a float at the surface (Hamner 1982; Heine 1985). The major restriction for open water diving research is weather. Rough seas, snow, rain, and winds of 20 knots or more endanger launch and recovery of the dive boat, so we did not dive when the weather deteriorated. The only other factor that prevented diving was the presence of leopard seals in the water. These seals are large predators on penguins and marine mammals, and they have occasionally harassed divers in Antarctic waters. Although we did not enter the water near leopard seals, on several dives leopard seals came in to inspect us, but did not harm the divers.

We use CF200 dry suits and Thinsulate underwear designed by Diving Unlimited, Inc. in San Diego. These can keep us comfortable in near-freezing water for 5 continuous hours of diving and snorkeling. If one plans to be in the water that long, however, precautions must be taken to protect the lips from frostbite. A full face mask is one possibility, and another is a neoprene balaklava that protects the exposed skin when wearing a regular face mask. We're still using DUI suits that we bought in 1980. Each year we return them to DUI for leak tests and repairs and for modifications as the design improves. The most important feature of our dry suits for diving in the water column is the automatic vent valve on the left shoulder of the suit. The diver descends to the desired depth and trims out, and then during ascent just rolls slightly to let air bubble out of the valve and maintain neutral buoyancy. We always wear stabilization jackets with the dry suits as an added safety measure, usually keeping them deflated during the dive. We prefer the ScubaPro jacket because of its rigid framework and because the inflation device also functions as an alternate breathing source. Single-hose regulators are usable in these coastal waters in summertime, but occasionally one would freeze up and free-flow. Since we avoided decompression diving, this was annoying rather than dangerous, as the diver could ascend to the surface at a normal rate.

For a typical dive we suited up on shore or on deck. Our scuba gear and weights were put into a rubber boat which was then lowered into the water. Cameras and fragile collecting gear were handed down to the boatman and then the divers climbed into the boat and put on their tanks and gear at the dive site. The boatman was always in contact with the station or the ship by radio and announced the beginning and end of our dives. If the boatman needed to abort the dive for some reason, such as deteriorating weather, he could pull on the line descending from the float to signal the safety diver.

BIOLOGICAL OBSERVATIONS

Underwater observations revealed that adult *Euphausia superba* behave much like schooling fishes, occurring in schools that range in size from under 100 individuals to enormous aggregations containing 30,000 animals/m^3 (Hamner *et al.* 1983, Hamner 1984a). One aspect of our research was to examine the onset of schooling in juvenile krill. The eggs hatch at depths of more than 1,500 meters and the solitary larvae migrate to the surface. They aggregate underneath the sea ice and begin to form social groupings of swarms and then of schools which remain associated with the ice for some time. The ice protects the small krill from many predators and at the same time provides food in the form of ice algae at a time of year when there is little or no phytoplankton in the water column.

Another focus of our research was predation on *Euphausia superba*. In the austral fall of 1986 we made some interesting observations in the area of the Gerlache Strait on baleen whales, which are major predators on the Antarctic krill (Stone and Hamner 1988, Hamner *et al.* in press). Many baleen whales feed along the western Antarctic coast during the austral summer before migrating north to their breeding grounds. In one photograph we counted 150 whale spouts on the horizon. We saw one whale with scars on its back, which probably were caused by collision with a ship. We don't know if this happened in Antarctic waters or in its winter breeding grounds off South America. Minke whales were by far the most common baleen whale in this area, followed by humpback whales. Southern right whales, probably the most endangered whale species, were scarce, but one of our sightings of a right whale extended their known range south by 400 miles. Our sightings and others are encouraging, for they suggest that the southern right may be repopulating several areas of the Southern Ocean around Antarctica after being almost exterminated by 1820.

We did some diving with humpback whales, and there are many applications for diving research with whales. Diver observations are one of the few possible ways to sex the animals out in the ocean, a fundamental piece of information needed to describe the populations. Whales spend only about 20% of their time at the surface, so unless they can be studied underwater we simply will not learn much about their biology. Divers can tag whales and learn their behavioral patterns and feeding habits, and, if they get close enough, they can collect skin, parasite, and blood samples. Another application of diving with whales is rescue and disentanglement. Many whales become tangled in fishing gear, nets and traps into which they will follow fish. Divers often enter these fish traps, take down the netting, and help persuade the whale to leave. Divers should take some basic precautions when working with whales. Only one or two divers should be in the water at one time. The divers should always be in a position where the whale can see them. Usually SCUBA gear should not be used because bubbles bother the whales and make them skittish. We usually snorkel without a weightbelt to be positively buoyant. An important reminder: U.S. citizens must have a permit to dive with whales anywhere in the world. If one has a valid reason to approach and investigate whales, however, obtaining the required permit is not difficult.

One of the major goals of our whale research in the Antarctic was to identify individual whales, which is done by photographing the pigmentation on the ventral surface of the tail. Identification of individuals is necessary for long-term estimates of population size and for determining migratory routes by comparing identification photographs taken in different areas. In the North Atlantic 3,800 whales have been identified. In the Antarctic we have identified only about 30 individuals, so comparable work with whales in Antarctica is just beginning.

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OPERATIONAL STRATEGIES FOR ARCTIC RESEARCH DIVING

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The Department of Fisheries and Oceans, Central and Arctic Region's diving program supports a wide range of studies including food chain dynamics and toxicology, marine mammal behavior and ecology and habitat assessment. The majority of divers are full time staff members but the program also includes summer students, graduate students, and visiting scientists. Dives rarely exceed 20 m and profiles fit the description given an average Canadian scientific diving operation (Sparks 1984). The regional diving program also supports sub-Arctic projects (see Fudge 1984, Townsend and Butler 1984) and many of the strategies outlined in this paper apply to most cold weather operations.

In general Canadian Arctic diving activities have become more sophisticated over the past three decades. Scuba operations have been expanded to include helmet, rebreather and ADS technology (Townsend 1985, Elsey 1985, Nuytten 1985) and the short term exploratory efforts of the wet suit pioneers have been replaced by programs promoting quantitative long-term studies.

Papers outlining detailed methodology for working in the Arctic environment are available (Bright 1972, MacInnis 1972, Anderson 1974, Jenkins 1976, and Rey 1985) and the UNESCO Code for Scientific Diving (Flemming and Max 1988) provides additional information for polar, cold water, and under ice diving operations.

This paper reviews the essentials of Arctic diving operations and provides information on administrative, training, equipment selection and on-site procedures.

ADMINISTRATION AND COORDINATION

Expedition diving safety and effectiveness is greatly enhanced through a project orientated approach to dive planning, coordination and control. It is most effective if the scientist in charge delegates diving coordination and control to a diver in charge. This delegation separates the technical aspects of the diving program from the scientific elements, a division that enhances the effectiveness of both components. Divers can be scheduled individually for prerequisites such as medical examinations, remedial training and equipment but a project overview is necessary for team coordination, major equipment (such as compressors) mobilization, logistics, and on-site preparedness.

Medical examinations are an essential prerequisite for any Arctic diving program. The "part-time" diving scientist should be reminded that limits and skills decrease with age and inactive life styles and that the quality of underwater research is influenced by diver preparedness. Medical examinations, conducted by a physician who understands the rigors of diving, should include pulmonary function tests and active ECGs, especially for those over 40 years of age. Such tests allow excellent cardiac performance assessment, promote fitness awareness and provide training incentives.

TRAINING

Pre-expedition training is strongly recommended under conditions as close to the Arctic environment as possible. Polar expeditions involve major transitions (light, temperature, and travel) that stress even seasoned divers. Divers adjust better to polar conditions if training strategies involve ice-covered, cold water exercises. Regulator free-flow and suit over-inflation exercises must be covered.

Efficiency and quantitative sampling ability of the diver is usually restricted in the first few operational dives even after a field checkout. Effectiveness is further curtailed by the usual "start-up" equipment malfunctions.

EQUIPMENT SELECTION AND PREPARATION

The success of polar diving operations depends to a large extent on proper selection and use of equipment. Variable volume neoprene or vulcanized dry suits combined with pile, foam, Thinsulate, polypropylene, or wool underwear provide a wide range of insulative capabilities. Hands remain the most difficult body part to keep warm. Dry gloves or mitts attached directly to the suit with wrist rings and snaps promote manual dexterity, diver effectiveness, and extend mission duration. Hoods with closed foam under-bonnets or air pockets also increase diver insulation and warmth. For ice diving operations light-weight surface supply helmets with dry head operation enhance insulation capability and have the added advantage of hard wire communications (Figure 1). Through water, communication units are generally unreliable and are limited by short battery life.

Double-hose U.S. Diver Royal Aqua Master regulators have proven to be more reliable than high performance single-hose models. Dry suit inflator hoses can be attached to the hookah port of this regulator and cylinder pressure can be monitored with submersible pressure gauges attached to the high pressure port of the valve stem. Twin cylinders are most commonly used and aluminum tanks prove superior to steel, especially under conditions where restricted base facilities limit equipment rinsing. As a safeguard, a separate pony cylinder with a spare regulator can be attached between the double as an emergency alternate breathing source.

In addition to scuba and surface supply operations, rebreathers have been used in polar operations. Rebreathers require considerably more maintenance than conventional modes and a dedicated support technician is required if long term reliability is to be expected.

Recently remote camera and ROV systems were used to extend program capabilities and video/single reflex camera combinations provided real time viewing with enhanced resolution. During trials the remote systems were tested in shallow water with helmeted divers present. This diver/machine interface provided ground truth observations and

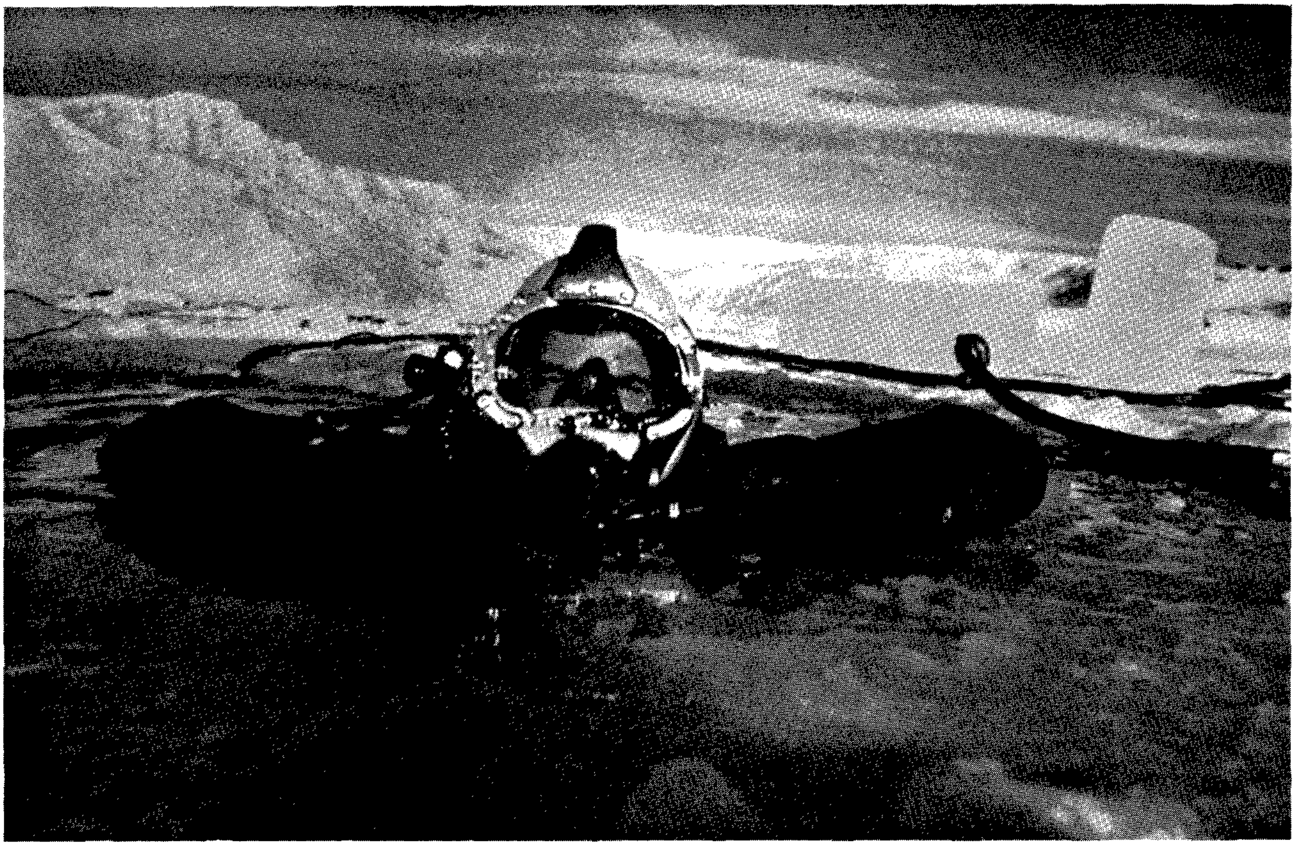

Figure 1. The dry head, hard-wire combination of helmet operations greatly increase diver effectiveness and safety. This is especially true when an ice platform is present.

commentary which greatly assisted top-side visual interpretation, operator effectiveness, and experimental design.

Equipment preparation and coordination is especially important for polar operations. However, most "off-the-shelf" scuba equipment does not tolerate sub-zero air and water temperatures. Plastics equipment is especially susceptible to breakage. Regulators and "through water" communications are also unreliable, especially during winter operations. To maximize effectiveness, compressors should be outfitted with additional water absorbent cartridges.

Operational remoteness cannot be stressed too strongly and first aid capabilities must be part of expedition contingencies. Contingencies should be reviewed, first aid equipment inventoried and replenished and oxygen supplies secured. Oxygen supplies can be greatly increased by stocking medical grade oxygen for welding applications.

ON-SITE CONSIDERATIONS

Physically and mentally fit, well equipped divers operating with simple, well planned diving procedures, maximize the safety and effectiveness of polar programs. Cold is an ever present factor, and warm, windproof staging areas not only greatly enhance comfort and promote effectiveness but if they are mechanized (tracked vehicles, aircraft, or ships) they also provide valuable pre- and post-dive logistical support.

Once the dive team arrives, on-site medical personnel should be contacted and evacuation routes to hyperbaric facilities identified and tested. Arctic transportation and evacuation remain uncertain even in ideal situations and all contingencies are limited by weather and ice conditions. Distances to definitive medical facilities are very large and transportation time can easily exceed twelve hours. As with any remote operation, prevention is the key.

During dives, topside tenders are especially susceptible to cold, but waterproof, insulated mitts and boots make the job far more comfortable. Frostbite on the face is common and sun glasses should be worn if tenders spend long periods in direct, bright sunlight. Post-dive strategies for divers generally involve donning additional outer garments over the dry suit unless undergarments are uncomfortably wet. Moderate exercise promotes rewarming as does the comfort of a heated shelter. Fire risk and carbon monoxide poisoning should always be considered whenever a heater is used.

In general, the more surface support available, the better. This applies to both open water free swim and sub-ice operations. In open water operations, surface tenders can help stage and recover divers and provide lookout and recall capabilities. A communication method is especially necessary where divers could be injured by drifting ice or marine mammal encounters.

In sub-ice operations, surface tenders form a critical part of the dive team and are responsible for the overall safety of the dive. In addition to actual dive support, tenders are a welcome addition during dive hole production, a task that can be accomplished by melting, augering, or blasting. Under extreme conditions regulator freeze-up remains a problem that can be minimized by keeping regulators warm prior to diving. If the diver does not breathe through the regulator until submerged and then does so in a slow, even manner, free-flow situations can be controlled.

During ice diving operations all divers are connected to the surface by a line. Although divers can have their own rope and tender, a very effective way to deploy scientific teams is to have a safety diver attached to the surface and the work diver attached to the safety diver by about 4 m of rope. This arrangement allows the data collector unrestricted access to the task and allows effective tether control between in-water personnel and the surface. Light weight webbing harnesses secured to nylon ropes with two antipodal, non-locking carabiners provide a positive, easily disconnected surface-to-diver attachment. Hard wire, light weight masks or light weight helmets greatly increase communication capability and also enhance data documentation and storage.

In a more specialized application, a modified push-pull helmet system was used during a sub-ice algae respiration study. Bottled high pressured air was passed through a regulator panel and then carried to and from the diver via pressurized air hoses. Air was supplied on demand and was exhausted back to the surface, thereby eliminating in-water exhaust bubbles. All in-water regulator components were contained within the helmet and freeze-up problems were therefore eliminated. However, the return hose was susceptible to ice blockage and this hose required extra venting before and after use to prevent ice plugs from forming. The bulky nature of the system also required considerable logistical support.

Large ice augers were most commonly used to gain access through single-year ice. Multi-year ice, however, often prevented access and in these situations, adjacent single year ice holes were used as entry sites. Separate holes were also used for lead diving with the stable access point providing insurance against diver entrapment in case of ice closure. Flow edge sites rank as the most exciting dive locations in the Arctic but strong currents and unstable ice conditions greatly increase the risk of entrapment. It is strongly advised that tethers be used under such conditions.

Even in "open water" situations, moving ice is an ever-present factor and surface support and recall capabilities form a critical part of any free swim summer operation. Tides and surf also constrain diver capabilities, especially with the bulky dry suits necessary for cold water protection. Collection bags and sampling gear further complicate diver resistance and swimming capabilities.

In addition to environmental problems, biological hazards must also be considered. The polar bear remains a serious threat to any Arctic operation for tenders and divers alike. However, a trained bear dog greatly improves top-side surveillance capabilities (Figure 2). Walrus, especially at the deep water flow edge sites, represents a very dangerous adversary. In deep water locations walrus feed on seals! If this diver was given the choice of meeting a bear on land or a walrus in the water, he would choose the former! Inuit hunters should also be kept advised on diving locations. Although no accidental shootings have been reported, free swimming divers look alarmingly like seals! It is recommended that at least one hunter be hired as top-side support. It has been our experience that after some "down south" training, Inuit hunters make excellent divers.

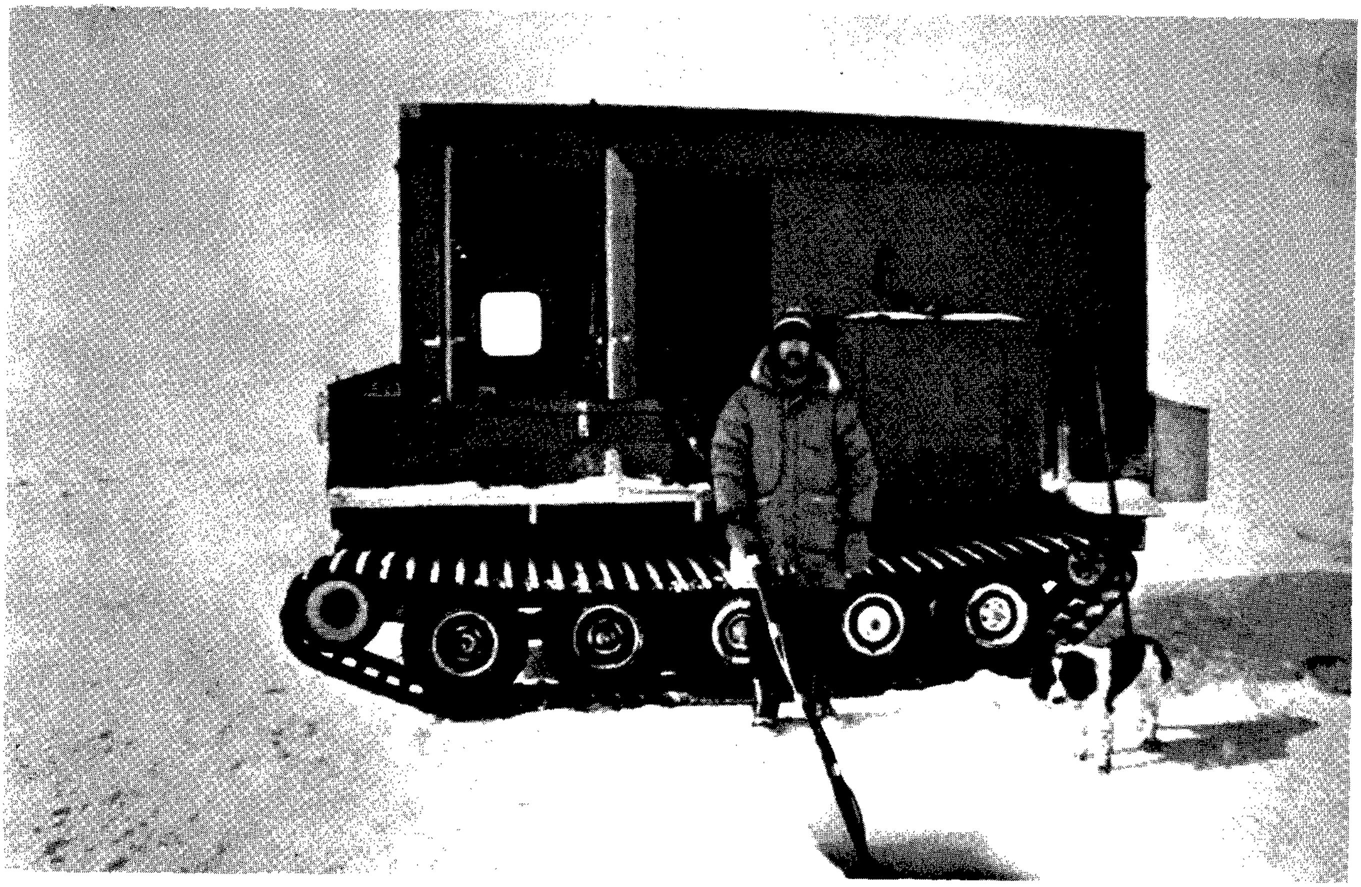

Figure 2. Cold is an ever-present factor, both above the surface and below. A trained dog greatly improves top-side "bear watch" capabilities.

SUMMARY

Table 1 provides a summary of common on-site problems and solutions. I would like to thank the AAUS for the opportunity to participate in this symposium. I commend their efforts in promoting polar diving training programs.

Table 1. Common On-site Problems and Solutions.

Problems	Operational Strategies
Operationally Remote	Simple, well-planned projects with established emergency evacuation contingencies.
Cold	Pre- and post-dive travel plans, heated windproof shelters, dry hands, feet and head, well-serviced equipment.
Moving Ice	U.W. communication or recall capability.
Surf and Tides	Physically fit divers, reduced umbilicals and surface support with recovery capability.
Manual Dexterity	Dry hands and five finger gloves.
Hostile Marine Mammals (walrus, bear)	Surface support with recall capability.
Repetitive Diving	Well serviced gauges, top-side control and on-site oxygen.
Data Collection and Transfer	Diver to diver and diver to surface communication with recording capability.
Accidental Shootings	Advise local villages of diving activities.

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