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NAVY DIVING: WHO'S DOING IT AND UNDER WHAT CONDITIONS

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Naval Medical Research Institute
Bethesda, Maryland

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The key word in Navy program management today is responsiveness. Is your program responsive to the needs of the fleet? This question holds true for training and personnel management programs, as well as research. Before one can determine whether a Navy program is responsive, it is necessary to know what the needs of the fleet are. For example, in the case of diving, what are the present and projected requirements for fleet operations? Establishing future requirements involves the subjective assessment of future fleet needs, but evaluating present requirements can

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be done by looking at the operations taking place now. This statistical survey is a first attempt to assess the adequacy of the data available and to provide a rough statistical description of the environment, personnel, and procedures presently existing in current Navy diving operations. The survey is a joint effort between the Navy Safety Center and the Naval Medical Research Institute. The fleet diving log data for the 24-month period from January 1972 through December 1973 has been analyzed for this study. During this period 127,103 dives and 83 accidents (.0653%) were recorded. The results of this analysis have possible widespread application in policy decisions about diver personnel management, diver training, and future diving research.

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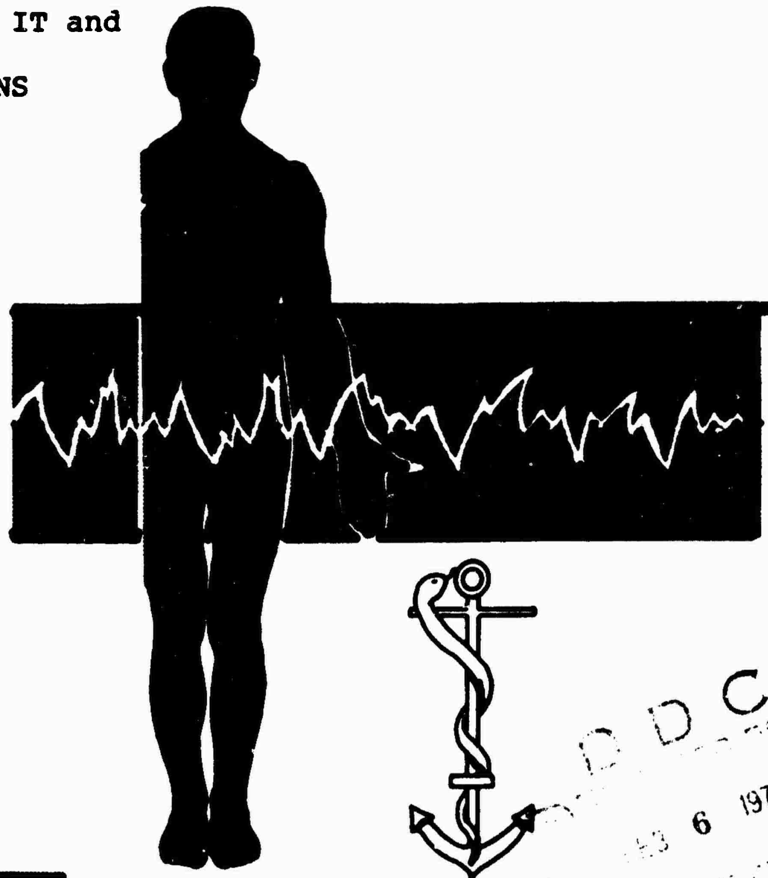

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NAVY DIVING: WHO'S DOING IT and UNDER WHAT CONDITIONS

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NAVY DIVING: WHO'S DOING IT AND UNDER WHAT CONDITIONS. T.E. Berghage, P.A. Rohrbaugh, A.J. Bachrach, and F.W. Armstrong. Behavioral Sciences Dept., Naval Medical Research Institute, Bethesda, Maryland 20014, USA.

The key word in Navy program management today is responsiveness. Is your program responsive to the needs of the fleet? This question holds true for training and personnel management programs, as well as research. Before one can determine whether a Navy program is responsive, it is necessary to know what the needs of the fleet are. For example, in the case of diving, what are the present and projected requirements for fleet operations? Establishing future requirements involves the subjective assessment of future fleet needs, but evaluating present requirements can be done by looking at the operations taking place now. This statistical survey is a first attempt to assess the adequacy of the data available and to provide a rough statistical description of the environment, personnel, and procedures presently existing in current Navy diving operations. The survey is a joint effort between the Navy Safety Center and the Naval Medical Research Institute. The fleet diving log data for the 24-month period from January 1972 through December 1973 has been analyzed for this study. During this period 127,103 dives and 83 accidents (.0653%) were recorded. The results of this analysis have possible widespread application in policy decisions about diver personnel management, diver training, and future diving research.

Navy diving
diving logs
diving statistics

INTRODUCTION

BACKGROUND

The U.S. Navy diving community is a multifaceted organization involving diving operations, training, and research. A common thread running through all of these is the need for relevant fleet information. Decisions are constantly being made regarding what type of equipment needs to be developed, what type of basic research needs to be initiated, what type of training needs to be instituted, and what diver manpower requirements need to be met for present and future Navy operations. To make intelligent decisions on these crucial questions it is essential that the responsible persons have at their disposal as much relevant information as possible. Certainly one of the most relevant pieces of information is what type of diving the fleet is doing. Historically, this information has been obtained in a rather nonsystematic way by rotation of personnel, investigation of accidents, and word of mouth.

Information on what type of people are using what kind of equipment in what kind of environments seems to be basic to all of the above decisions. For example:

- If most of the Navy's dives are made in shallow water with no visibility, then perhaps the requirements for a large number of deep diving personnel with perfect color vision should be re-evaluated.
- If most of the operational diving is being done by second class divers in cold water using scuba equipment, then perhaps the emphasis placed on these factors in diver training should be evaluated. It is possible that divers are being overtrained in some areas and undertrained in others.
- If the greatest fleet requirement is for scuba divers and the fleet diver billets are set up for second class divers, then perhaps the Navy should re-evaluate its diver billet structure.

- If fleet divers are experiencing an unusually high incidence of decompression sickness for a given set of dive conditions, then perhaps a research effort should be initiated to explain why.

All of these questions require that information about fleet diving be intelligently evaluated. The data base for formulating this information is available at the Navy Safety Center. Presently these computerized data are used to tabulate and analyze Navy diving accident statistics. If accident statistics are the only information resulting from this huge data-gathering activity, then the effort is probably not worthwhile. If, however, these data are made available and utilized by Navy decision makers in formulating future diving policy, then the fleet diver's task of recording each dive is not in vain.

OBJECTIVES

This report presents descriptive statistics on operational Navy diving. It is intended for those individuals who are making the decisions concerning the Navy diving program. It is hoped that this compilation will provide specifics on which to base such decisions, but more importantly, it is intended to stimulate interest among the policy makers to require that more complete information be available for future decisions. In addition, it is hoped that the commercial underwater community may benefit from this information and respond with information from their own operational diving.

DATA RECORDING SYSTEM

Information about each U.S. Navy dive is supposed to be recorded on an OPNAV Form 9940/1 (Figs. 1a and b). These diving log forms are then forwarded to the U.S. Navy Safety Center in Norfolk, Virginia. Upon arriving at the Safety Center the forms are visually checked by the personnel in the Diving Safety Division. From there the information is

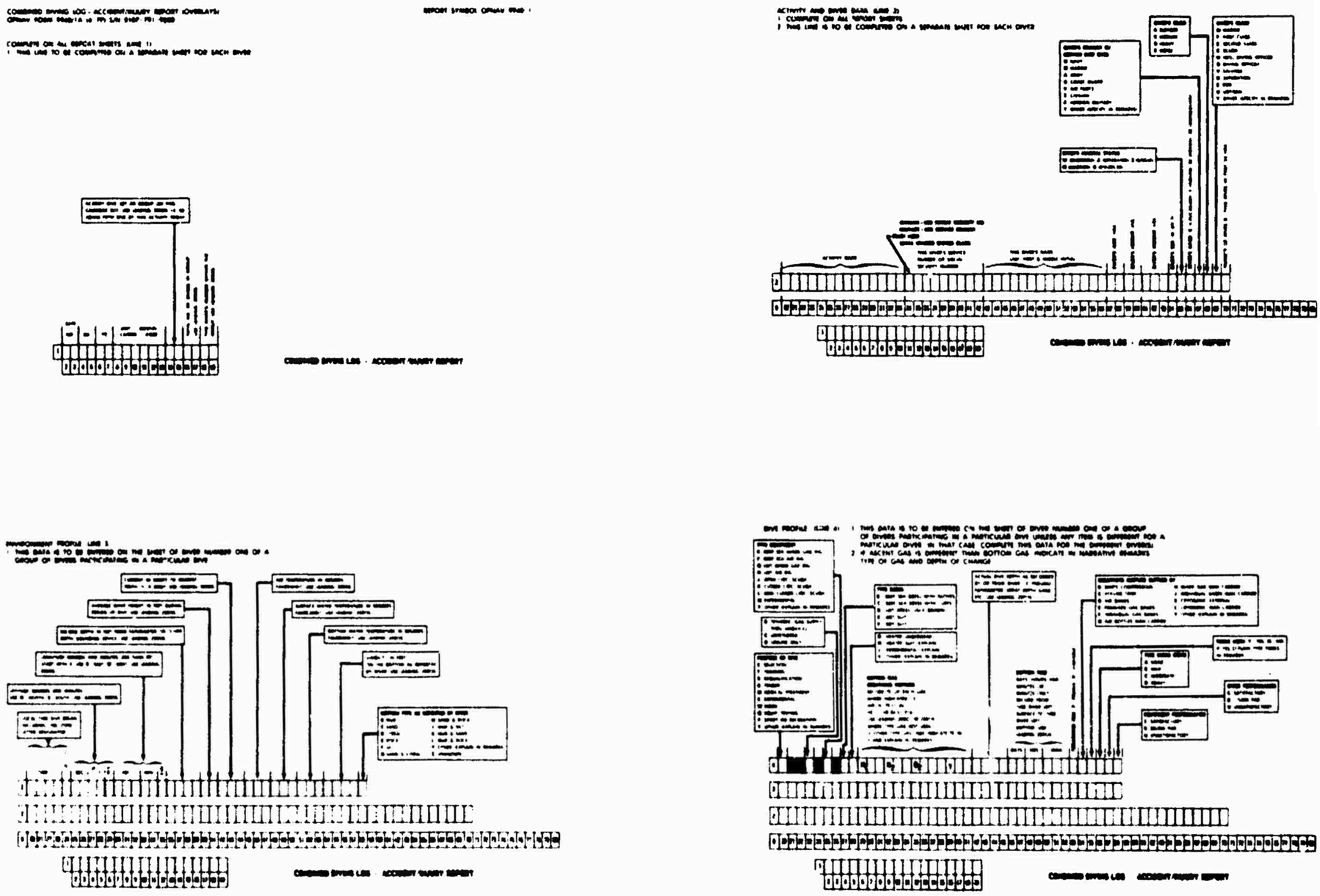
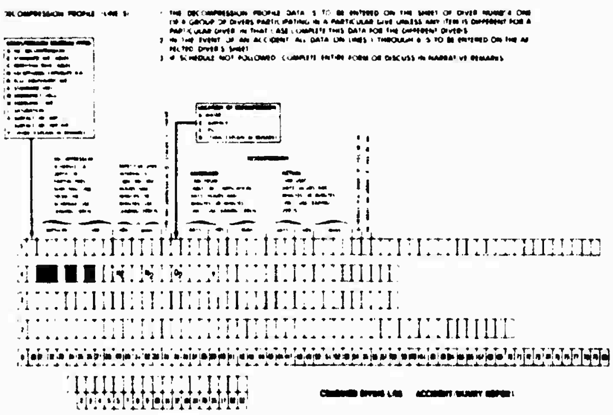
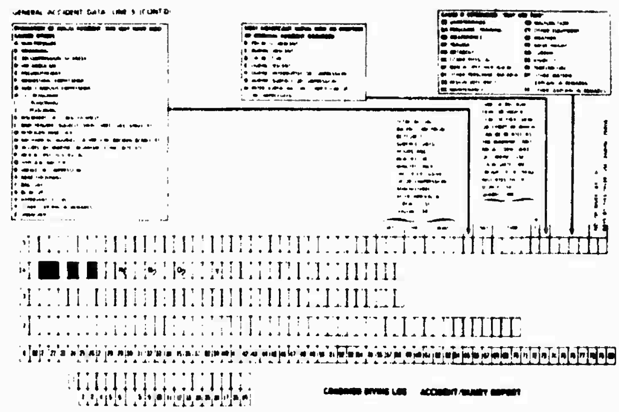
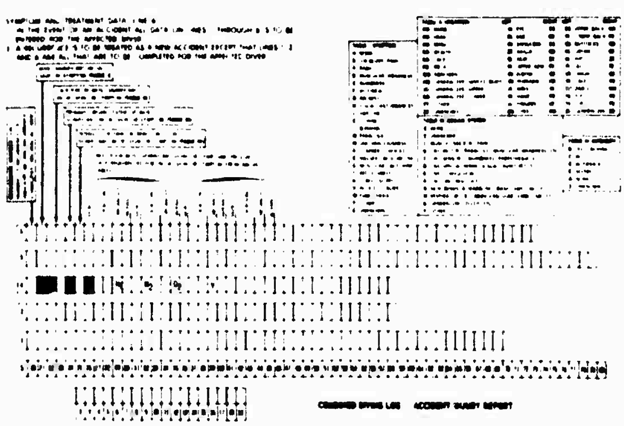


Fig. 1. OPNAV Form 9940/1, Combined Diving Log-Accident Injury Report







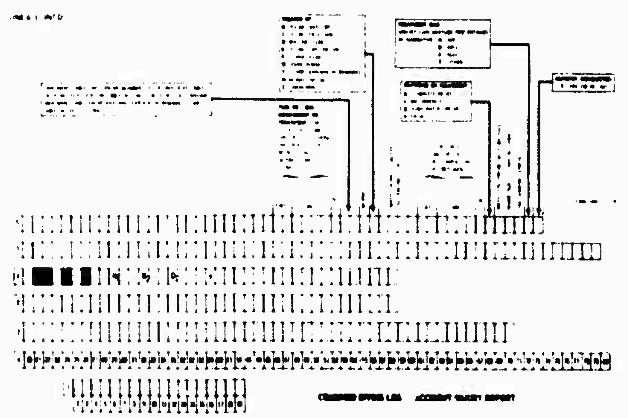


Fig. 1. OPNAV Form 9940/1, Combined Diving Log-Accident Injury Report (Cont'd)

key-punched and entered into the computer storage banks. Approximately 60 to 70 thousand divers are entered into the system each year by this procedure.

SOURCES OF ERROR IN DIVING LOG DATA

How accurately the diving log figures represent the activities of the fleet is open to question. It would be naive to think that every fleet dive made is recorded in the data bank. Navy divers often go into the water for one reason or another and do not record it. What portion of the dives are recorded is unknown.

In addition to dives not being recorded, there are a number of dives recorded that are not actually made. Some individuals are suspicious of data banks and their possible use to keep track of diver qualifications. Therefore, there are requalification dives erroneously entered into the system. To the authors' knowledge this is an unsubstantiated fear among the divers in that the Navy Safety Center data bank has never been used as an investigative, regulatory, or enforcement tool. How many of these factitious requalification dives are entered in the system is unknown, but in looking at the total dive figures (Fig. 2) this does not appear to be a major problem.

A third source of concern with the diving log data is the number of errors that are made in recording actual dives. With the institution of Form 9940/1 in 1970 there were a number of data recording problems and a substantial increase in the number of recording errors. Now that the form has been in use for almost 6 years the number of obvious erroneous entries has decreased. The present overall error rate appears to be running at less than 2%. For the purposes of this study only data from dives made and recorded between January 1972 through December 1973 were

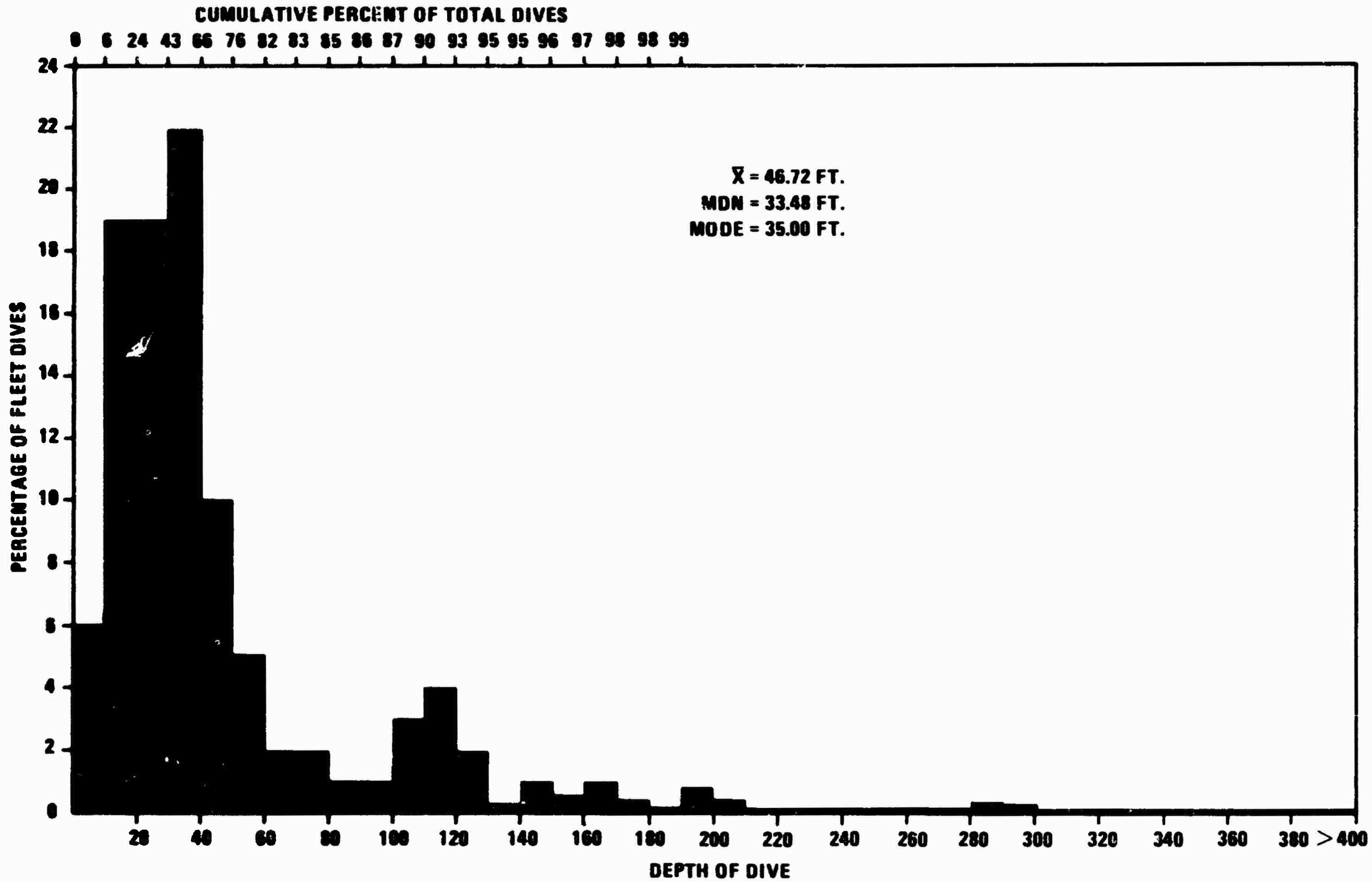


Fig. 2. Distribution of Navy dives by depth.

used. By not using the data obtained during the first 2 years the authors have avoided the major portion of the errors resulting from erroneous data recording.

DATA DESCRIPTION

Data on 127,103 recorded Navy dives were obtained from the U.S. Navy Safety Center for this study. Information from each dive record was abstracted on 26 different variables arbitrarily divided into three groups: procedural, environmental, and personnel. The groups and variables assigned to each are shown in Table 1.

The information gathered was tabulated and analyzed in two ways: first, all of the dives were grouped together and statistics calculated to describe Navy diving in general; second, the dives were grouped into 12 dive categories to allow selective evaluation of the variables for various types of Navy diving. The dive categories used are a modification of those originally suggested by Doll and Berghage (1967). The categories, their definitions, and their abbreviations are given in Table 2.

NAVY DIVING IN PERSPECTIVE

To understand and appreciate the full scope of Navy diving, it is essential that we first obtain general descriptive statistics on all recorded fleet dives. This section is focused on an overall view of the Navy diving environment, the personnel involved, and the equipment and procedures used.

NAVY DIVING ENVIRONMENT

Dive Depth

Perhaps one of the most interesting and talked about dive parameters is the maximum depth obtained during a dive. Commercial companies often build their advertising and reputation around the depth to which they are

TABLE 1

Data obtained and analyzed for each recorded Navy dive

Variables		
Procedural	Environmental	Personnel
Type of equipment used	Dive depth	Height
Type of diving dress used	Bottom time	Weight
Equipment performance	Breathing media	Weight-height ratio
Purpose of dive	Air temperature	Body build
Tools used	Wave height	Age
Decompression schedule used	Surface water temperature	Marital status
Decompression location	Bottom water temperature	Type of work
Class diver	Current	Did an accident occur?
	Bottom type	
	Visibility	

TABLE 2

Categories used in the analysis of Navy fleet dives

	Abbreviation	Description	Definition	
			Depth (fsw)	Bottom time (min)
Standard dive categories	SS	Shallow short	<100	<30
	SM	Shallow medium	<100	30-60
	SL	Shallow long	<100	>60
	MS	Medium short	100-200	<30
	MM	Medium medium	100-200	30-60
	ML	Medium long	100-200	>60
	DS	Deep short	201-300	<30
	DM	Deep medium	201-300	30-60
	DL	Deep long	201-300	>60
Special dive categories	Sub. Sat.	Subsaturation	>300	720
	S. Sat.	Shallow saturation	≤300	≥720
	D. Sat.	Deep saturation	>300	≥720

capable of diving. Sport divers like to boast about the deepest depth to which they have been able to dive. Navy diving projects that receive the most recognition and publicity are those that extend the Navy's deep diving capability. Stories about record deep dives and new deep diving hardware capture the headlines and occupy our thoughts. Such projects attract the attention of the general public and lure individuals into the diving field.

When one looks at the dive depth statistics, however, a different picture of the diving field emerges. Figure 2 shows that 82% of the recorded fleet dives are made to depths of 60 fsw or less. From these statistics it would appear that the majority of Navy operational dives are in shallow depths. There are two possible reasons for this: either the Navy lacks the capability to take on jobs in deeper water, or the jobs requiring fleet divers are generally located in shallow water. It seems fairly obvious from the Navy's deep diving record that it has the equipment, personnel, and procedures to perform deep dives if necessary. One has to conclude then that the Navy's present deep diving program is in support of an operational capability rather than a current fleet requirement.

One asks, If the average depth of the Navy's diving is only 47 fsw, why are so many of the fleet divers trained for deep mixed gas diving? Why is the Navy spending several hundred thousand dollars to build deep dive systems? And, Why is a major portion of diving research money channeled into deep diving research? The answer to these questions appears to be two-fold. First, occasionally there are critical operational situations that require the ability to dive to deep depths. Although these occurrences are rare they are usually of an immediate (or classified) nature and there isn't time to contract for commercial services. It appears that Navy stategists have concluded that the defense posture of this country requires a deep underwater operational capability. The second reason why the Navy has an interest in deep diving is that the government desires to maintain a technological advantage in the undersea area. The commercial use of deep diving in the world is built upon the research foundation established by the U.S. Navy. Continuation of this competitive edge held by the United States is dependent upon the Navy's deep diving research program.

Acceptance of the above rationale for the Navy's continued efforts in deep diving does not alter the fact the 99% of the fleet dives are done at depths less than 200 fsw. Acknowledgment of this fact should lead to some changes in emphasis in the diving Navy of the future.

Bottom Time

The average (median) amount of time spent on the bottom during operational fleet dives is 37 min. The distribution of bottom times shown in Fig. 3 is very positively skewed, indicating that the bulk of Navy dives are less than 90 min. The short bottom times on Navy dives indicate that most of the fleet diving jobs involve short-duration tasks. It appears the amount of major underwater welding and construction being done is limited; further, fleet utilization of the saturation diving techniques seems to be very restricted. Yet despite these relatively short bottom times and the restricted utilization of saturation techniques, Navy divers spent during the 2 years of this survey over 97,242 man-hours under increased hydrostatic pressure!

The justification for saturation diving is essentially the same as that for deep diving: deep diving and saturation diving go hand-in-hand; in any deep dive the divers will by necessity reach a saturated condition during the decompression. And, as with deep diving technology, the saturation diving research and technology that presently allows commercial

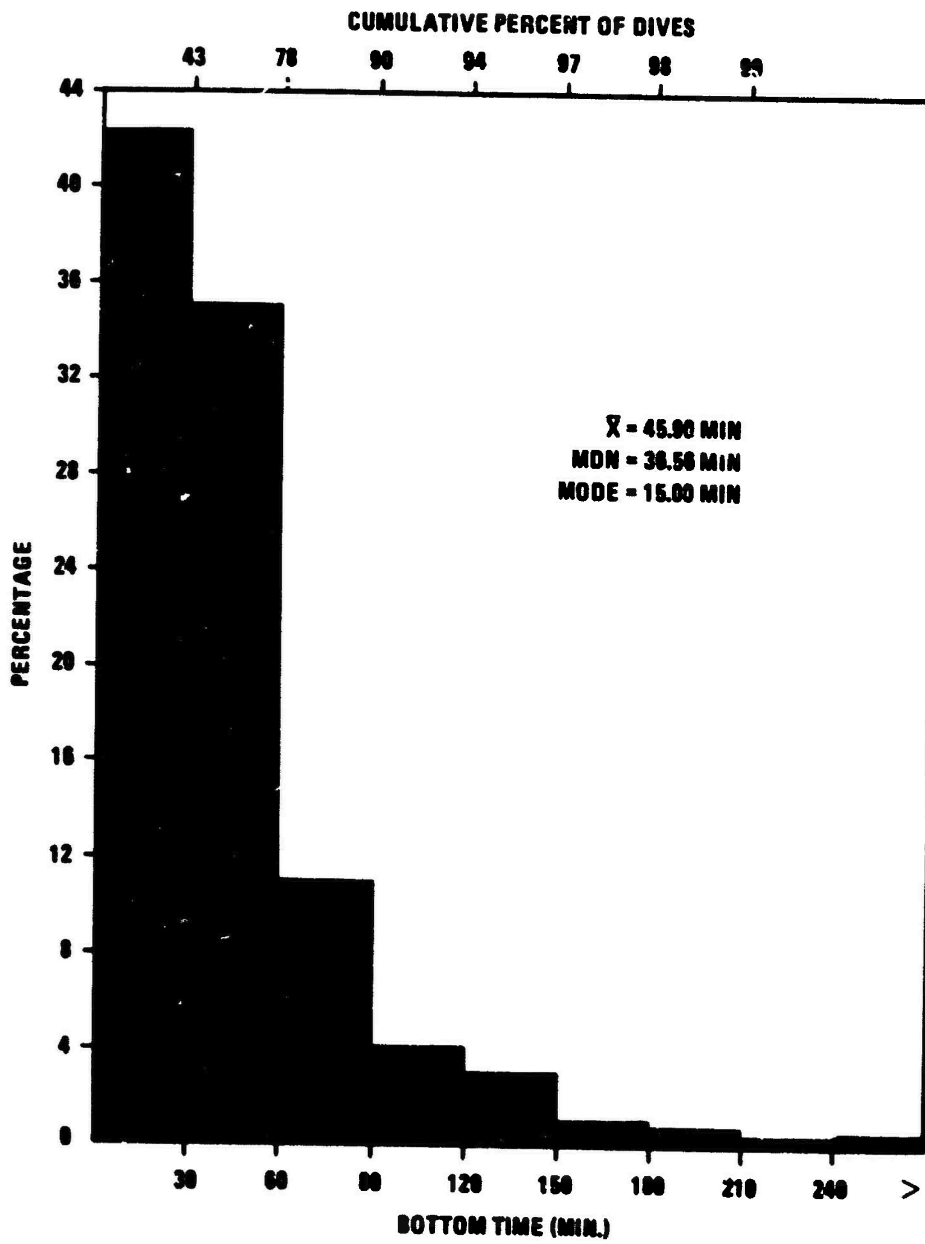


Fig. 3. Distribution of Navy dives by bottom time.

diving firms to work at deep depths for weeks at a time was developed by the U.S. Navy and is presently part of its operational capability.

Breathing Gases Used

As would be expected due to the shallow diving depths of the fleet (Fig. 2), the primary breathing gas is compressed air (Fig. 4). Compressed air has been used on 114,926 (about 89%) of the dives made in the last 2 years.

Surface Air Temperature

Certainly the U.S. Navy must be prepared to dive in almost any part of the world regardless of the surface temperature. Air temperature is a critical variable in diving in that its effect on the performance of the surface support personnel is often of critical importance. Surface temperature is also important in that it affects the diver and his equipment prior to and following the immersion phase of his dive. For example, breathing gas regulators have been known to malfunction due to extreme cold, and some decompression computers have been shown to be temperature dependent.

Figure 5 shows the distribution of surface temperatures recorded during fleet dives. The average air temperature is 71.5°F (21.9°C). Only 8% of the dives made were from surface environments where the air temperature was lower than 50°F (10°C). Certainly diving in cold weather is no fun and it is easy to understand why not too many dives are made under these conditions. It is difficult to believe, however, that the need for fleet divers ceases to exist when the temperature falls to below 50°F. Perhaps if equipment and training were designed for the cold, adverse environment, more diving would be done. For the majority of the fleet diving, however, it appears that surface temperature conditions are quite favorable. It is reasonable to assume that the values presented here are

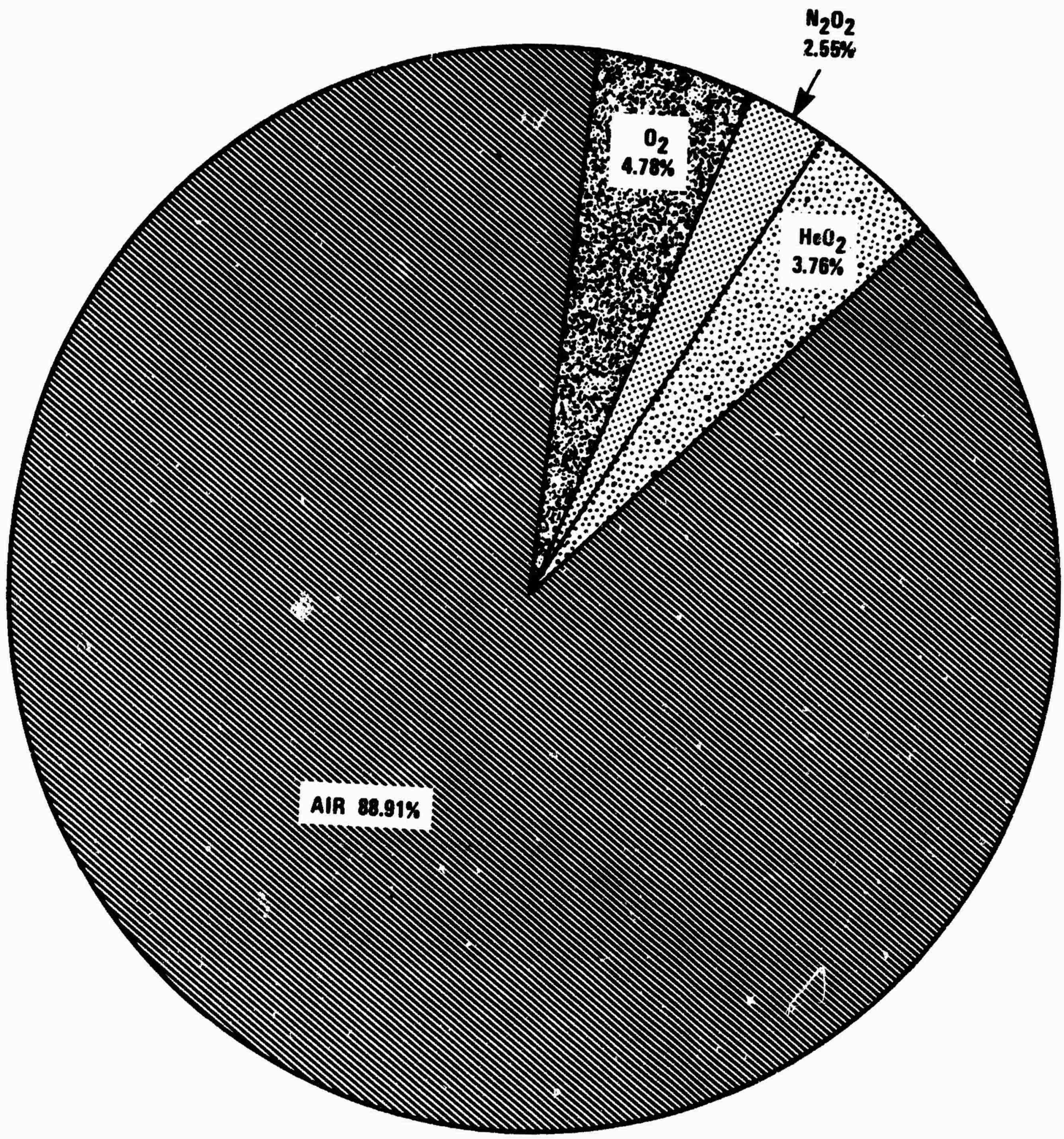


Fig. 4. Breathing mixtures used on U.S. Navy dives.

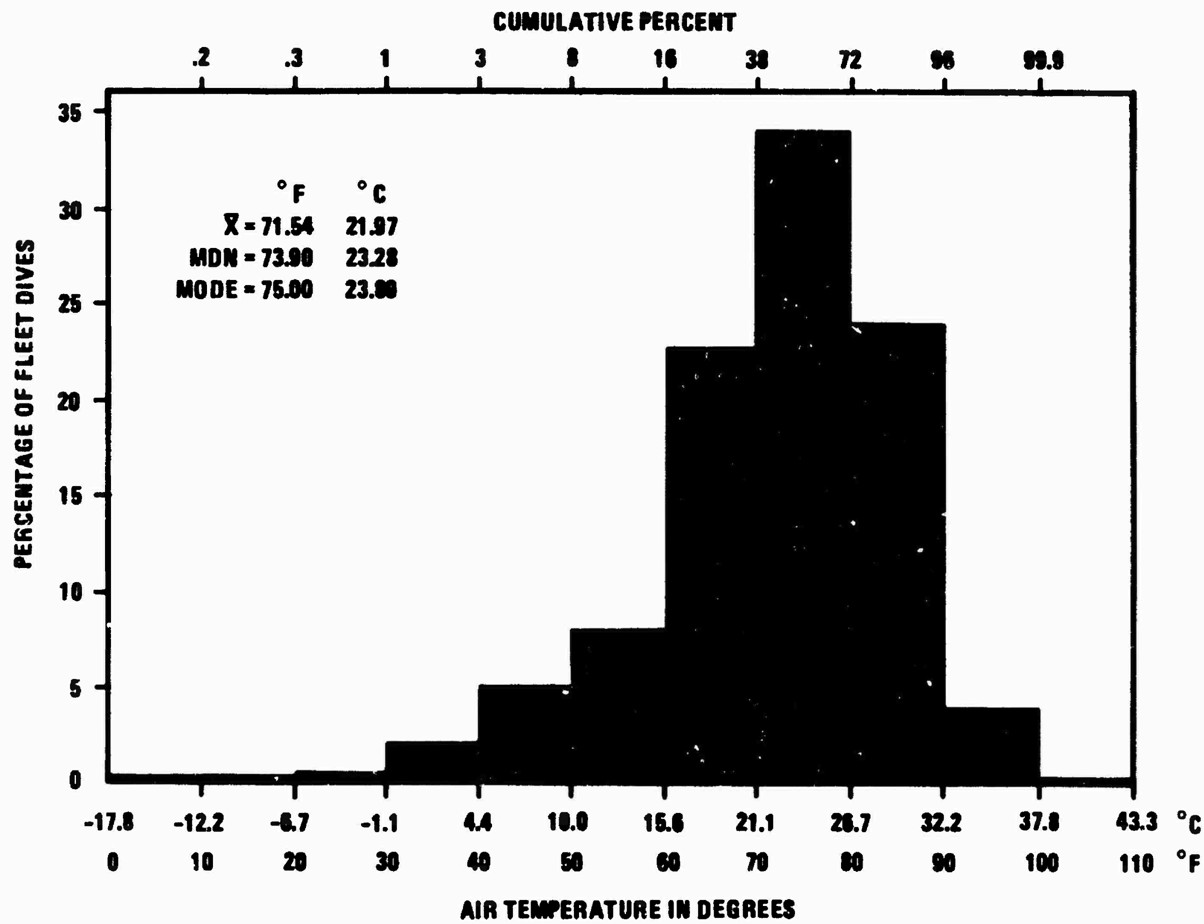


Fig. 5. Distribution of air temperatures during Navy dives.

fairly accurate in that measures of surface temperature are usually quite readily available. However, the same statement cannot be made in regard to water temperature.

Surface and Bottom Water Temperature

It would be naive to think that two measures of water temperature, one at the surface and one on the bottom, are obtained during each fleet dive. When this information is filled in on a diving log sheet, it is probably a diver estimate. How accurate these estimates are is open to question. The investigators were unable to find anything in the research literature on how well humans can estimate temperature either in air or in the water. The problems associated with temperature estimation in the water are compounded by increased pressure and immersion. Both of these factors tend to increase heat conduction away from the body and distort the perception of environmental temperature.

Figures 6 and 7 present the water temperatures that were recorded on the fleet diving log sheets. This data should be viewed with some skepticism in view of the above comments. It is presented here because it is the only information we have on the topic. The difference between surface air temperature and surface water temperature is about 5°F. Although the difference is in the right direction, the magnitude does not appear great enough. The same observation can be made for the 3°F difference between the surface and bottom water temperatures.

Wave Height

Figure 8 shows a tabulation of the sea states in which fleet dives were made. The wave height data indicates that most fleet diving is done in relatively calm water. Here, as for most of the other variables, one cannot be sure the environment is not controlling the diving. It may be

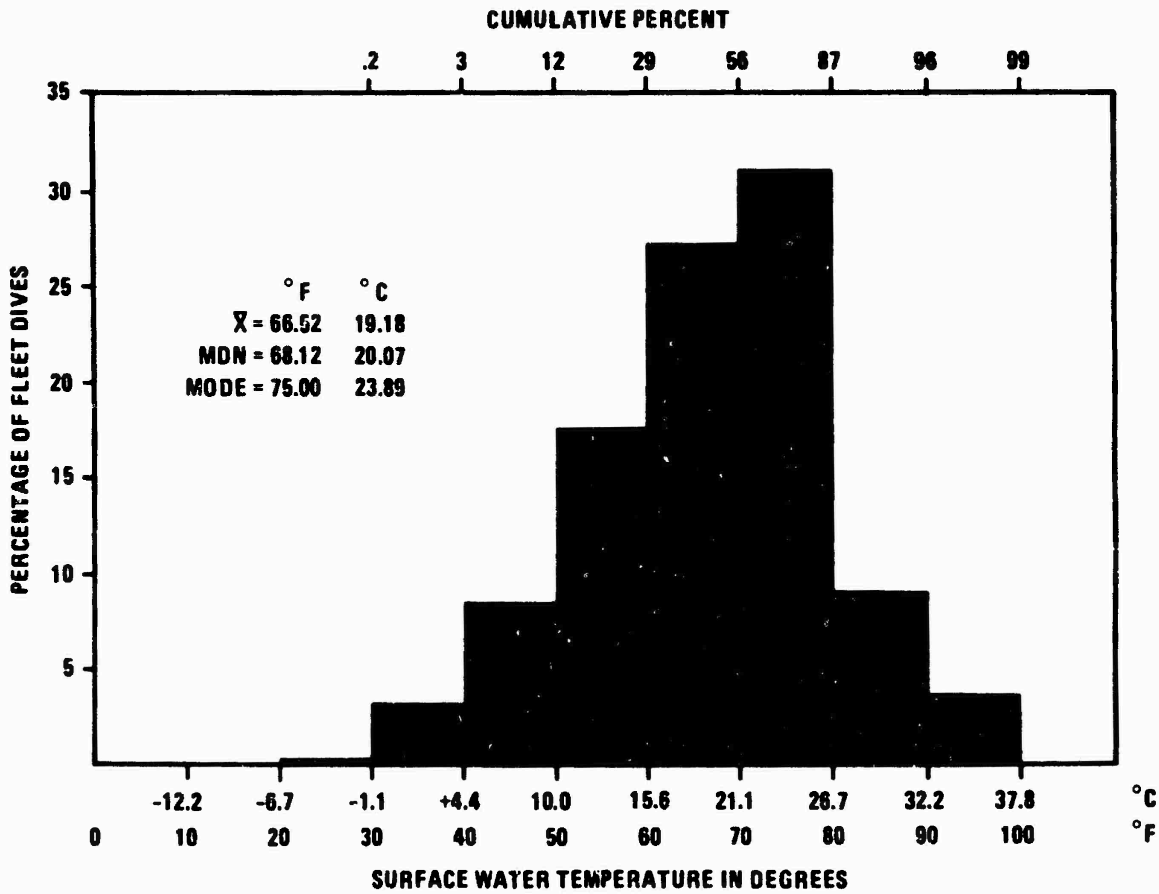


Fig. 6. Water temperatures recorded on fleet dive log sheets.

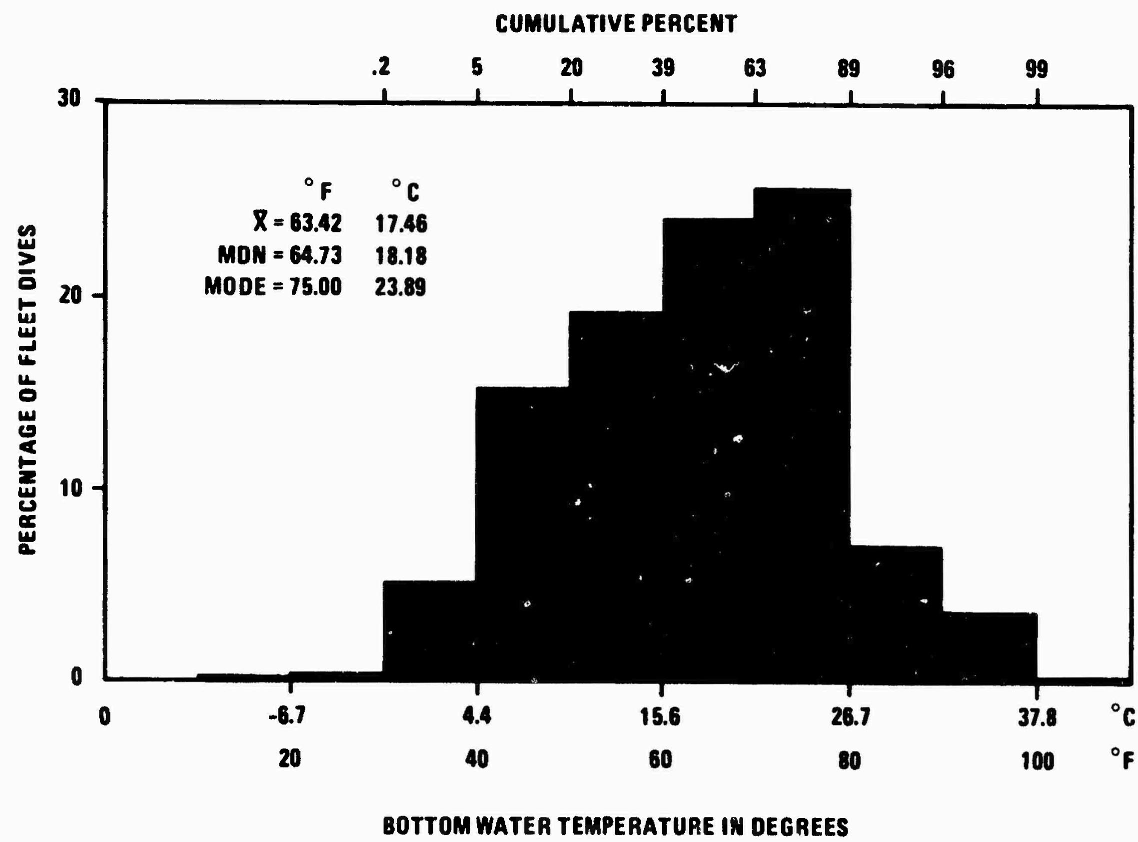


Fig. 7. Water temperatuies recorded on fleet dive log sheets.

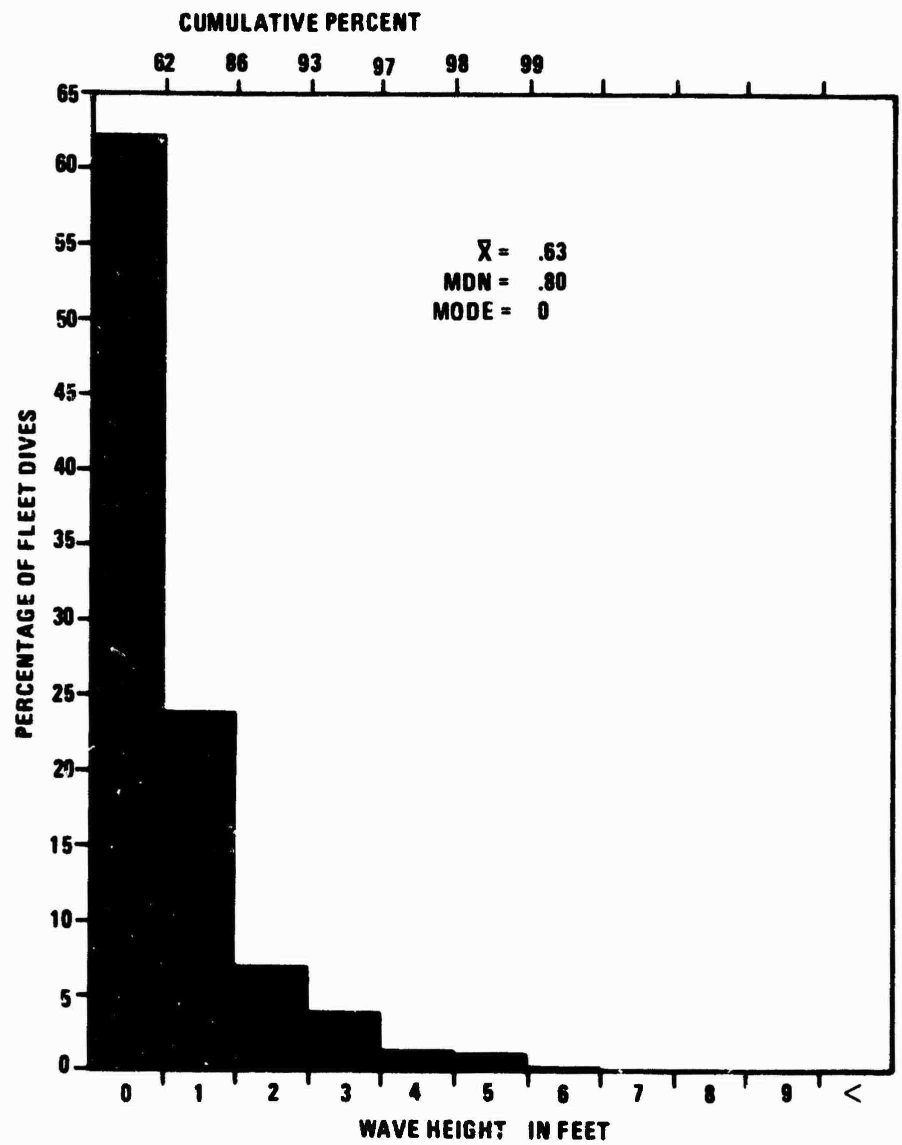


Fig. 8. Sea state during Navy dives.

that if high sea states exist dives are not made. It has long been recognized that the conditions at the air-water interface govern the type and extent of diving done. Again, as with surface temperature, it is difficult to believe that diving requirements cease to exist once the environment becomes adverse. Certainly diving from a surface vessel is extremely hazardous during rough weather and improved techniques need to be developed. Because of the problems associated with the surface conditions, the lockout submarine has been developed and is presently used commercially. Submarines, however, are extremely expensive diving platforms and probably are not feasible for routine fleet diving.

Current

As shown in Fig. 9, 95% of the fleet dives are done in waters where the current is estimated to be less than 1 knot. It is a well-recognized fact that diving in a current stronger than 1 knot is extremely difficult and almost all of the diver's efforts are taken up with maintaining position and stability. For those situations which require work to be done in currents more turbulent than those shown in Fig. 9, some alternative systems are required. This problem, to the authors' knowledge, has not been adequately dealt with, and no research effort is presently directed toward it.

Sea Floor Conditions and Visibility

Over half of the dives made in the U.S. Navy are done with mud and silt sea floor conditions (Fig. 10). Only about 32% are made under conditions that afford the diver good footing. Because such a large proportion of the diving environment involves mud and silt, divers usually are required to work with very limited visibility (Fig. 11). There is often zero visibility in the turbid waters of the bays and harbors, and the divers are required to work by touch and feel alone. This restricted

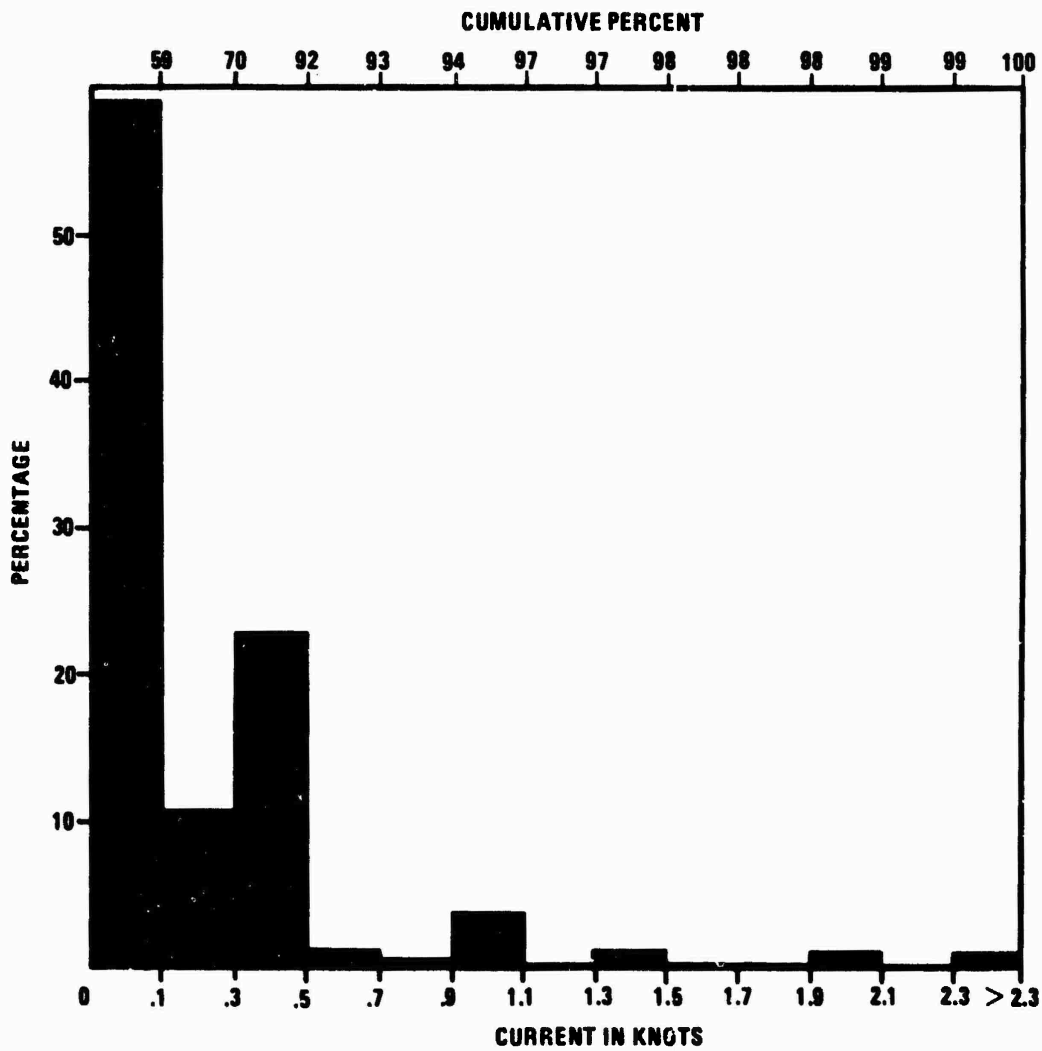


Fig. 9. Current intensity during Navy dives.

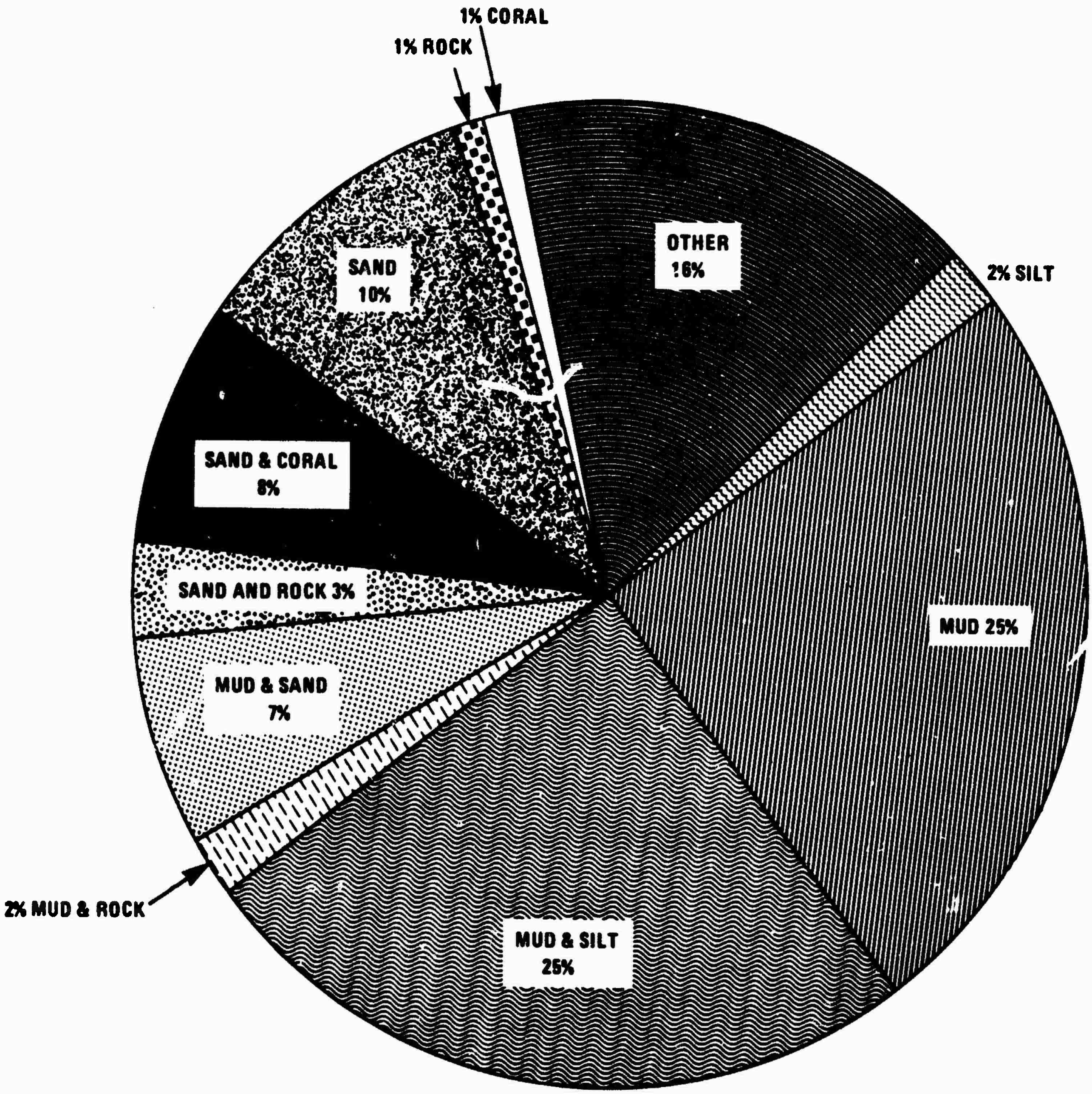


Fig. 10. Sea floor conditions during Navy dives.

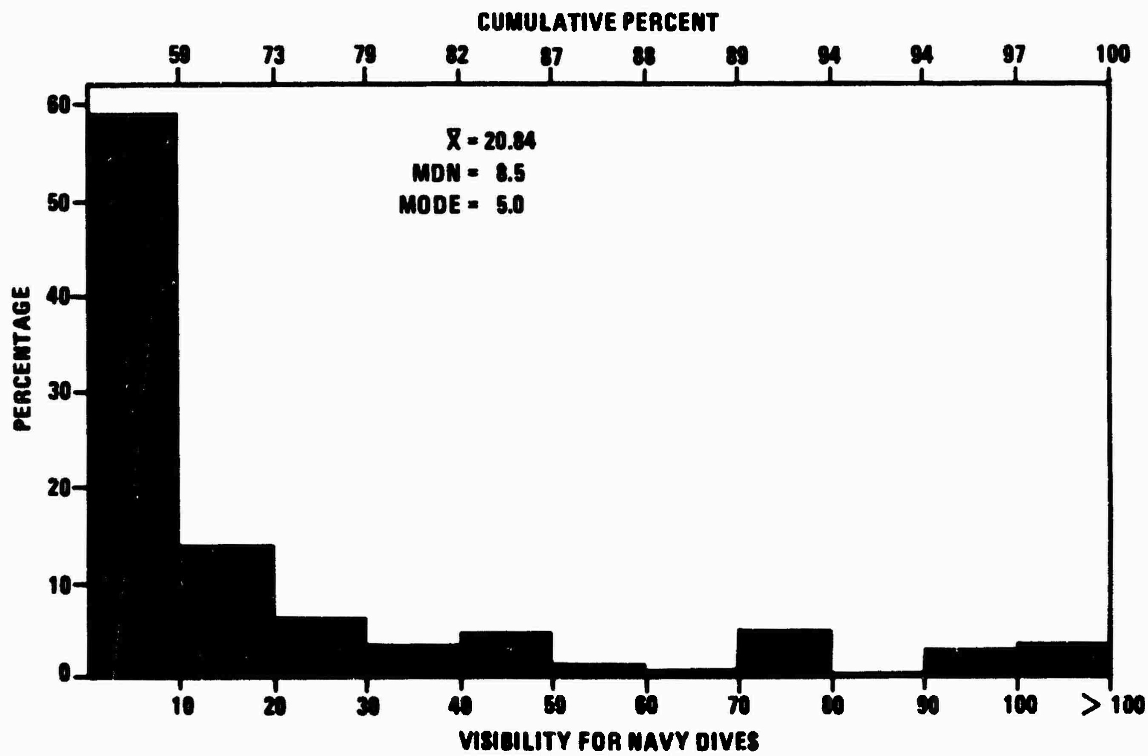


Fig. 11. Visibility on Navy dives.

visibility and the need to work by feel alone is one of the reasons submarines with manipulators and divers in one-atmosphere suits have not gained wider acceptance; both of these systems require that the operator be able to see his work project. Without this visual feedback the mechanical linked systems are inoperable. Presently only the diver has a tactile sense to use during dives with limited visibility.

NAVY DIVING PERSONNEL

Age

The average age of the fleet diver making operational dives is 27.6 years (Fig. 12). This is probably one of the most accurately recorded pieces of data on the diving log sheets, yet even it had about 1% obvious errors. The age data are important in that they provide a baseline for comparing other populations. Some of the diver subpopulations that have been studied are shown below.

Diver Subpopulation	Average Age
Diver First Class students*	25.4
Divers involved in diving-related accidents between 1956 and 1965+	28.0
Divers suffering from decompression sickness while still under pressure‡	31.1

*Bain and Berghage 1973.

+Berghage 1966.

‡Summitt and Berghage 1971.

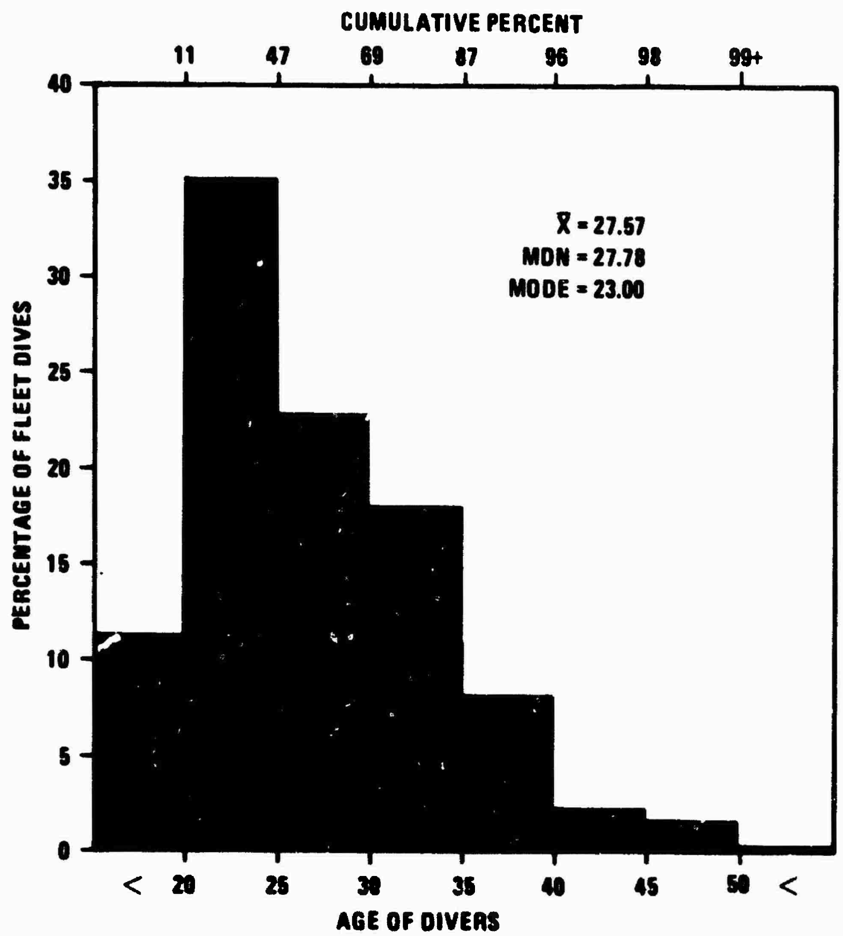


Fig. 12. Age of fleet divers.

Several of these studies have included statements that the significance of age as a factor could not be assessed because baseline data was not available for divers. This problem is now corrected. The data in Fig. 12 show the distribution of ages for those individuals making fleet dives. These data are different than the average age of fleet divers in that they are weighted by the number of dives made by each individual diver. If a 20-year old diver makes 40 dives, his age is entered into the average 40 times. All of the above diver subpopulations are statistically different from the fleet diver population making the operational dives. The student diver population is younger, as one would expect. The divers involved in accidents and suffering from decompression sickness while still under pressure are generally older. They may be older because older divers are selected for these advanced diving jobs, or it may be that older divers are more susceptible to decompression sickness. Now that age baseline data are available, controlled studies of these questions are possible. Such baseline data are also important in research experimental design. With the information given in Fig. 12 the researcher can decide when he has a representative sample of the fleet diving population for his study.

Height

As with the age data there have been many studies that have collected height data with no knowledge of the underlying population distribution. Figure 13 presents the best height information presently available for U.S. Navy divers making fleet dives. These data obtained by self-report are probably not as accurate as a complete anthropometric study of the population, but they do correlate very closely with the two diver anthropometric samples that have been taken. Beatty, Berghage, and Chandler (1971) found the average height of divers to be 71.16 inches. In a second more complete study Beatty and Berghage (1972) found the height to be 69.38 inches. The

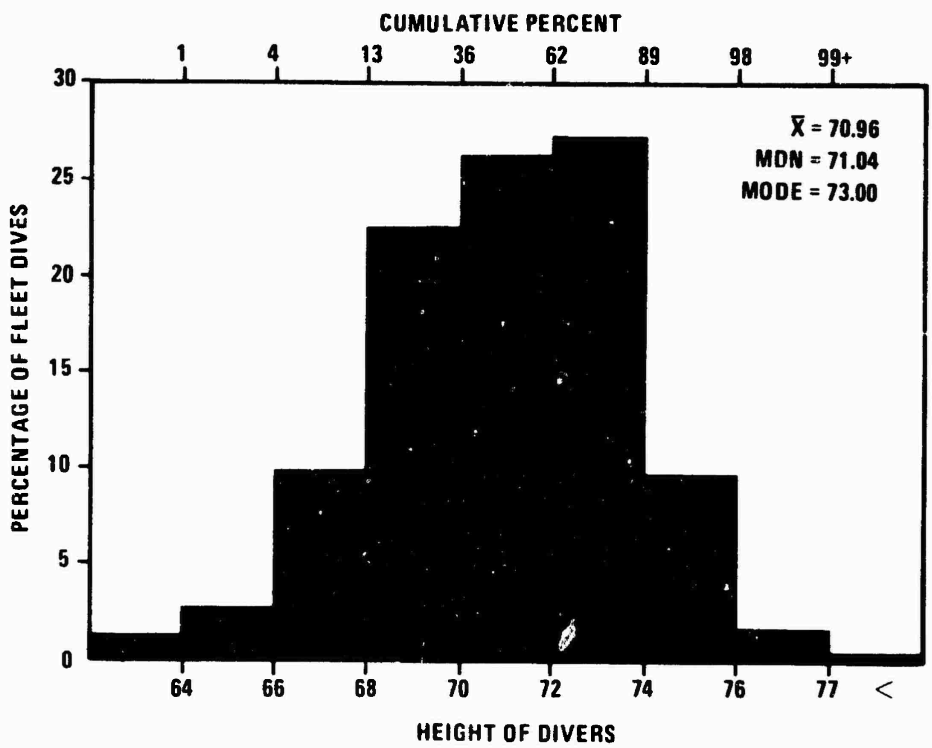


Fig. 13. Height distribution of fleet divers.

average height found in this survey is 70.96 inches. All of these heights are within one-half a standard deviation of each other. Some additional studies that have reported diver height are shown below.

Investigators	Study	Reported Height (in)
Berghage (1966)	Summary statistics of U.S. Navy diving accidents	70.0
Kelley, Berghage, and Summitt (1968)	Diving accidents in 1967	71.0
Summitt, Berghage, and Tammany (1970a)	Diving accidents in 1968	70.3
Summitt, Berghage, and Tammany (1970b)	Diving accidents in 1969	70.2
Summitt and Berghage (1971)	Cases of decompression sickness occurring under pressure	70.2

All of these figures are in keeping with the results of this survey.

Weight

The distribution of weight for divers making fleet dives is shown in Fig. 14. Because these data are based upon self-reports rather than actual measurements, they are subject to error. People are notorious for underestimating their weight and these estimates are probably no exception. The two studies on diver anthropometrics, for which actual measures of weight were obtained, provide weights that are significantly higher than

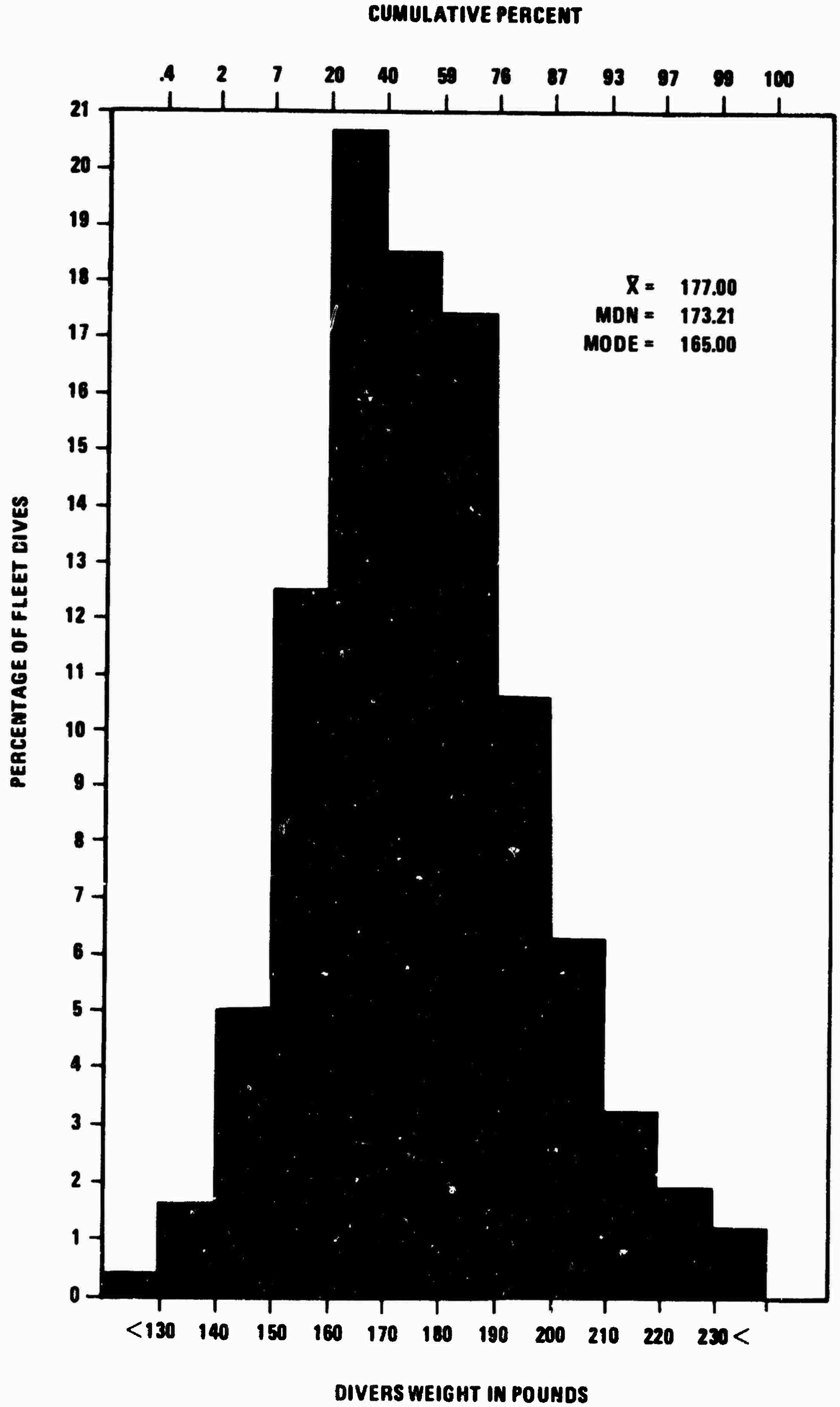


Fig. 14. Weight distribution of fleet divers.

the results obtained in this survey. The average estimated diver weight contained in the five reports on diving accidents is in support of the results of this survey. The studies that gathered actual measures should be used as the baselines for human engineering and biomedical studies. It is important to note, however, that when weight estimates are the only figures available to an investigator, they will normally be 7 to 9 pounds lighter than the actual weight values. The weights reported in the above referenced studies are as follows.

Study	Weight
Actual Weight Measures	
Beatty, Berghage, and Chandler (1971)	187.9
Beatty and Berghage (1972)	179.7
Average	183.8
Estimated Weight Measures	
Berghage (1966)	171.0
Kelley, Berghage, and Summitt (1968)	185.0
Summitt, Berghage, and Tammany (1970a)	177.0
Summitt, Berghage, and Tammany (1970b)	161.2
Summitt and Berghage (1971)	181.7
Average	175.2

Results of this survey gave an average weight of 177.0 pounds.

Weight-to-Height Ratio

Several studies have suggested that weight density is an important factor in the uptake and elimination of gas from the body. As such its influence in decompression sickness is something that should be considered. Three different studies have provided statistics on weight-to-height ratios for diving accident victims. All of these studies point up the fact that no baseline data are available against which a comparison can be made. Therefore, the importance of the weight density factor cannot be assessed. The results presented in Fig. 15, although slightly low owing to underestimated diver weight, are the best data presently available. The diving accident studies in which weight-to-height ratios are reported are listed below. The diver weights used in these studies are also estimates and are probably 7 to 9 pounds below the actual values.

Study	Years Covered	Average Ratio
Kelley, Berghage, and Summitt (1968)	1961-1966	2.47
Kelley, Berghage, and Summitt (1968)	1967	2.59
Summitt, Berghage, and Tammany (1970a)	1968	2.52
Summitt, Berghage, and Tammany (1970b)	1969	2.40

The mean weight-to-height ratio found in this study is 2.52. This value is not statistically different from the values reported for divers suffering from decompression sickness. Presently available evidence indicates that the weight-to-height ratio is not a very useful measure for predicting decompression sickness susceptibility.

Body Build

The body-build category on the diving log sheets provides very little in the way of useful information. Few people describe themselves as either slender or heavy, and almost no one is willing to describe himself as obese

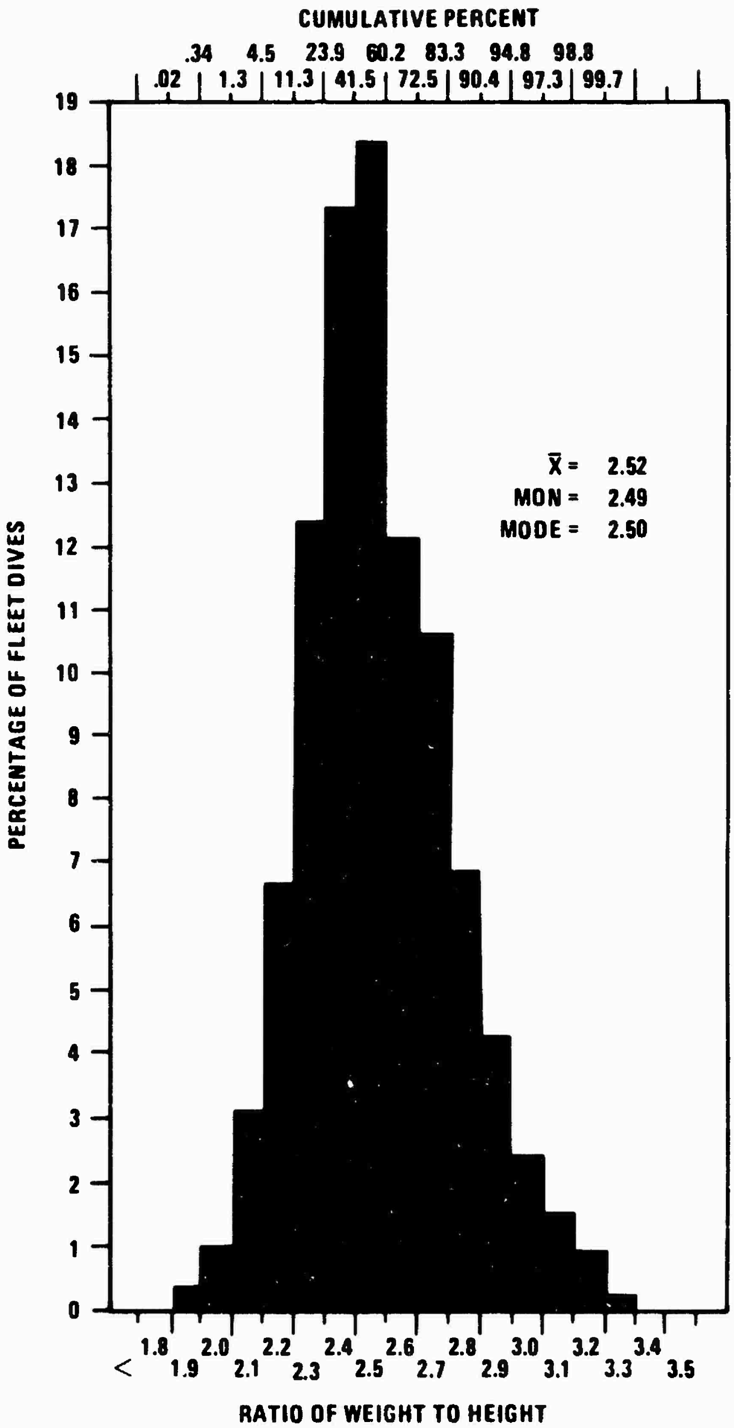


Fig. 15. Ratio of weight-to-height in fleet divers.

As shown in Fig. 16, 77% of the divers report that they are of a medium build. The study by Beatty and Berghage (1972) in which actual anthropometric measures were taken found that Navy divers have heavier bone structures, more subcutaneous fat, are heavier in weight, and shorter in stature than the general population. These factors seem to indicate that a relatively large proportion of the diver population should fall into the heavy body-build category. The inconsistency in the body-build data suggests that this item on the diving log sheets should be eliminated. If information on body build is needed for a given study, it can be attained from the height-and-weight data.

Type Work

The title of this category of information is misleading. A more appropriate title would be "Level of Work" or "Degree of Exertion" (Fig. 17). In filling out his log sheet the Navy diver is supposed to estimate the level of physical effort that was involved. The rationale for such an item is that the level of physical exertion has been linked in the research literature with most of the common diving ailments such as decompression sickness, oxygen toxicity, and compressed air narcosis. Studies that have tried to confirm this relationship with the data from the diving log sheets have all provided negative results (Kelley, Berghage, and Summitt 1968; Doll and Berghage, 1967; Summitt, Berghage, and Tammany, 1970a; 1970b). It appears that the subjective reporting of physical exertion is so imprecise and is affected by so many extraneous variables that it is of no value. This item should probably be eliminated from the diving log sheet, unless it can be more precisely defined.

Class Diver

Second class divers do more diving than any other classification of Navy diver, accounting for about 25% of the recorded fleet operational

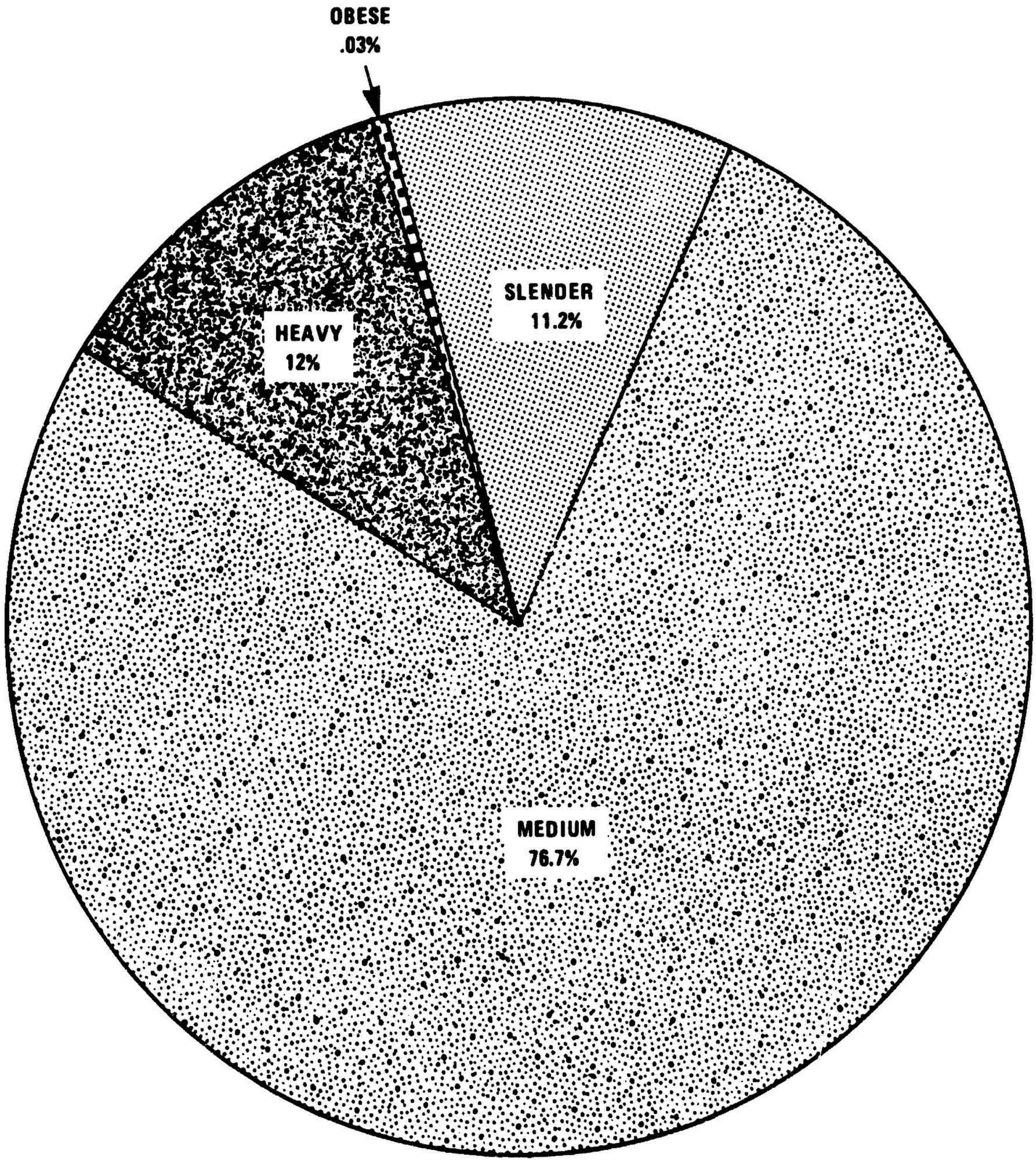


Fig. 16. Body build data on fleet divers.

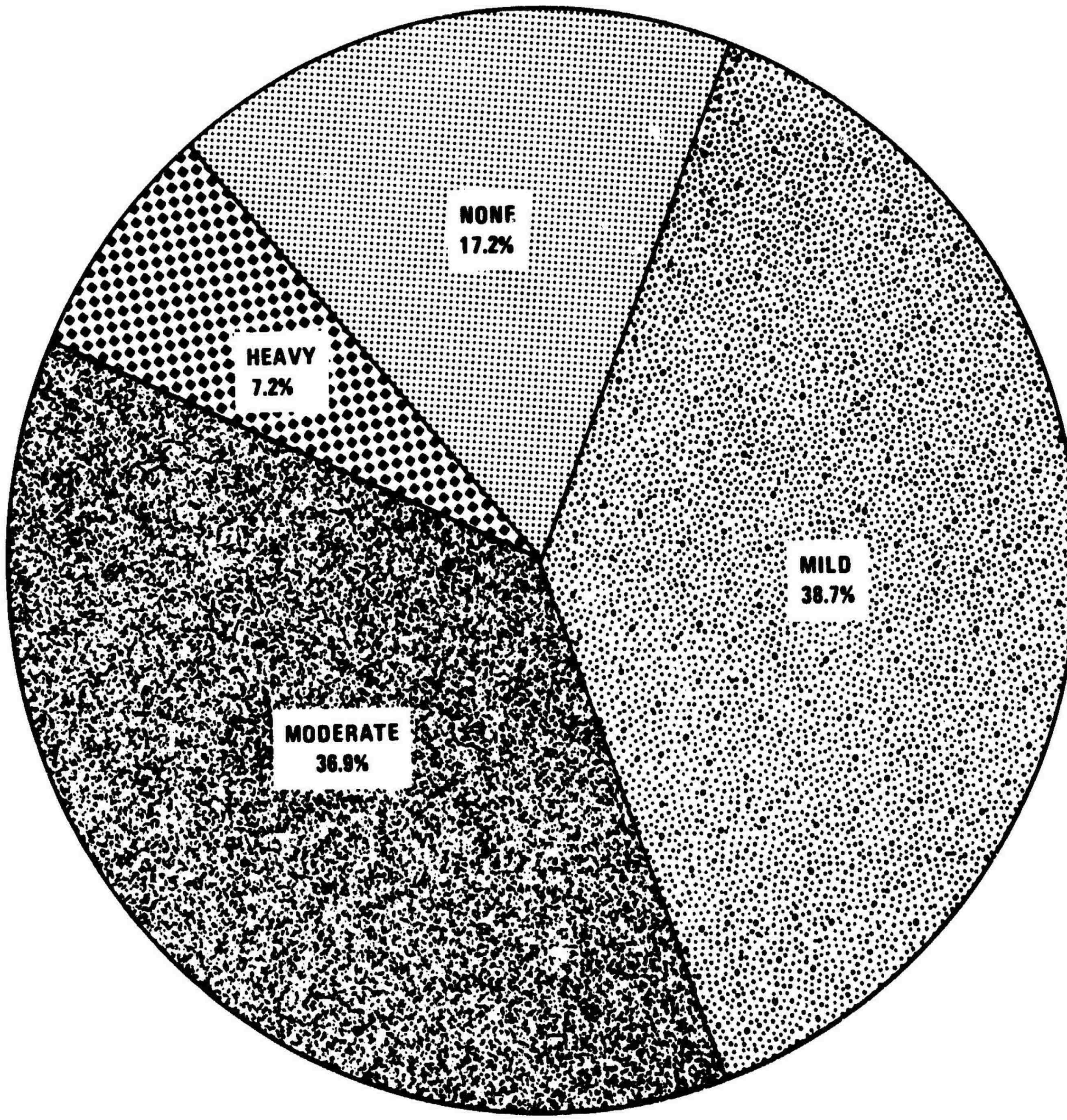


Fig. 17. Type work (level of work) recorded for Navy dives.

dives. This finding is not too surprising in that this classification contains the largest number of working divers. The only real unexpected result in Fig. 18 is the large proportion of dives made in which the diver classification was "other." It is hard to see why these divers could not classify themselves using the present diving log categories; the present Navy diving designations are listed below.

Officers

Ship Salvage	Explosive Ordnance Disposal
Diving Officer	Underwater Demolition Team Officer
$He\text{-}O_2$ Diving Officer	Seal Officer
Ship Salvage Diving Officer	Submarine Medical Officer

Diving Medical Officer

Enlisted

Master Saturation Diver	UDT Swimmer
Master Diver	UDT Swimmer & Explosive Ordinance Disposal (EOD)
Deep Dive Systems Diver	Combatant Swimmer (SEAL)
Diver First Class	SEAL & EOD
Medical Deep-Sea Diving Tool	EOD
Salvage Diver	Underwater Photographer
Scuba Diver	

UDT Hospital Corpsman

There are many more diving designators than there are categories on the diving log sheets, but the existing categories on the logs cover the basic types of training for all of the above designators. Perhaps the answer to the problem is to include a space for the diver to record his actual NEC (Navy enlisted classification) or NOBC (Navy officer billet classification) number. In this way the "other" category could be avoided as a catch-all.

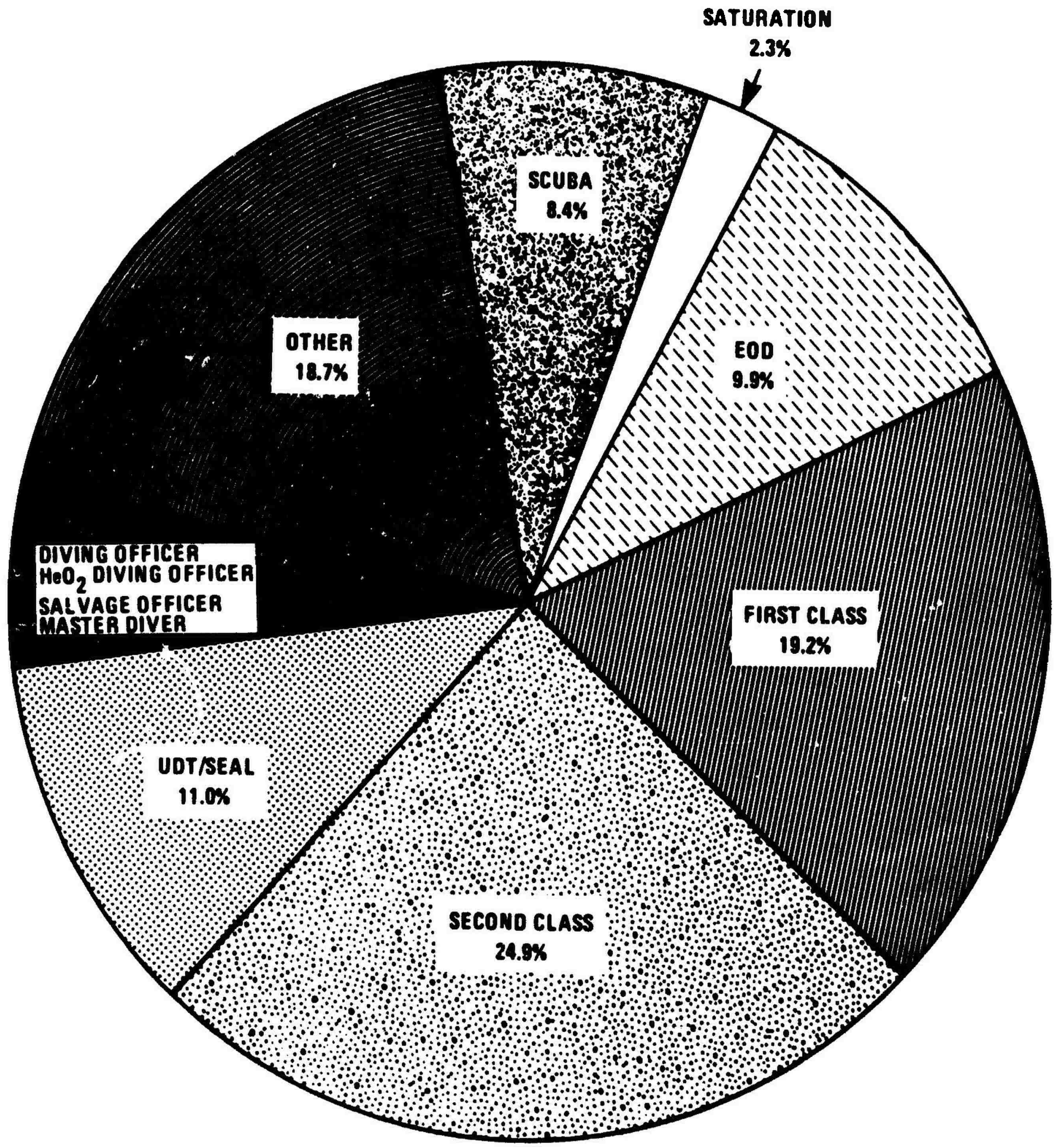


Fig. 18. Classifications of divers on fleet dives.

Until this problem is solved it is impossible to determine accurately the amount of diving being done by the various types of divers.

Marital Status

The need for this kind of information on diving log forms is questionable. Granted, marital status has been related to such things as longevity, mental illness, absenteeism, and several measures of job performance. The studies showing these results, however, had good criterion measures against which to evaluate the marital status categories. The diving log form does not contain a good criterion measure, therefore the gathering of this type of information serves no real practical value. The time involved to record marital status itself is minimal; however, when the category is grouped with three or four other pieces of worthless information, recording time could amount to 1 or 2 min/form or one or two thousand man-hours/year, e.g. $\frac{63{,}500 \text{ dives/yr} \times 2 \text{ min/form}}{60 \text{ min/h}} = 2118$ man-hours.

An effort should constantly be made to keep the paper work of the fleet as simple and unobtrusive as possible. Gathering information because we might find a need for it someday is not sufficient justification for the item. The information in Fig. 19 is presented only because it is available.

NAVY DIVING PROCEDURES

Over half the diving done in the U.S. Navy is done for reasons other than direct fleet support (Fig. 20). Training and requalification of divers accounts for about 46% of the dives; an additional 8% involves equipment testing, experimental work, hyperbaric therapy, and diver selection; the remaining 46% is recorded as working dives. Presently the U.S. Navy is making 1.2 support dives for each operational working dive. All of these dives, however, serve the function of maintaining diver operational proficiency and sustaining the Navy's undersea capability.

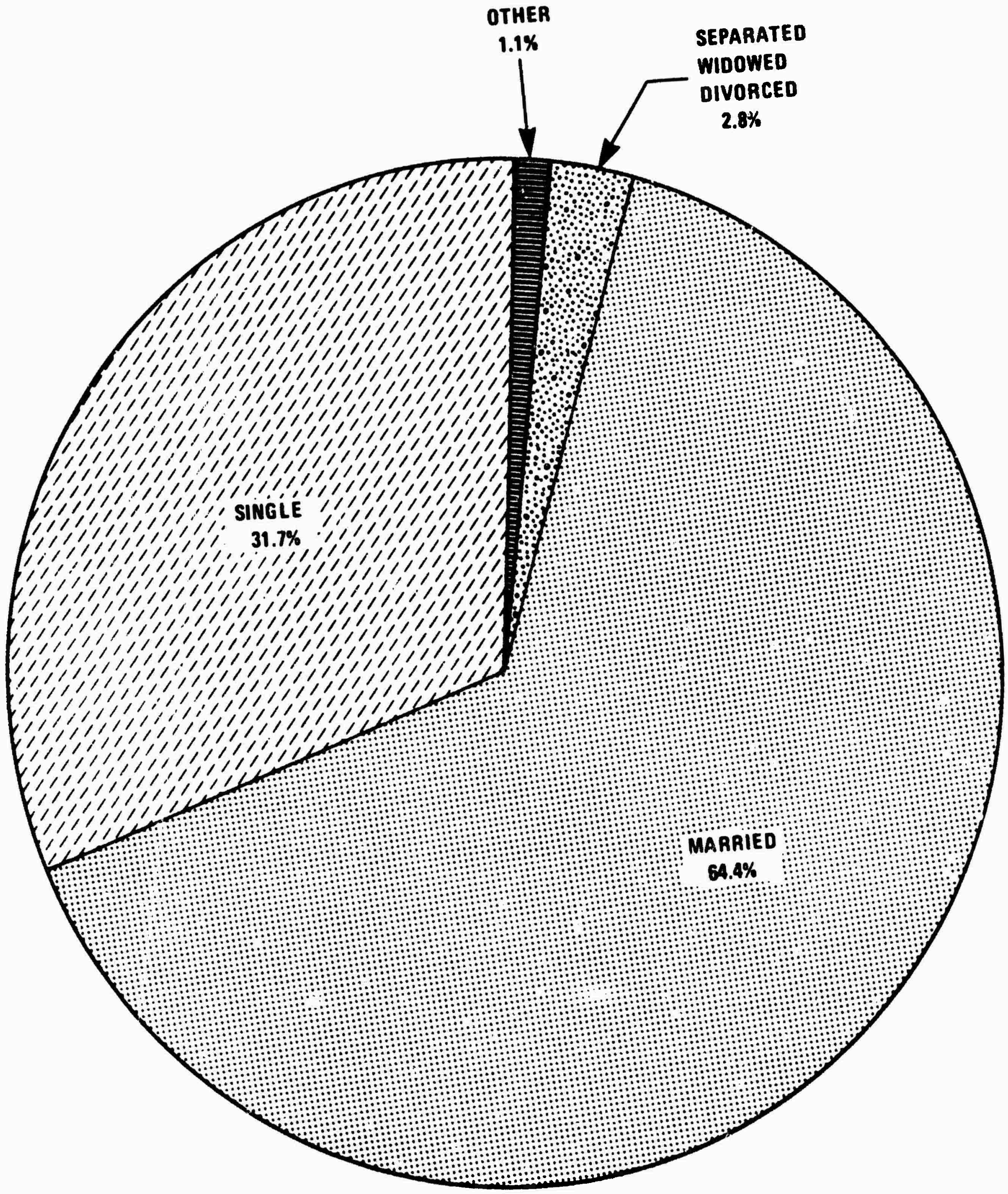


Fig. 19. Marital status of fleet divers.

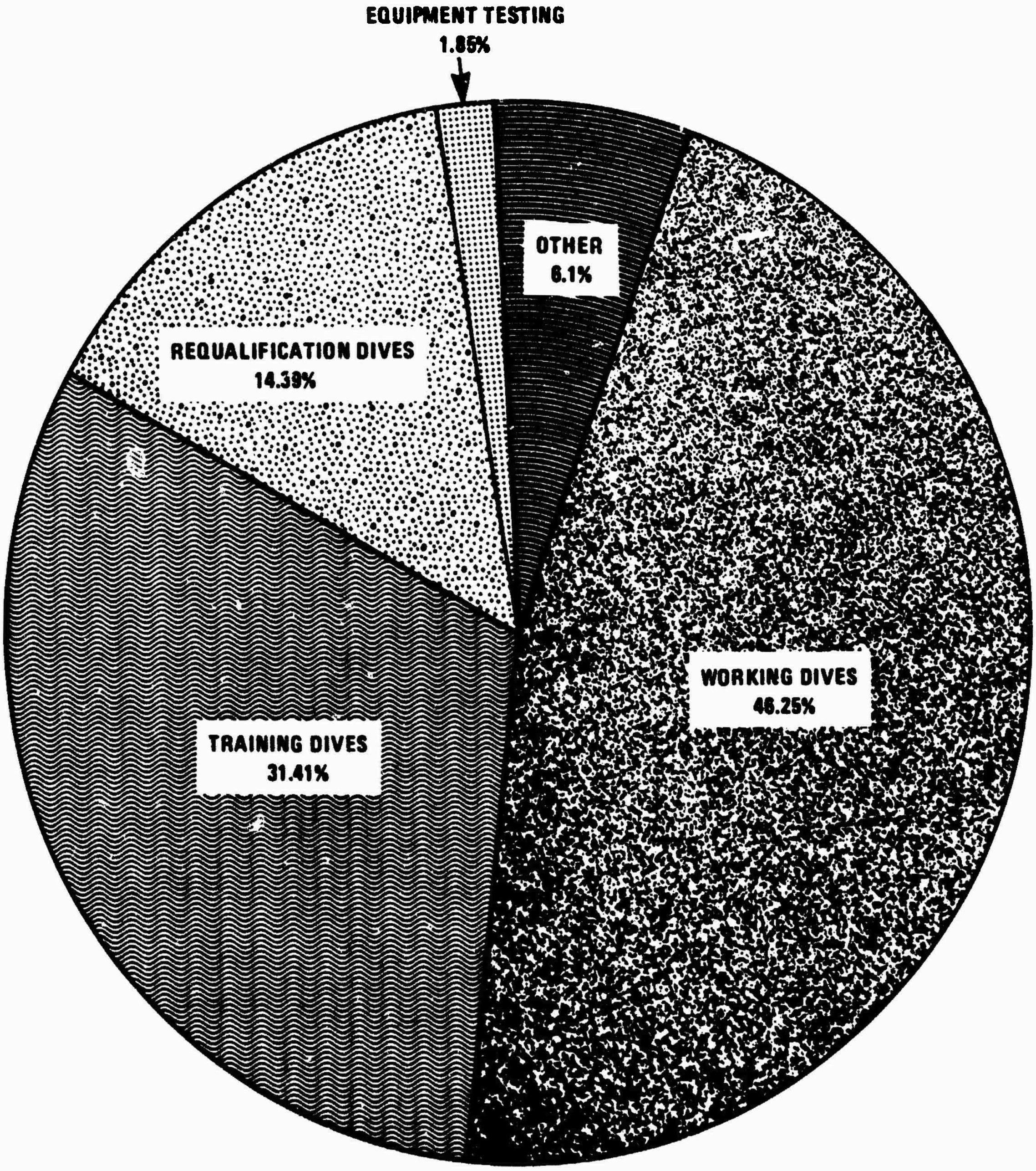


Fig. 20. Purpose of fleet dives.

The contribution made by Navy support dives in advancing U.S. underwater technology should be recognized. The advanced technological position that this country has achieved is largely the result of research efforts sponsored by the U.S. Navy. Only in the last 10 to 15 years has private industry made a significant contribution to this research effort.

Diving Equipment

It has been recognized for some time that most of the fleet diving is done with simple open-circuit scuba. The equipment is deceptively easy to operate, easy to maintain, requires little surface support equipment, and has therefore received widespread fleet acceptance and usage. Diving equipment that requires fine calibration, extensive set-up time, surface-support equipment, or unusual amounts of maintenance are just not used by the fleet diver. The diver working in the water on a daily basis wants and needs equipment he can dependably use on a moment's notice. One of the reasons the Mark V hardhat diving system has been around so long is that it meets the above criteria. The Mark V, as was shown by Armstrong, Bachrach, Conda, Holiman, and Egstrom (1974), is heavy, cumbersome, and hard to work in, but it is simple to operate, rugged and dependable, and requires very little maintenance.

Because scuba equipment is so deceptively simple to operate, relatively little time is spent learning to use it in the Navy training program. In contrast, based upon the equipment usage shown in Fig. 21, there is a disproportionately large amount of training time spent learning to use the helium-oxygen Mark V system.

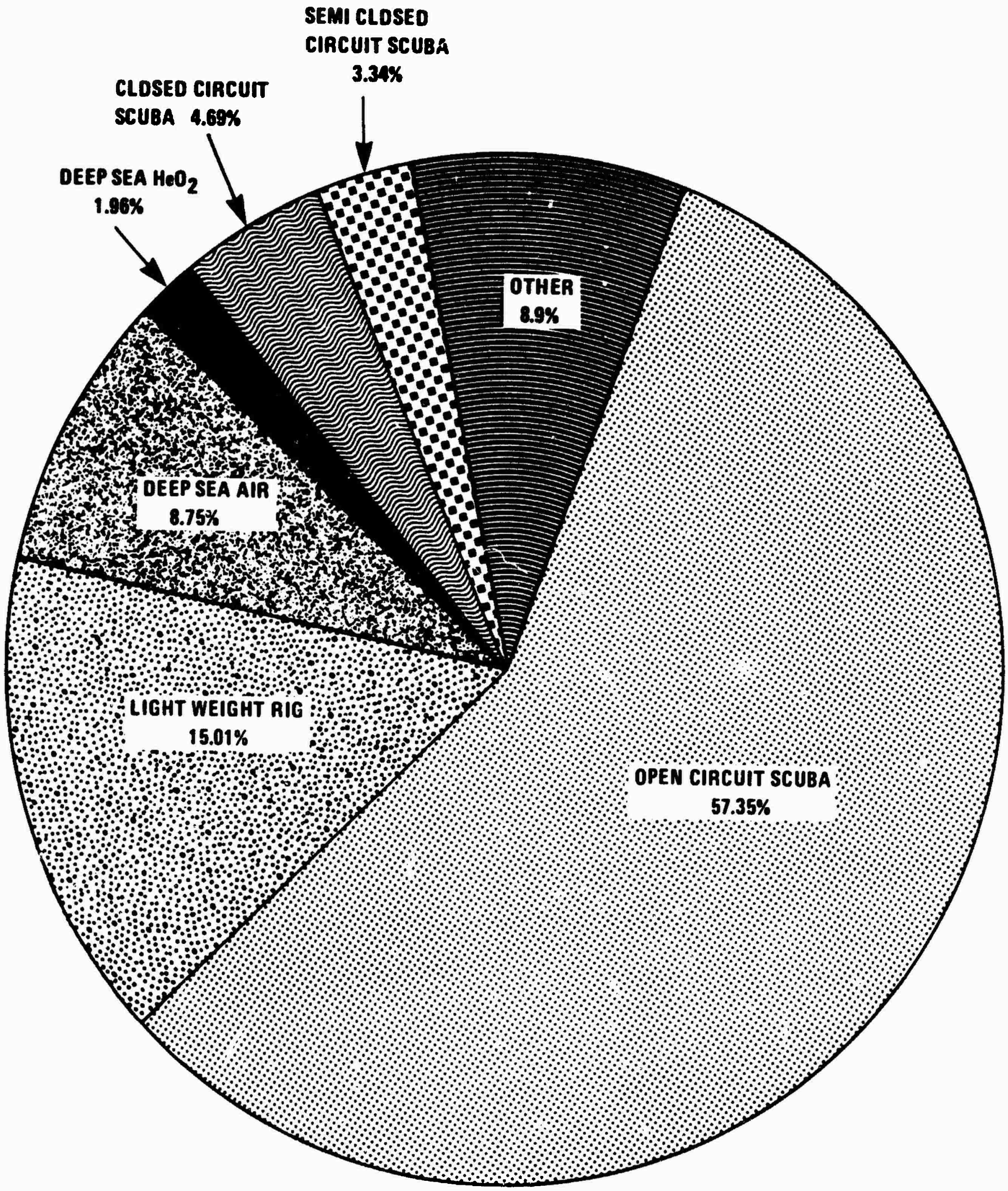


Fig. 21. Diving equipment used on fleet dives.

Deep-sea helium-oxygen diver training involves several weeks, yet only about 2% of the fleet dives involve the use of this type of equipment. Of this 2% the majority of the dives are probably training dives, therefore the actual operational utilization of this type of training and equipment is very small indeed.

The "other" category shown in Fig. 21 is probably growing from year to year because of the new equipment being introduced into the fleet for which there are no descriptive categories on the diving log sheets. Future revisions of the diving log sheet must expand the equipment codes to allow identification of the actual equipment being used. There should also be an in-depth survey of the various equipment categories to determine who is using the various types of equipment for what purpose and under what conditions. A more detailed study of this type could be very helpful in evaluating future Navy training requirements.

Equipment Performance. The diving log sheet entries on equipment performance indicate that on about 1% of the fleet dives the equipment performs below par or unsatisfactorily. It is difficult to know how to interpret this finding without additional information. Between 1% and 3% of the recorded dives are made for experimental or equipment test purposes. It may be that on these dives the equipment is not performing satisfactorily. The finding is presented here with the acknowledgment that its meaning is nebulous and that there is a need for a more detailed analysis of equipment failures than is possible through the diving log sheets.

Type Dress Used

It is not at all surprising to find most of the diving being done in wet suits (Fig. 22). Wet suits in various configurations are being used with all types of diving masks and helmets. The large "other" category indicates that the descriptive codes included on the diving log sheets are

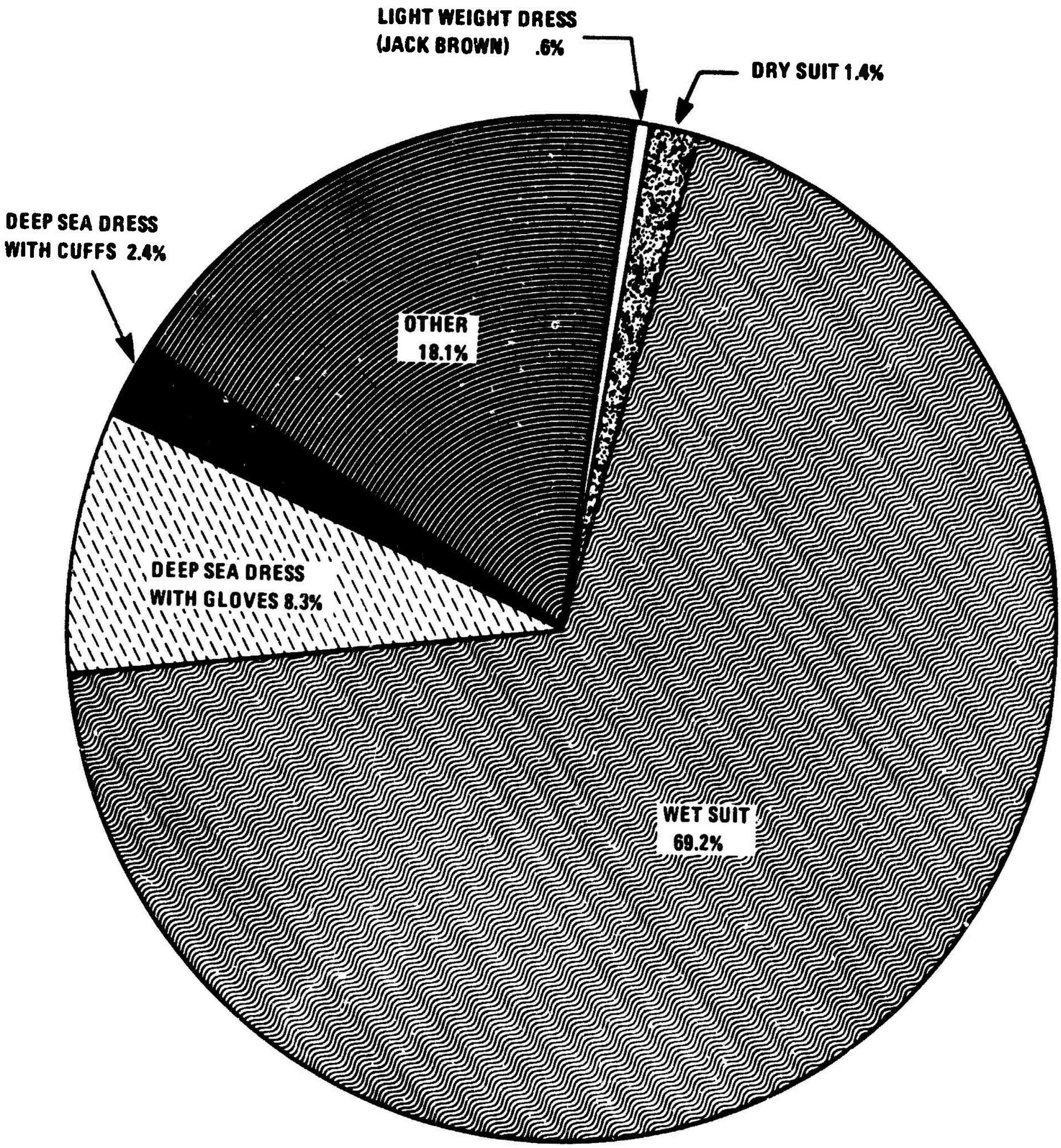


Fig. 22. Type dress used on fleet dives.

not all-inclusive. An obvious code missing is one for "bathing suit." The water temperature data in Figs. 6 and 7 indicate that a large proportion of dives are made in water warmer than 75°F and probably are made in bathing suits. Another type of dress now in the Navy inventory which is getting wider utilization is the hot water suit. Dives presently made with the hot water suit have to be recorded with the "other" code. To reduce the use of the "other" code this area of the diving log sheet should be updated and corrected to reflect the type of dress actually being used.

Tools Used

On 66% of the recorded fleet dives no tools were used. It would be interesting to know what kind of activities were engaged in during these dives; however, this kind of information is not presently available (Fig. 23). It has been suggested that a "diver activity" category be added to the log sheet; the category should list the various types of activities that divers are required to perform (e.g. screw changes, hull inspections, and the like). This suggestion has never been implemented because the list of activities is either prohibitively long or no concensus can be reached among divers. Perhaps an alternative suggestion would be to list the types of tools used (e.g. hydraulic, hand, electrical).

To estimate the effectiveness and reliability of various tool configurations it is essential to know how often the various tools are used. The structure of the present diving log form makes it impossible to obtain this kind of information. Future diving log sheets should attempt to provide additional information in this category.

Decompression Schedules Used

As indicated in Fig. 24 only 6.8% of the recorded Navy dives involved the use of decompression schedules. In terms of numbers, this amounts

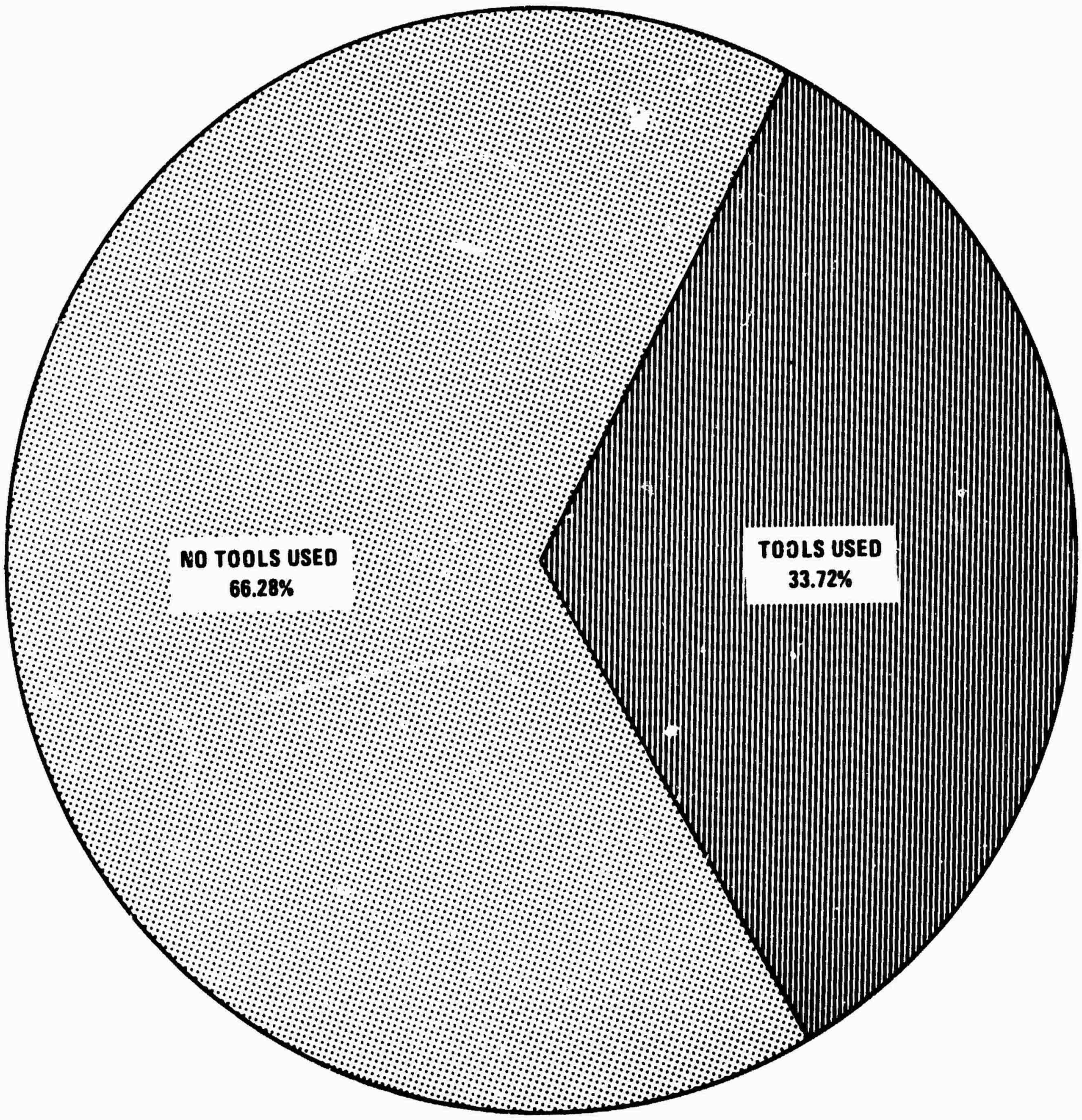


Fig. 23. Tools used on fleet dives.

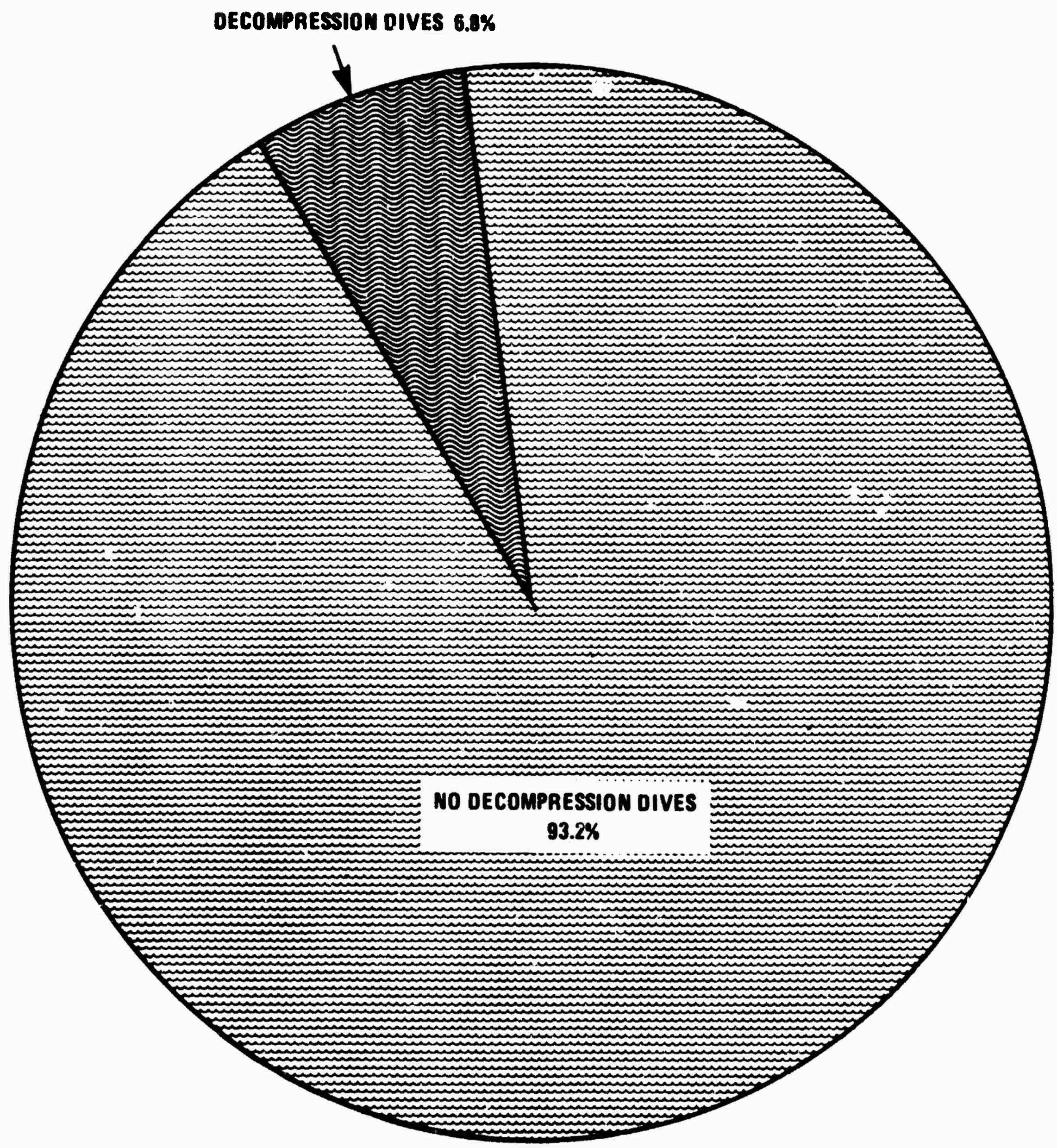


Fig. 24. Percentage of fleet dives using decompression schedules.

to about 4300 decompression dives per year. The distribution of these dives among the various decompression schedules is shown in Fig. 25. Of those dives requiring the use of decompression schedules, about half involve the standard air tables; another 30% involve the standard helium-oxygen tables; all other tables make up the remaining 20%. It is a bit surprising that not more of the decompression dives involve the standard air tables. It appears that a variety of decompression profiles is essential for fleet operations.

Presently about 2% of the decompression dives involve the use of the saturation decompression schedules. It will be interesting to follow this statistic in the future to see if it increases or decreases. In commercial diving it is definitely on the increase. The development of saturation techniques is also attracting a major portion of the Navy's diving research dollars. If the number of saturation dives done in the Navy does not increase in the future it will indicate that the Navy's diving R&D program is largely directed toward an operational capability as opposed to a current operational requirement.

Decompression Location

As shown in Fig. 26, 78% of the decompression dives still involve decompression in the water. This proportion will probably not change very much despite the advent of the PTC (Personnel Transfer Capsule) and the DDC (Deck Decompression Chamber). These devices will be used only during deep dives and since most of the Navy's diving is shallow, the prospects for continued decompression in the water remain high. These data are significant only to re-emphasize the point that development of decompression schedules should include testing with the subjects immersed so as to approximate the environment in which they will be used.

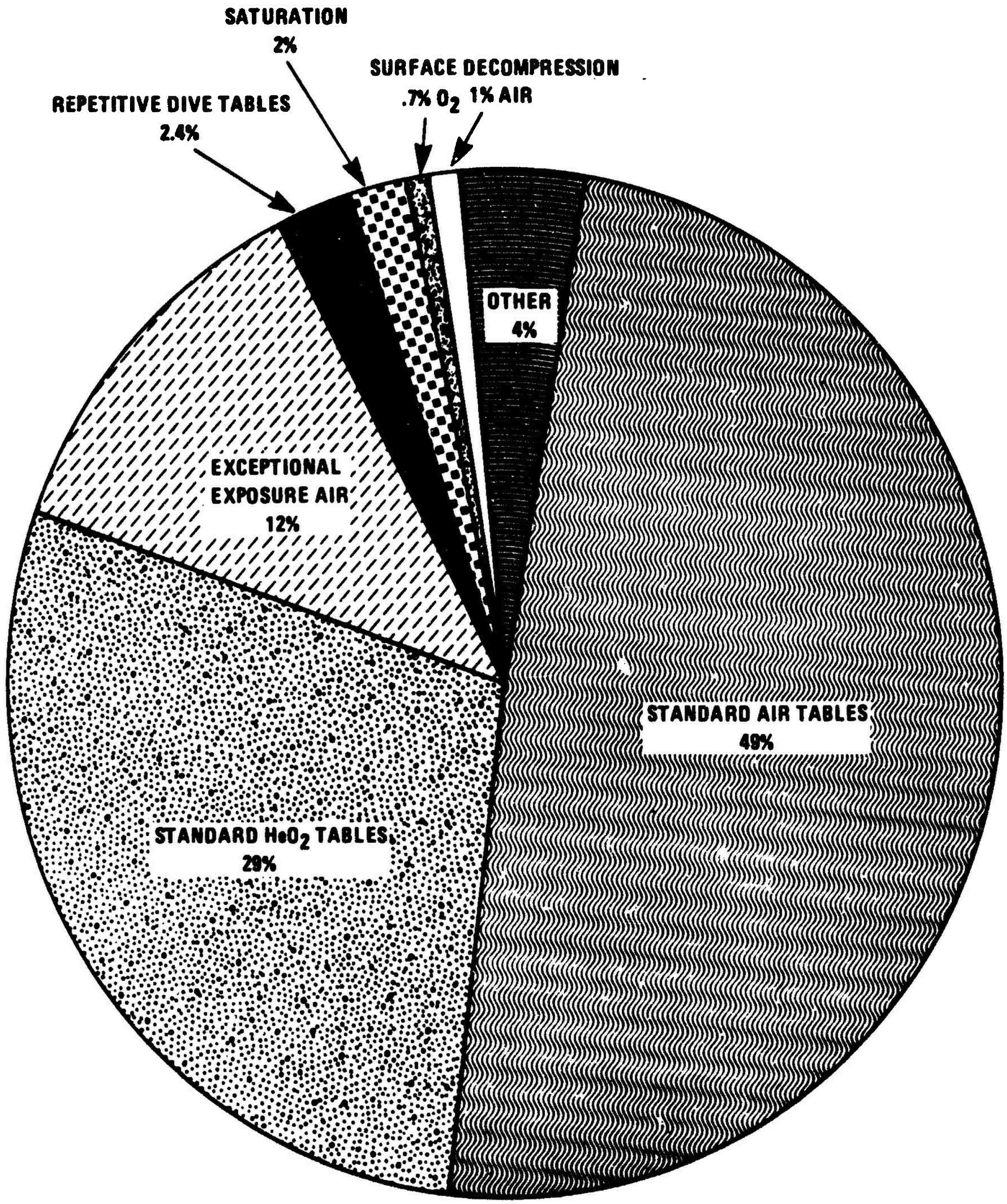


Fig. 25. Percentage of fleet dives using various decompression schedules.

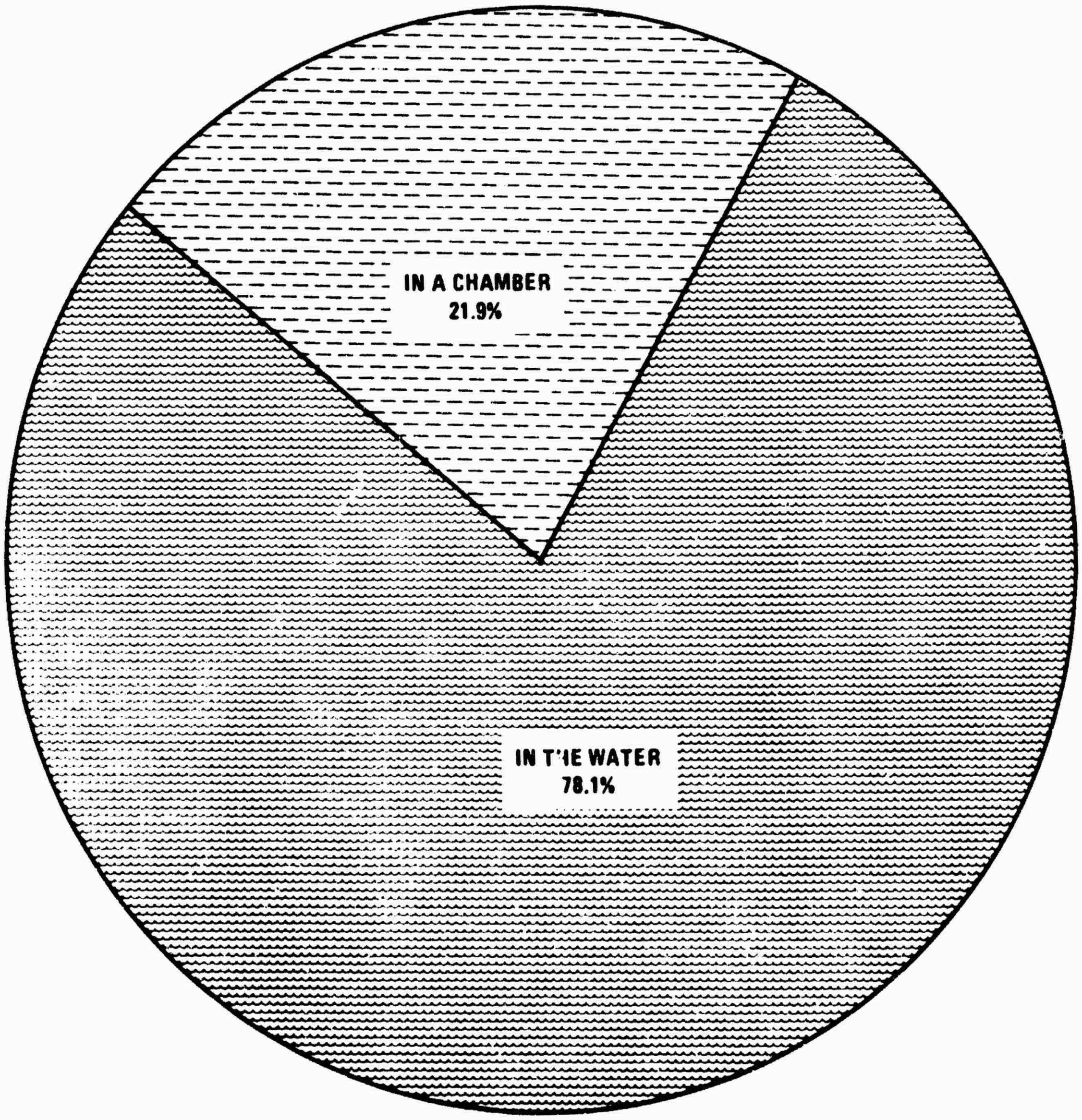


Fig. 26. Decompression location.

ANALYSIS OF NAVY DIVING STATISTICS

The analysis of diving data presented in this section of the report is based upon the dive category system described in Table 2. Letter designations will be used to identify the various dive categories.

DISTRIBUTION OF DIVES BY CATEGORY

As indicated in Fig. 2 most of the reported Navy dives are at relatively shallow depths. Figure 3 further indicates that most of the dives are of short duration. A composite of these results can be seen in the distribution of dives by category in Fig. 27a. Seventy percent of the dives are found in the shallow-short and shallow-medium (less than 100 fsw and less than 60-min duration) dive categories. Only about 1% of the recorded dives are deeper than 200 fsw, and less than 0.3% of the dives are made in a saturation diving mode.

When the distribution of dives in each category (Fig. 27a) is compared with the distribution of actual time spent under pressure (Fig. 27b), some striking statistically significant ($p<.001$) discontinuity is evident. Despite the fact that 12% of the dives are made in the medium depth category (100-200 fsw), these dives account for only about 3% of the time spent under pressure. Saturation diving, on the other hand, accounts for less than 0.3% of the dives, yet these dives constitute over 20% of the time spent under pressure (1012 man-days). The large proportion of time spent under pressure during saturation dives is a little misleading if one is interested in productive underwater work time. Because the saturation diver actually lives in the hyperbaric environment, he spends a good portion of his time under pressure in nonproductive activity. If the saturation diver spent 4 hours each day working in the water, this would only be about 17% of his workday. Productive work time as a proportion of total time under pressure is even smaller because of the long days of

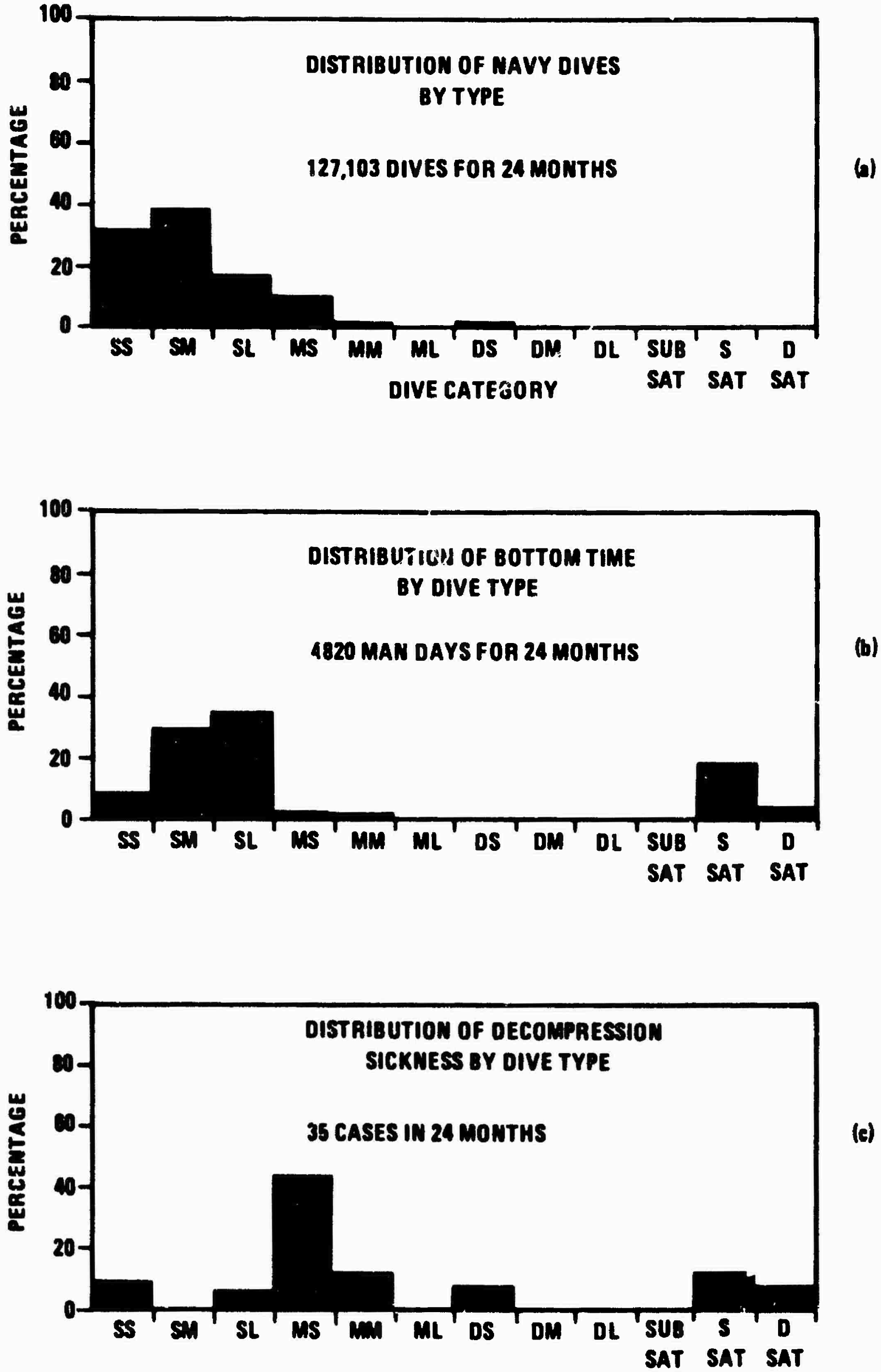


Fig. 27. Distribution of Navy dives.

decompression following the saturation exposure. The highest proportion of actual underwater work time to time under pressure is found in the shallow dives, where the decompression time is relatively short and the diver does not live in the pressure environment.

The distribution of dives and time under pressure among the various categories is also of value to the research physiologist interested in studying the physiological stresses associated with fleet diving. He will want to direct his attention to different dive categories depending upon whether he wished to look at the number of pressure exposures (dive cycles) or the time spent under pressure.

DISTRIBUTION OF DECOMPRESSION SICKNESS BY CATEGORY

Another comparison among dive categories worth exploring is the distribution of decompression sickness (Fig. 27c). The medium depth categories (100-200 fsw) account for 12% of the dives made, and 3.5% of the time spent under pressure. They also account for 57% of the decompression sickness. The extremely small proportion of saturation dives done (0.3%) account for 20% of the decompression sickness that occurred.

These figures, which at first glance are rather startling, require some explanation and qualification. First, only 35 cases of decompression were reported during the 24-month period covered by this study. That averages out to 17.5 cases per year, or considering all dives produces an incidence of about 0.03%. Even if one considers just those dives that require the use of a decompression schedule (4302 dives/year), the incidence is still only 0.41%. This incidence rate compares very favorably with any that has previously been reported. Despite these very favorable figures, the fact remains that the distribution of the cases that do occur is not uniformly distributed ($p<.001$), or even distributed proportionally, among those categories having the most recorded dives ($p<.001$). From a research and development point of view this disproportionate distribution of decompression sickness should signal a need for additional information. If the Navy ever expands its saturation or deep diving program, it is reasonable to expect that there will be a corresponding sharp increase in the incidence of decompression sickness.

ANALYSIS OF ENVIRONMENTAL DATA

Dive Depth

The average (median) dive depth within the various depth categories does not show any statistically significant shift (Table 3). In other words, the average depth does not change between the short, medium, and long bottom-time categories. A visual inspection of Fig. 28, however, seems to indicate that within the shallow and medium depth categories there is an inverse relationship between depth and bottom time. The longer the dive, the shallower the dive depths.

Within the three deep dive categories the large proportion of dives to depths between 280 and 300 fsw are probably training dives. The Naval School of Diving and Salvage still uses a 285-fsw dive as a demonstration of nitrogen narcosis and a 320-fsw dive as a qualification for $He\text{-}O_2$ diving.

The total number of dives in the special categories of subsaturation and shallow and deep saturation are so few that even relatively minor changes in the diving results in rather gross changes in the shape of the distribution statistics. These statistical distributions should be disregarded due to the relatively small sample sizes involved.

Bottom Time

A statistical analysis (chi square) of the median bottom times among the various dive categories indicates no significant changes in the times

TABLE 3

Median depths for the various dive categories (fsw)

		Bottom time			
		Short	Medium	Long	$\bar{x}$
Depths	Shallow	30.40	31.47	30.79	30.89
	Medium	120.19	113.82	108.46	114.16
	Deep	253.00	273.50	292.67	273.06
	$\bar{x}$	134.53	139.60	143.97	
Special dive category		Sub. Sat.	S. Sat.	D. Sat.	
		476.5	135.2	1009.5	

$\bar{x}$ = mean.

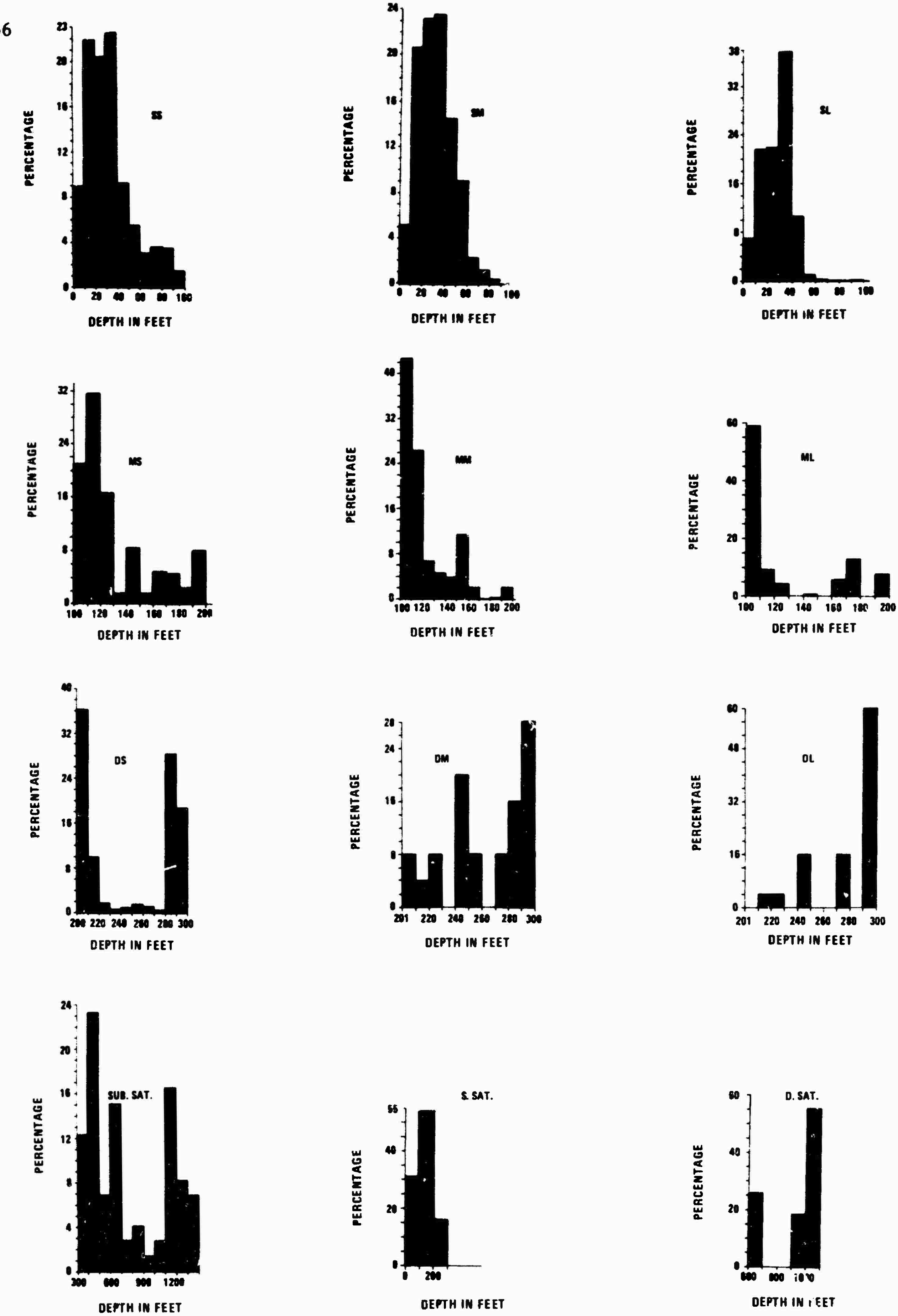


Fig. 28. Relationship between depth and bottom time.

spent at the different depths (Table 4). However, a visual inspection of Fig. 29 and a review of the mean values in Table 4 indicate a shift in bottom times with depth. Just as was noted in the section above on the analysis of dive depths, there appears to be an inverse trend in the direction of shorter bottom times for deeper dives. This result is nothing unexpected in that it just confirms what has generally been the accepted rule in the fleet: if you have to dive deep, keep the bottom time as short as possible to minimize the required decompression time. The interesting thing about these results is that the shift in bottom time is not more significant. Required decompression time increases at a very rapid rate with increased depth, and one would suspect that there would be a corresponding decrease in the time spent at these deeper depths. The indication is that deep dives are avoided whenever possible, but that when they are made, the divers may spend as much time at these deep depths as they do on shallower ones.

Breathing Gases

Figure 30 shows the proportion of dives made in each dive category with the various breathing mixtures. One is not surprised to find that compressed air is the predominant breathing media until he gets into the deep dive and special dive categories. Even in the deep dive category there is a relatively large proportion of the dives made with compressed air. Some of these dives can be accounted for by chamber dives that are made to demonstrate nitrogen narcosis in the training program. The number of dives made for this purpose, however, are relatively few and could not possibly make up the totals recorded in this dive category; the subsaturation category is also questionable. One must conclude from these figures that either there is extensive use of the

TABLE 4

Median bottom times for the various dive categories (min)

		Bottom time			
		Short	Medium	Long	$\bar{x}$
Depths	Shallow	17.80	44.49	90.47	50.92
	Medium	8.25	42.99	68.46	39.90
	Deep	7.78	38.44	67.81	38.01
	$\bar{x}$	11.28	41.97	75.58	
Special dive category		Sub. Sat. 26.33 hrs.	S. Sat. 2.52 days	D. Sat. 5.70 days	

$\bar{x}$ = mean.

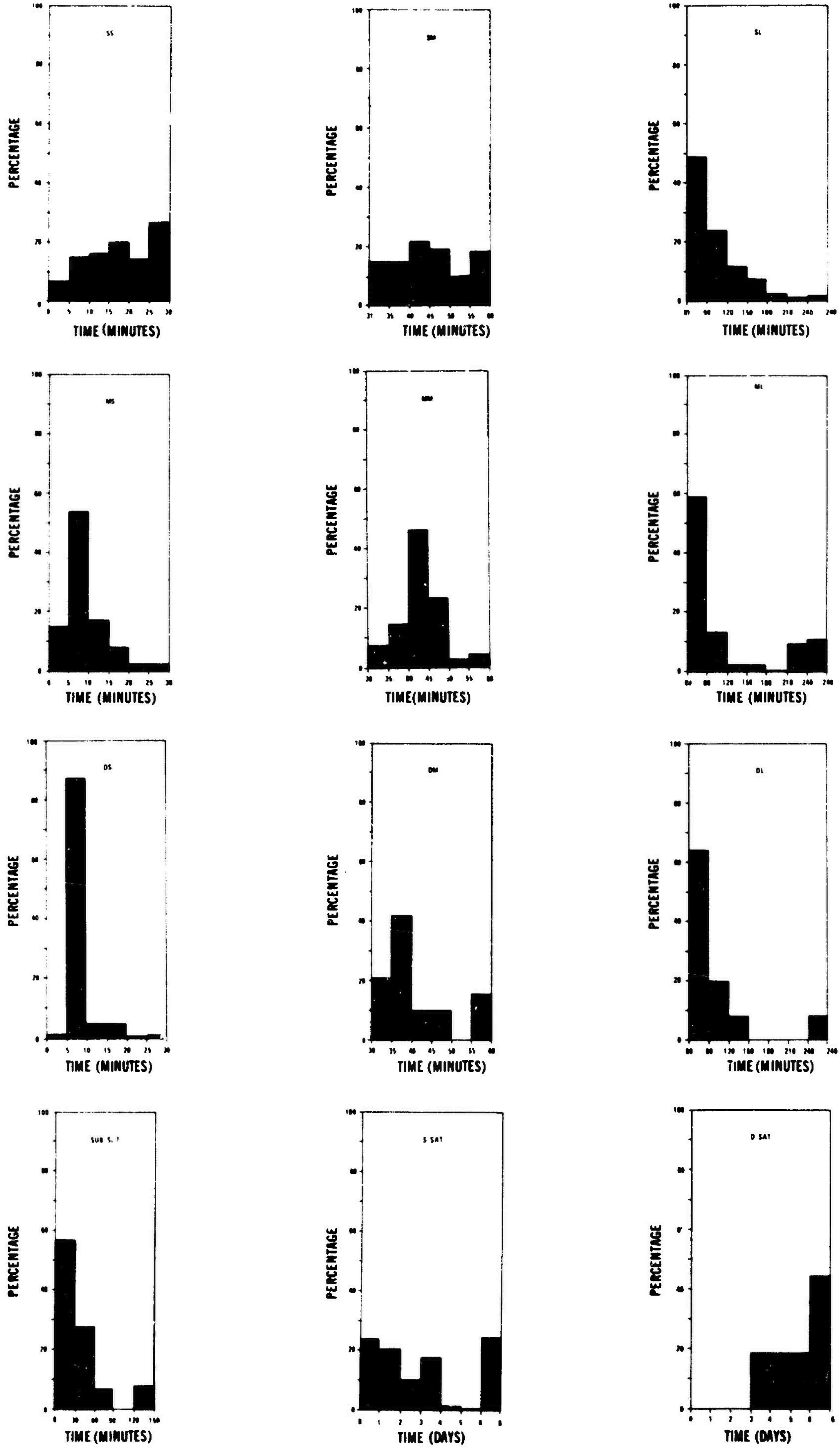


Fig. 29. Median bottom times among dive categories.

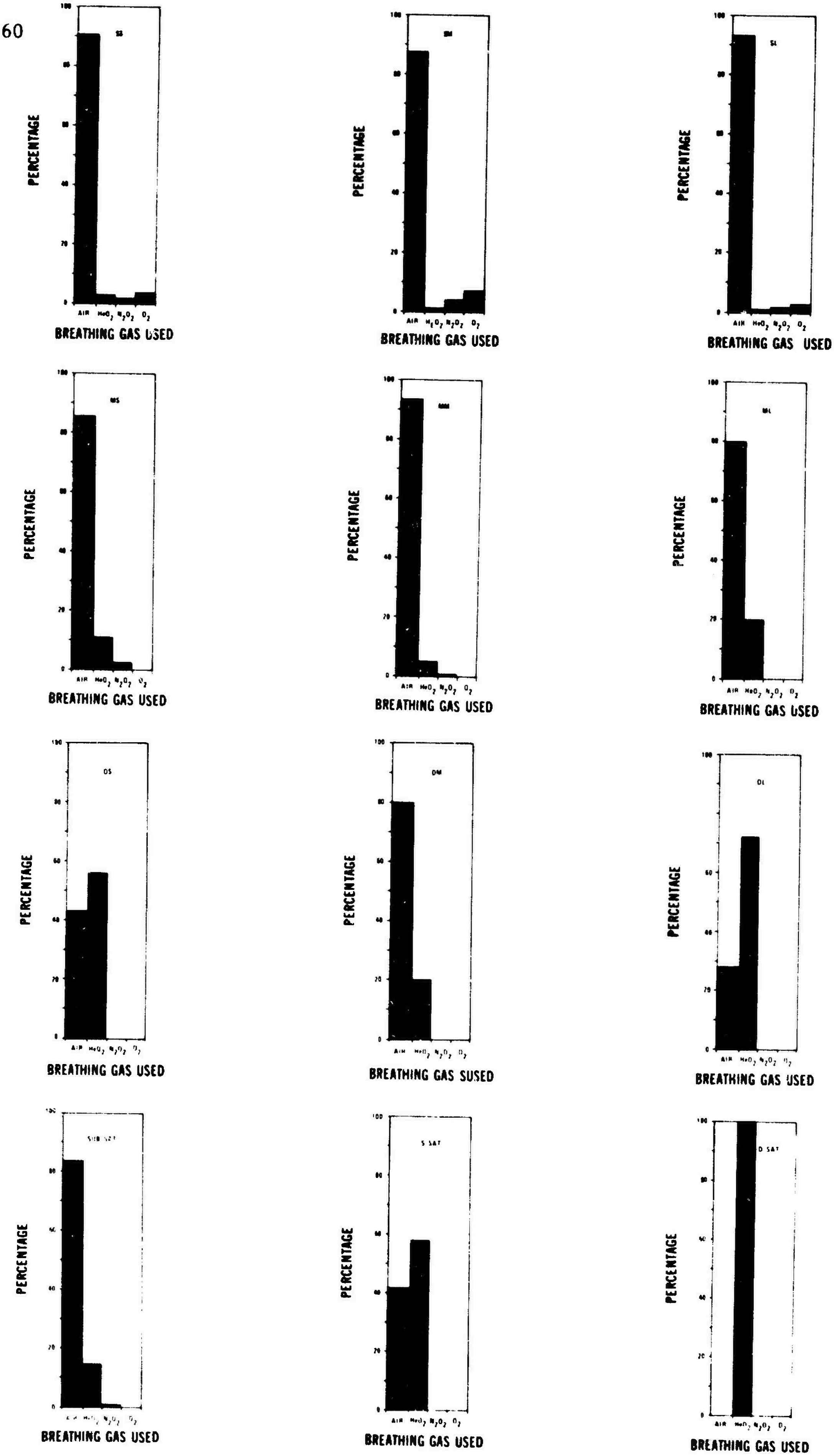


Fig. 30. Breathing gases used in various dive categories.

Navy's exceptional exposure air tables or there are a number of recording errors on this item. Which is the correct interpretation is impossible to determine.

The large number of shallow oxygen dives is probably made up of two components, hyperbaric oxygen treatments and Underwater Demolition Team training for clandestine operations. Most of the oxygen exposures are probably due to the latter, but it is impossible to determine what proportion is accounted for by each.

Surface Air Temperature

The distribution of surface air temperature among the 12 dive categories is not uniform. However, a statistical evaluation of the median temperatures (Table 5) shows no significant changes. Even the mean values shown in the margin of Table 5 fail to show any trend. Based upon this information there appears to be no relevance of these data for fleet diving other than that noted in the first section of this paper (i.e. the effects of air temperature on surface support personnel, as well as the diver and his equipment).

Surface and Bottom Temperature

Neither surface water temperature nor bottom water temperature show any consistent shift among the nine standard dive categories (Tables 6 and 7). The bottom water temperatures for the three special dive categories are statistically different from those in the standard dive categories and perhaps indicate the thermal gradient effects of deeper dives. Yet if this reasoning is correct, one should expect to see a systematic reduction in water temperature across the standard depth categories. This shift is not indicated. In fact, if one goes by the mean values in the margin of Table 6, there is a reverse of the trend one would expect. The explanation of this is unclear.

TABLE 5

Distribution of surface air temperature for the various dive categories (^{o}F)

		Bottom Time			
		Short	Medium	Long	$\bar{x}$
Depths	Shallow	73.76	72.62	69.63	72.00
	Medium	74.50	75.20	72.55	74.08
	Deep	75.13	76.50	73.25	74.96
	$\bar{x}$	74.46	74.77	71.81	
Special dive		Sub. Sat.	S. Sat.	D. Sat.	
category		70.41	73.52	76.00	

$\bar{x}$ = mean.

TABLE 6

Surface water temperatures for the various dive categories (^{o}F)

		Bottom time			
		Short	Medium	Long	$\bar{x}$
Depths	Shallow	66.83	66.08	67.26	66.72
	Medium	68.90	71.75	66.21	68.95
	Deep	74.40	79.95	74.50	76.28
	$\bar{x}$	70.04	72.59	69.32	
Special dive		Sub. Sat.	S. Sat.	D. Sat.	
category		63.79	64.46	68.50	

$\bar{x}$ = mean.

TABLE 7

Bottom water temperatures for the various dive categories (^{o}F)

		Bottom time			
		Short	Medium	Long	$\bar{x}$
Depths	Shallow	63.31	62.86	64.86	63.68
	Medium	64.37	64.59	64.50	64.49
	Deep	73.10	73.88	74.50	73.83
	$\bar{x}$	66.93	67.11	67.95	
Special dive category		Sub. Sat.	S. Sat.	D. Sat.	
		55.06	49.41	48.50	

$\bar{x}$ = mean.

For the nine standard dive categories there is an average difference of 3.3°F in water temperature between the surface and the bottom. For the special categories the difference is 14.6°F. As mentioned earlier in the report, bottom water temperatures are probably estimated and their validity is in question.

Wave Height and Current

As indicated in Tables 8 and 9, there is no systematic shift in either wave height or current among the standard dive categories. Environmental conditions do not appear to change much among the various categories of Navy diving. The median wave height is about 1 ft and the range is from 0 to 6 ft. Estimates of the current have ranged as high as 1.7 knots with the median about 0.2 knot. The vast majority of Navy diving is done within very narrow environmental limits and these limits do not appear to change much from dive category to dive category. To the authors' knowledge the environmental limits that restrict operational diving have never been defined or spelled out.

Sea Floor Conditions and Visibility

There seems to be no systematic shift in sea floor working conditions among the various dive categories. Table 10 shows the distribution of dives among the various depth categories for the different bottom conditions. It appears that once the divers move out of the shallow depth category there is a substantial drop in the number of dives made in the mud. Of the recorded shallow dives made, over 45% are made in a mud or silt environment. For the medium- and deep-depth categories the corresponding percentages are 28.7 and 27.3, respectively.

Visibility at a sea floor work site is generally governed by two factors: the amount of available light and the turbidity of the water.

TABLE 8

Median wave heights for the various dive categories (ft)

	Bottom time			
	Short	Medium	Long	$\bar{x}$
Shallow	.80	.82	.68	.77
Medium	.97	1.01	.93	.97
Deep	.69	.63	.68	.67
$\bar{x}$	.82	.82	.76	
Special	.80	1.21	1.10	1.04

$\bar{x}$ = mean.

TABLE 9

Median current for the various dive categories (knots)

		Bottom time			
		Short	Medium	Long	$\bar{x}$
Depths	Short	.17	.18	.14	.16
	Medium	.17	.16	.19	.17
	Long	.14	.13	.13	.13
	$\bar{x}$	.16	.16	.15	
Special		.17	.32	.37	.29

$\bar{x}$ = mean.

TABLE 10

Percentage of dives made with various sea floor conditions

Conditions	Depth Shallow	Medium	Deep
Mud	16.4	8.8	7.5
Silt	1.1	1.0	4.0
Mud & Silt	21.1	12.3	13.8
Mud & Sand	5.7	5.7	1.6
Mud & Rock	1.3	0.9	0.4
Sand	11.8	15.7	6.9
Coral	0.6	2.7	0.0
Rock	0.8	1.5	0.3
Sand & Coral	9.3	9.1	8.0
Sand & Rock	4.8	3.5	0.2
Other	24.3	26.5	57.3
Unknown	2.3	12.3	0.1

The mud and silt conditions that are so prevalent in shallow dives tend to increase water turbidity and consequently reduce visibility. The sea floor conditions found on deep dives are much more stable, but the amount of available light is greatly reduced. The medium-dive depth categories appear to provide the optimum work site visibility. Sea floor conditions are fairly stable and the amount of available light provides useful levels of illumination. The results on reported visibility shown in Table 11 are in keeping with this interpretation of the trade-off between turbidity and available light.

The visiblity figures shown for the special dive categories are difficult to interpret because so many of these dives were done in chamber environments.

ANALYSIS OF PERSONNEL DATA

Age

As was pointed out in the section on Navy Diving in Perspective, divers involved in diving accidents and those suffering from decompression sickness while still under pressure are older than the average fleet diver. It was speculated that this finding might be the result of the normal chronology of an individual advancing through the diver training program. To be part of a deep diving unit, a diver must have had a number of years' experience diving to lesser depths. The data trend in Table 12 tend to support this hypothesis, although the shift in median age is not statistically significant.

Height

As shown in Table 13, diver height does not seem to be related in any way to the various dive categories. The variations within the table can be accounted for by chance alone.

Weight

Just as with diver height, the distribution of diver weight by dive

TABLE 11

Median reported visibilities for the various dive categories (ft)

		Bottom time			
		Short	Medium	Long	$\bar{x}$
Depths	Shallow	12.83	7.55	7.46	9.28
	Medium	12.15	14.72	16.21	14.36
	Deep	7.59	6.25	5.43	6.42
	$\bar{x}$	10.86	9.51	9.70	
Special dive category		Sub. Sat.	S. Sat.	D. Sat.	
		7.41	21.3	41.0	

$\bar{x}$ = mean.

TABLE 12

Median diver age for various dive categories
(yr)

		Bottom time			
		Short	Medium	Long	$\bar{x}$
Depths	Shallow	24.1	24.8	26.8	25.2
	Medium	26.7	29.2	24.5	26.8
	Deep	28.4	26.8	27.3	27.5
	$\bar{x}$	26.4	26.9	26.2	
Special dive		Sub. Sat.	S. Sat.	D. Sat.	
category		25.8	27.6	30.6	28.0

$\bar{x}$ = mean.

TABLE 13

Median diver height for various dive categories
(in)

		Bottom time			
		Short	Medium	Long	$\bar{x}$
Depths	Shallow	70.1	70.2	70.0	70.1
	Medium	70.1	70.2	70.2	70.2
	Deep	69.8	68.9	70.6	69.7
	$\bar{x}$	70.0	69.7	70.8	
Special dive		Sub. Sat.	S. Sat.	D. Sat.	
category		70.3	70.3	70.8	70.4

$\bar{x}$ = mean.

category doesn't show any significant shift. There is a slight trend toward heavier divers making deeper dives (Table 14), but it is not statistically significant.

Weight-to-Height Ratio

Again, as with the analysis of the variables of weight and height, there does not appear to be any significant shift in the weight-to-height ratio for the various dive categories. There is a slight increase in the ratio with depth, but this could be a result of the age of the divers involved or possibly just a chance factor (Table 15).

Body Build

Based upon the previous three tables (height, weight, and weight-to-height ratio) one would suspect there is no statistically significant shift in diver body build among the various dive categories. There does not appear to be any predive selection based upon body build (Table 16). This means that all decompression schedules must be capable of handling a random sample of Navy fleet divers. Schedules developed in the future must be tested on representative samples of Navy divers. Information from this report could be used for the determination and selection of subjects for those tests.

Work Level

It is obvious in Table 17 that there is a reduction in the amount of heavy work associated with increased depth. There appears to be a deliberate attempt to avoid heavy exertion during deep dives. Whether this is a conscious effort to avoid possible decompression complications, or whether it is simply a response to breathing denser gases cannot be determined.

For the other work levels there does not appear to be any systematic change associated with either depth or time on the bottom. A

TABLE 14

Median diver weight for the various dive categories
(lb)

		Bottom time			
		Short	Medium	Long	x̄
Depths	Shallow	174.4	175.1	176.0	175.2
	Medium	176.0	180.0	178.2	178.1
	Deep	179.4	179.2	181.3	180.0
	x̄	176.6	178.1	178.5	
Special dive		Sub. Sat.	S. Sat.	D. Sat.	
category		180.0	176.9	170.7	

x̄ = mean.

TABLE 15

Median weight-to-height ratio for the various dive categories

		Bottom time			
		Short	Medium	Long	$\bar{x}$
Depths	Shallow	2.43	2.44	2.46	2.44
	Medium	2.45	2.50	2.49	2.48
	Long	2.52	2.55	2.53	2.53
	$\bar{x}$	2.47	2.50	2.49	
Special dive category		Sub. Sat.	S. Sat.	D. Sat.	
		2.47	2.47	2.38	

$\bar{x}$ = mean.

TABLE 16

Percentage of divers in each category with the various body builds

Depth	Bottom time	Body build			
		Slender	Medium	Heavy	Obese
	short	11.2	78.4	10.4	.0
Shallow	medium	11.3	76.8	11.9	.0
	long	9.9	76.5	14.6	.0
	short	13.0	74.9	12.1	.0
Medium	medium	12.5	69.4	17.8	.3
	long	7.4	76.4	16.2	.0
	short	12.3	72.5	15.2	.1
Deep	medium	12.0	64.0	24.0	.0
	long	8.0	72.0	20.0	.0
Special	Sub. Sat.	8.1	77.9	14.0	.0
dive	S. Sat.	8.8	79.4	11.8	.0
category	D. Sat.	22.2	66.7	11.1	.0

TABLE 17

Distribution of work loads among the various dive categories

Depth	Bottom time	Work level			
		None	Mild	Moderate	Heavy
Shallow	short	15.8	41.4	36.9	5.9
	medium	13.7	39.2	41.2	5.6
	long	6.9	36.3	41.1	15.7
Medium	short	44.4	31.5	21.1	3.0
	medium	44.5	37.5	17.5	.5
	long	23.2	58.6	12.3	5.9
Deep	short	42.8	46.1	11.1	0
	medium	12.0	44.0	44.0	0
	long	32.0	32.0	36.0	0
Special dive category	Sub. Sat.	30.2	25.6	33.7	10.5
	S. Sat.	15.9	55.9	18.1	10.1
	D. Sat.	0	62.9	37.1	0

shift in behavior such as we see here could be due to the lack of any deep operational heavy-work requirements or a possible environmental limitation on operational performance. The reasons for these results must still be determined. The avoidance of heavy work loads at deep depths is an important area for investigation.

Class Diver

Classification of the divers making the various types of dives is shown in Fig. 31. The one aspect of this figure hard to explain is the large proportion of dives in the deep and subsaturation categories that are made by second class divers. Navy second class divers are qualified in their training to dive to 200 fsw on air. Why these divers are making dives to depths deeper than 200 fsw is not understood. It is possible that these are errors in recording the dives, but the proportion is so large that this explanation seems unreasonable. It is also possible that these deep dives are training dives for second class divers undergoing training to become first class divers. This explanation is plausible in that almost half of the deep dives are for training purposes.

Another interesting observation that can be made from Fig. 31 concerns the relatively small proportion of the shallow saturation dives that are made by saturation-qualified divers. One of two interpretations can be made of this result: either saturation training is not needed for this type of dive, or inappropriately trained people are being used on these dives. The authors believe that saturation training is useful for divers making shallow saturation dives; they believe the reason that saturation-qualified divers have not been utilized by Activities making shallow saturation dives is because those Activities do not have access to divers with this qualification and must operate with the personnel they have.

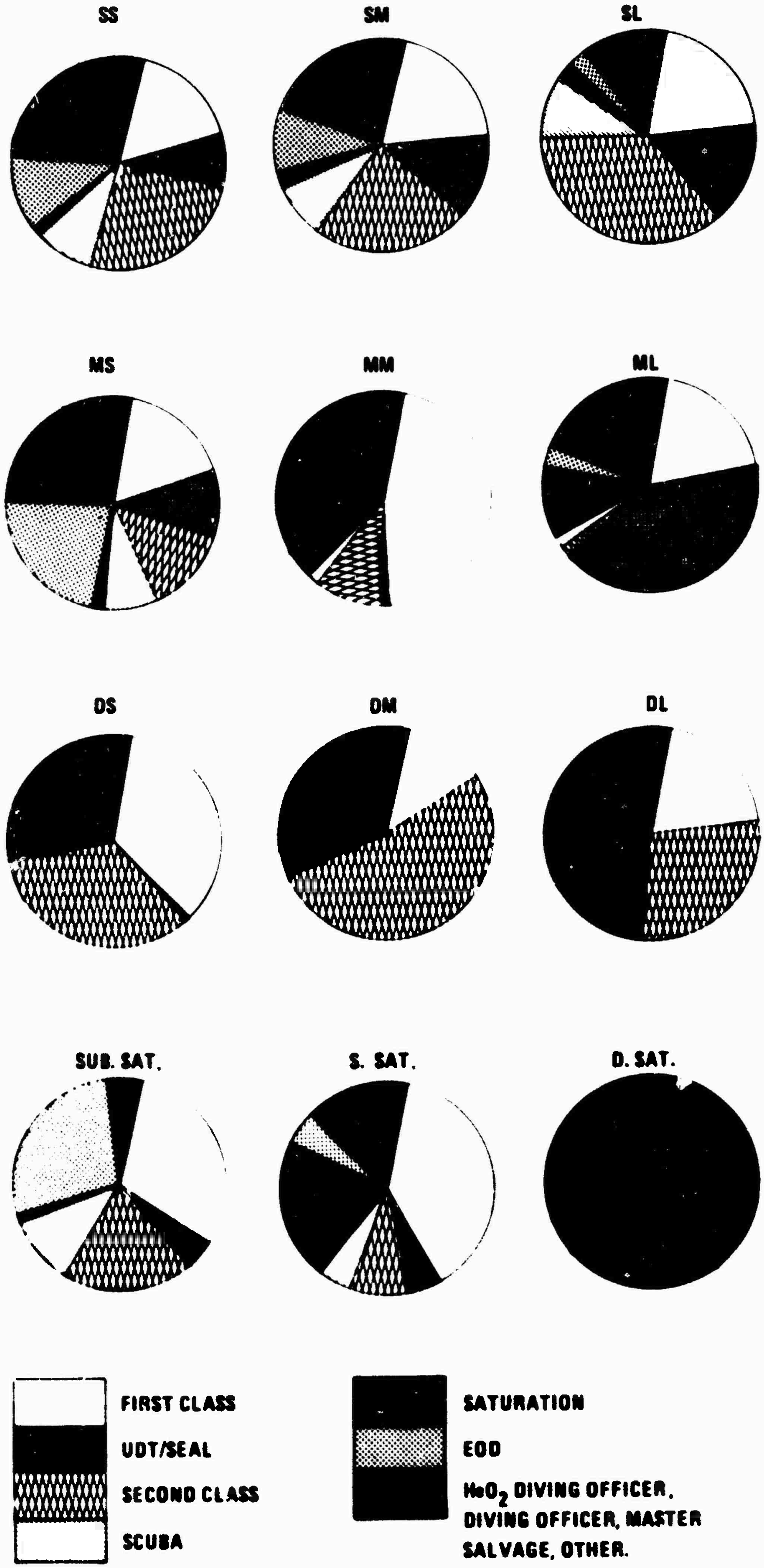


Fig. 31. Classification of divers making the various types of dives.

Marital Status

The distribution of divers among the various dive categories by marital status of the diver is shown in Table 18. There is only one trend worth mentioning in this table and it is not statistically significant. There appears to be a greater tendency to use married divers for deeper dives. This may be an indication of some type of psychological screening going on at the diver supervisor level, or it may be due to chance. It is possible that supervisors are selecting their better adjusted, more stable divers for the deeper, hazardous dives. It is also possible that this is an age-related phenomenon. Several studies have shown personality adjustment and stability are positively correlated with marital status.

ANALYSIS OF PROCEDURAL DATA

Purpose of Dive

There are some interesting things to be seen in Fig. 32. Work dives appear to be the primary reason for making shallow dives. No deep saturation dives are presently being made by the Navy for the purpose of accomplishing useful underwater work; generally deep dives are made for experimental and training purposes rather than work. As stated earlier, commercial diving companies are utilizing the saturation diving technology developed by the Navy, but the Navy itself has yet to identify an operational project requiring the use of this diving technique.

Training dives are the second most frequent reason for diving in the Navy; for some dive categories training dives make up the primary reason. Dive categories used primarily for training include short (<30 min) and long (>60 min) medium-depth (100-200 fsw) dives; short (<30 min) and long (>60 min) deep-depth (200-300 fsw) dives; and shallow saturation dives (>12 hr and < 300 fsw). I requalification dives (which are actually training dives of a sort) were included with the training dives, they would account for almost as many dives as are made to accomplish actual underwater work.

TABLE 18

Distribution of dives among the various dive categories by marital status

Depth	Bottom time		Marital status			
			Married	Single	Separated or divorced	Widowed
Shallow	short		58.6	37.6	3.7	.1
	medium		63.2	32.9	3.7	.1
	long		74.1	22.2	3.5	.1
		$\bar{x}$ =	65.3			
Medium	short		66.7	28.5	4.6	.2
	medium		75.9	19.3	4.7	.1
	long		60.1	37.9	2.0	0
		$\bar{x}$ =	67.6			
Deep	short		78.9	17.4	3.6	.1
	medium		80.0	20.0	0	0
	long		76.0	20.0	4.0	0
		$\bar{x}$ =	78.3			
Special dive category	Sub. Sat.		75.6	23.3	1.1	0
	S. Sat.		79.8	16.4	3.7	0
	D. Sat.		96.3	3.7	0	0
		$\bar{x}$ =	83.9			

$\bar{x}$ = mean.

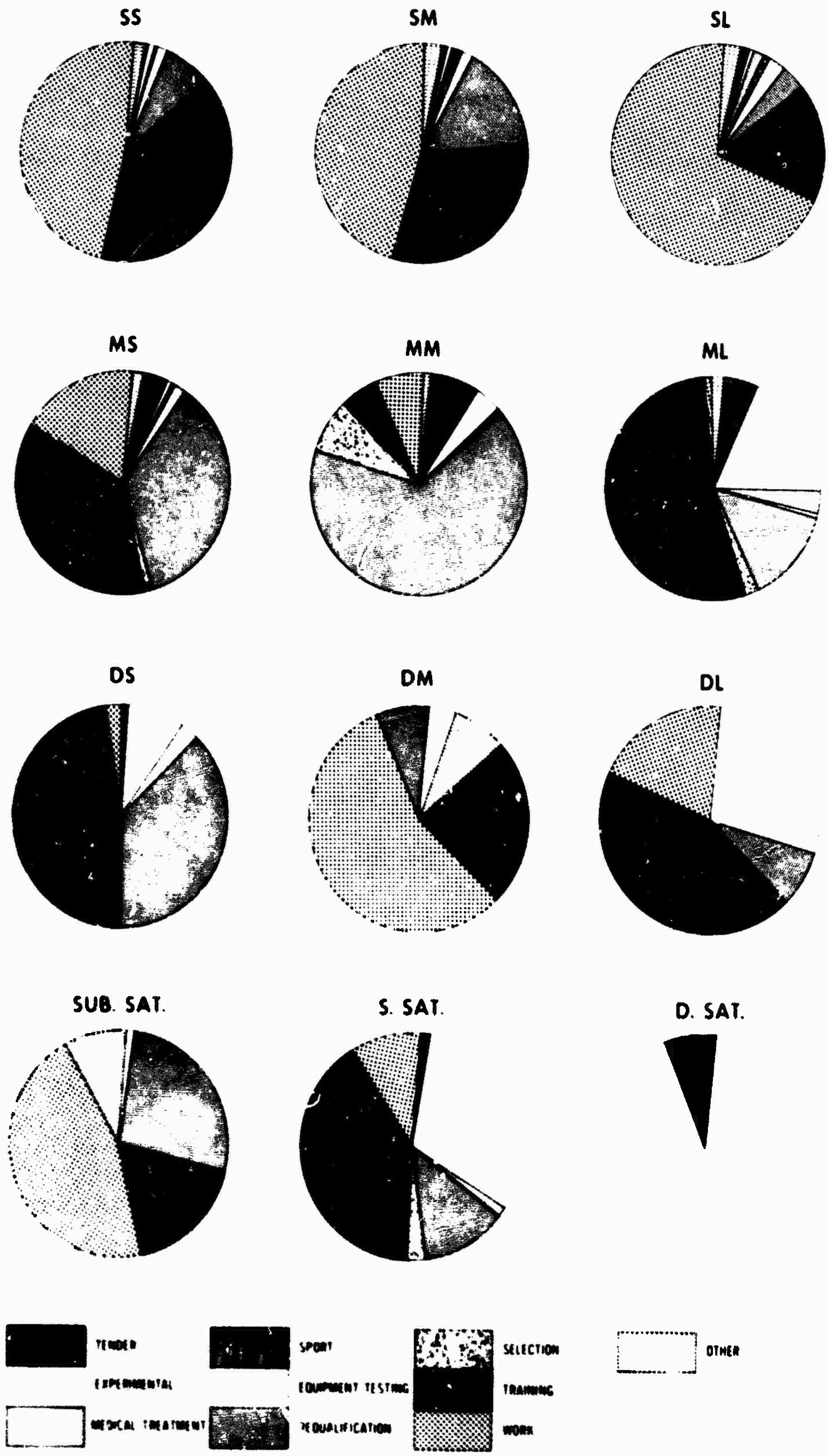


Fig. 32. Reasons for diving in the various dive categories.

It is possible that many shallow work dives go unreported. A diver who goes in the water three or four times in one day to work is probably not going to record each water entry. On the other hand, a diver who does not get in the water very often is going to make sure that when he does it gets recorded for qualification purposes. The result of this variable propensity to record data is that training and requalification dives are more likely to be recorded and consequently carry more weight in these results. Of course, this is speculation and subject to variable interpretation. It is, however, an alternative interpretation that could and should be checked with future data.

Diving Equipment Used

The information in Fig. 33 showing the type of diving equipment used is somewhat misleading and hard to interpret. The equipment classifications on the diving log sheets are not mutually exclusive categories. They appear to be open to varied interpretation or misinterpretation. The equipment classification entitled "Deep Sea Mixed Gas Rig" is intended to mean the modified Mark V helmet with a full canvas suit, weighted shoes, and weight belt. The diving log forms show that 10.7% of the saturation dives are made using this equipment. The authors doubt very seriously that this equipment was ever used on these dives. It would be extremely difficult if not impossible for a Mark V diver to work out of a Deep Dive System.

The log data also indicates that a number of open-circuit scuba dives were made to depths greater than 300 fsw. The Navy's current restriction on scuba dives is 130 fsw, so it doesn't seem reasonable that so many deep scuba dives are taking place. The equipment classification entitled "Closed Circuit Scuba" also produces problems. The very shallow dives in this category are probably closed-circuit oxygen dives, while the deep exposures in this egory are probably closed-circuit mixed-gas dives. The two types of

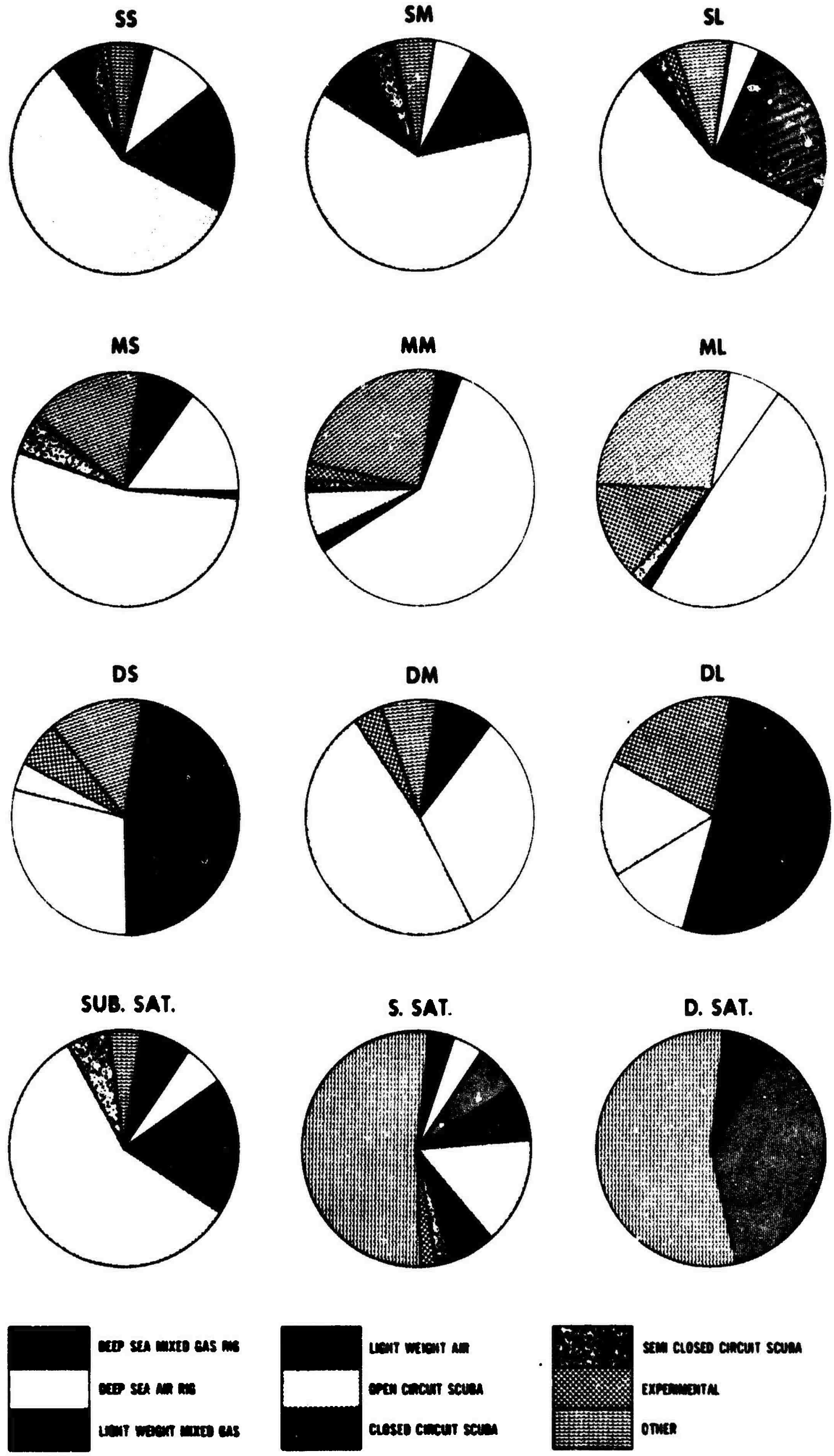


Fig. 33. Type of diving equipment used on various dives.

closed-circuit equipment involved are worlds apart in complexity and operational capability. Lumping all of these dives in the same equipment category is misleading. There are also problems associated with the "Deep Sea Air Rig" classification. The current Navy restriction on this type of equipment is 200 fsw, yet there are recorded dives to depths greater than 300 fsw.

There are obviously many errors or misinterpretations of how to record data in the diving equipment category. Before useful analysis and interpretation of the diving equipment data can be made, the diving log form will have to be changed. Each equipment classification will have to be made mutually exclusive so that only one kind or class of equipment is recorded under each code.

Type of Diving Dress Used

The recorded information on diving dress is more confusing than that on equipment (Table 19). The classification categories are not mutually exclusive or extensive enough to cover the types of diving dress being used. Before useful information can be derived from this data the classification categories must be changed.

Tools Used

As shown in Table 20, tools are used predominately on shallow dives (dives less than 100 fsw). There also appears to be a relationship between bottom time and tool utilization: the longer the dive the more often tools were used. The information obtained from this table, however, is not very helpful in that the reader has no idea of what kind of tools were used. The divers could be using something as simple as a hand tool or as sophisticated as the new hydraulic or electric tools. Regardless of what tools are used, they are all recorded on the diving log sheets in the

TABLE 19

Type of diving dress used in the various dive categories
(%)

Depth	Bottom time	Type of diving dress					
		Deep sea w/gloves	Deep sea w/cuffs	Light weight	Wet suit	Dry suit	Other
	short	10.1	1.6	1.5	69.4	1.0	16.4
Shallow	medium	4.5	1.1	.3	77.4	.7	16.0
	long	3.4	1.0	.2	72.0	.5	22.9
	short	16.7	6.0	0	48.8	5.0	23.5
Medium	medium	20.7	43.4	0	13.7	8.5	13.6
	long	3.5	3.9	0	58.6	2.5	31.5
	short	69.9	5.5	0	5.5	5.7	13.4
Deep	medium	40.0	0	0	40.0	0	20.0
	long	56.0	8.0	0	24.0	12.0	0
Special	Sub. Sat.	8.1	4.7	1.2	65.1	2.3	18.6
dive	S. Sat.	4.6	.4	.4	61.4	3.4	29.8
category	D. Sat.	7.4	0	0	74.1	0	18.5

TABLE 20

Proportion of dives in each dive category in which tools were used (%)

		Bottom time			
		Short	Medium	Long	$\bar{x}$
Depths	Shallow	30.9	32.5	61.6	41.7
	Medium	8.2	7.7	11.3	9.1
	Deep	4.9	20.0	32.0	19.0
	$\bar{x}$	14.7	20.1	35.0	
Special dive category		Sub. Sat.	S. Sat.	D. Sat.	
		36.1	39.1	0	

$\bar{x}$ = mean.

same way. If the tool information is going to be at all helpful, it is necessary that a more specific categorization be developed.

Equipment Performance

The information recorded in this category is potentially the most important information on the entire diving log sheet. Dissatisfaction with or malfunction of diving equipment is an important item to be identified. Diver performance and safety is dependent on the equipment and its use. Just as the Consumer Product Safety Commission is trying to identify unsafe products, so also the Navy should be identifying malfunction and failure in their equipment. A system should be set up so that each time a less-than-satisfactory equipment performance is recorded on the diving log sheet, the equipment components involved are identified and recorded. As this information accumulates, equipment design and manufacturing shortcomings will become evident. It is important to accumulate this information because the failure rates are very low, as is shown in Table 21. A relatively long period of time will be required to establish the statistical base that is needed. The unusually high failure rates for deep long dives is of special interest in that these are rather hazardous dives. Equipment reliability should improve with the depth of the dive; the deeper the dive the more reliable the equipment should be. The problem is that deeper dives usually require more sophisticated equipment and increased complexity usually results in lower reliability. To improve equipment reliability the Navy should monitor the fleet dives, identify the equipment problems as they arise, and institute the proper corrective measures.

Decompression Location

There are many problems with the data in Table 22. A great deal of misunderstanding appears to exist among the divers as to how to fill out

TABLE 21

Percentage of dives reporting substandard equipment performance shown by dive category

		Bottom time		
		Short	Medium	Long
Depths	Shallow	.25	.16	.08
	Medium	.20	0	0
	Deep	.11	0	4.00
Special dive category		Sub. Sat.	S. Sat.	D. Sat.
		0	2.52	0

TABLE 22

Percentage of decompressions performed in different locations for various dive categories

Depth	Bottom time	Decompression location			
		Water	Surface	PTC*	Other
Shallow	short	89.3	.7	0	10.0
	medium	76.7	2.5	0	20.8
	long	63.8	5.5	0	30.7
Medium	short	75.8	4.4	.2	19.6
	medium	89.3	3.3	.2	7.2
	long	28.2	2.6	0	69.2
Deep	short	78.1	9.5	0	12.4
	medium	80.0	0	0	20.0
	long	56.2	0	0	43.8
Special dive category	Sub. Sat.	50.0	0	0	50.0
	S. Sat.	15.9	0	0	84.1
	D. Sat.	13.0	0	0	87.0

*Personnel transfer capsule

this item. The very high use of the "other" category is indicative of the extent of the problem. Another indication of the inadequacy of this item can be seen in the number of divers who reported that their saturation decompression was performed in the water.

The conclusion that must be drawn from the above observations is that the "decompression location" information is completely useless in its present form. The structure of this item should be altered to provide worthwhile information, or the item should be omitted from the diving log sheet.

SUMMARY OF NAVY DIVING STATISTICS

The repeated reference throughout this paper to erroneous data, misinterpreted instructions, and biased recording procedures could lead the reader to believe that little if anything in this report is worthwhile. The reader could even question why the report was written. The aim of the authors in summarizing this report is to outline the positive aspects of the data, give the reader a feel for Navy diving statistics, and conclude by making a few constructive recommendations.

The U.S. Navy has in its diving log recording system the potential for an extremely valuable management tool. These data are potentially useful not only for evaluating diving accidents, but for projecting future trends, evaluating training adequacy, improving diving safety, and identifying areas of needed research.

The 24-month time period upon which this survey is based ran from January 1972 through December 1973. During this period 127,103 dives were recorded, an average of 63,552 dives per year. The dives during this 2-year period accounted for 97,242 man-hours under pressure, an average of 48,621 man-hours per year. This is an incredible amount of time under pressure considering that the average dive has a bottom time of only 31 min.

When one evaluates all of this diving along with the very low accident incidence of .0653%, one cannot help but be impressed.

Perhaps one of the most interesting aspects of this report is its description of the environment in which Navy diving is being done. Despite the large number of dives described above, the environmental conditions involved are quite restricted. Very little diving is done when the waves are greater than 2 ft high or when the current is greater than 1.5 knots. Ninety-nine percent of the dives are done in less than 200 feet of sea water. Very few dives are done in water colder than 50°F, or where the surface temperature falls below 55°F. All of these factors add up to an operational envelope that is quite limited. This is not to say that diving could not be done in more extreme environments, it just says that presently dives are not routinely performed outside this limited envelope. Given the choice of whether to dive or not when conditions are less than optimum, the decision usually is not to dive. Who makes this decision and why has not been determined. It could be the result of a number of interacting variables such as available equipment, training of the divers, or even the potential risk involved. The on-scene commander must evaluate all of these factors in making this decision.

Only 7% of the recorded fleet dives required the use of decompression schedules. This amounts to about 4300 decompression dives per year. During this number of yearly decompressions, 17.5 cases of decompression sickness occur, an incidence of about .41%. Most diving authorities believe that this is a reasonable level of risk for the Navy's diving program. An additional aspect of this problem is that almost all of the cases of decompression sickness have been of the pain-only type and were completely relieved with proper hyperbaric therapy.

A final point of interest in this report is the reason for the dive. In 54% of the dives the reason is something other than underwater work. Dives are made for training, requalification, experimentation, and equipment testing; there are 1.2 support dives of some type for every working dive. Whether people are willing to recognize and accept the fact or not, the Navy's diving program is, in large part, in support of an operational capability. Certainly there are fleet diving needs, and the Navy's present program seems to meet them fairly adequately. The fleet underwater work, however, accounts for only half of the diving done.

Throughout this report we have identified many problems in the present diving log recording system. The diving log is a potentially valuable source of information, but without adequate dive recording the whole system fails. Many items on the form require estimates that are extremely difficult if not impossible to make. Other items do not include mutually exclusive or sufficient categories to cover the dive conditions. Still other diving log items are unessential and of no practical value. A thorough re-evaluation of the diving log reporting system is needed. When this has been done the type of information reported here should be provided to the fleet on a regular basis; the information should be summarized periodically in historical perspective developed for use by the Navy diving training, research, and management communities.

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