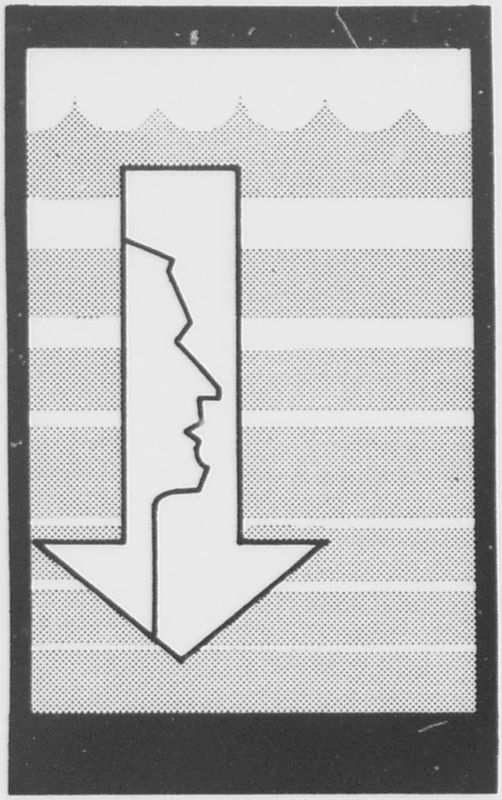
U. S. NAVY

DEEP SUBMERGENCE SYSTEMS PROJECT



RESEARCH REPORT 1-68

RESULTS OF PHYSIOLOGIC STUDIES
CONDUCTED DURING CHAMBER SATURATION DIVES
FROM 200 FEET TO 825 FEET

A PRELIMINARY REPORT

PREPARED BY

LCDR MARK E. BRADLEY, MC, USN
LCDR JAMES VOROSMARTI, MC, USN
CDR PAUL G. LINAWEAVER, MC, USN
CAPT WALTER F. MAZZONE, MSC, USNR

1 MAY 1968

80

TABLE OF CONTENTS

INTRODUCTION 1
BLOOD STUDIES - GENERAL 2
HEMATOLOGY 2
BLOOD CHEMISTRIES 3
LACTIC ACID DEHYDROGENASE 4
HAPTOGLOBINS 7
BLOOD CARBON MONOXIDE 12
COAGULABILITY STUDY..................................13
BLOOD LIPIDS 14
URINALYSES 15
FLUID INTAKE AND OUTPUT 16
BLOOD PRESSURE AND PULSE 17
VENTILATORY DYNAMICS STUDY 18
EXERCISE STUDY 33
HUMAN PERFORMANCE EVALUATION PROGRAM 52
HUMAN LEARNING AND MEMORY STUDY.......................56
VISUAL STUDIES 59
MICROBIOLOGICAL SURVEYS 63
BIBLIOGRAPHY 74

BLANK PAGE

INTRODUCTION

There has been relatively little investigation of the environmental effects of living at depths greater than 300 feet. That data which is available has usually been obtained during brief exposures to depth and on only a few subjects. In the past, conclusions that man could live and effectively work without detrimental effects to himself in a helium-oxygen environment at great depth have often been empirically derived.

From February 1967 to May 1968, The DEEP SUBMERGENCE SYSTEMS PROJECT TECHNICAL OFFICE conducted a series of saturation dives at the U.S. NAVY EXPERIMENTAL DIVING UNIT. These dives were designed to train and select aquanauts for the open sea SEALAB III experiments as well as to measure the psychophysiological effects on man's ability to work at great depths. The psychophysiological research program during these dives was conducted by the DEEP SUBMERGENCE SYSTEMS PROJECT TECHNICAL OFFICE MEDICAL DEPARTMENT with the assistance of the EXPERIMENTAL DIVING UNIT, the NAVAL MEDICAL RESEARCH INSTITUTE, BETHESDA NAVAL HOSPITAL and the NAVAL RESEARCH LABORATORY. This research program represents the most extensive effort yet undertaken to determine the effects on the man living at very high pressures in a helium-oxygen environment.

The purpose of this Summary Report is two-fold. First, it is designed to present the scope of the research program undertaken during the SEALAB saturation dives. Secondly, it will review those areas where physiological and psychological changes were found, and those areas where no changes were observed.

The data in this preliminary report was obtained during 14 saturation dives, ranging in depth from 200 feet to 825 feet. Psychological studies were conducted during "wet" excursion dives to depths of 300, 600, 825 and 1025 feet. Over 25,000 biomedical observations and measurements were obtained in the course of these dives.

Most of the data in this report has not been subjected to an extensive statistical analysis. It is felt though that such analysis will only confirm the conclusions presented in this report. Statistical analysis is presently being performed and will be given in the final reports.

BLOOD STUDIES

General Introduction:

A comprehensive survey was undertaken to evaluate the effects of deep saturation diving on the formed and chemical elements of the blood.

Blood samples were obtained at least once pre-dive and again post-dive, and usually daily in-dive. All samples were obtained by means of venipuncture at 1800 hours following a six hour fasting period. The specimens of whole blood were then placed in appropriately prepared and vented Vacutainer tubes. Blood sample decompression was at a rate of 15 ft/min. This rate has been found to produce no foaming or hemolysis of whole blood specimens. After reaching the surface, clotted blood specimens were doubly centrifuged and the serum required for the chemistries was pipetted off. All samples which were not immediately analyzed were refrigerated until delivery to the appropriate laboratory. When possible, all analyses were performed within 18 hours after the specimens were collected.

Hematology

The following studies were done daily on each subject with the exception of the 200 foot saturation dives when only pre- and post-dive specimens were obtained: Hematocrit, hemoglobin, total white cell count and differential white cell count.

The number of subjects sampled during each series of dives was:

200 ft.	12 subjects	24 samples
450 ft.	32 subjects	360 samples
600 ft.	5 subjects	90 samples

Reticulocyte counts were performed sporadically during the 600 foot dive noted above, and every other day on five subjects during an 825 foot saturation dive. All studies were performed immediately after decompression of the anticoagulated blood specimens. All analyses were made by laboratory technician Hospital Corpsmen attached to the Deep Submergence Systems Project Technical Office and to the Experimental Diving Unit.

No individual or group changes were found in any of the above studies which might have resulted from the saturation exposures.

Blood Chemistry Studies

The following determinations were made on specimens of doubly centrifuged serum by the Clinical Chemistry Laboratory at Bethesda Naval Hospital:

a. Sodium
b. Chloride
c. Potassium
d. Carbon dioxide content
e. Total protein
f. Albumin
g. Calcium
h. Alkaline phosphotase
i. Total bilirubin
j. Urea nitrogen
k. Glucose
l. Glutamic-oxalacetic transaminase

The SMA-12 autoanalyzer, an automated system which requires only small amounts of serum was utilized to make the above determinations.

The number of subjects sampled during each series of saturation dives was:

200 ft.	12 subjects	72 samples
450 ft.	[illegible] subjects	360 samples
600 ft.	5 subjects	90 samples

No changes were apparent in the above parameters as a result of these saturation dives.

Determinations of serum haptoglobins, lactic acid dehydrogenase with isoenzymes, phospholipids, lipoprotein distributions and blood carbon monoxide levels were also performed. These studies will be discussed in separate sections of this report.

LACTIC ACID DEHYDROGENASE

Total serum LDH determinations and isoenzyme distributions were performed in order to ascertain whether saturation exposures using helium-oxygen mixtures cause any tissue damage detectable by these methods.

These analyses were performed in the clinical chemistry laboratory at Bethesda Naval Hospital on the following number of subjects.

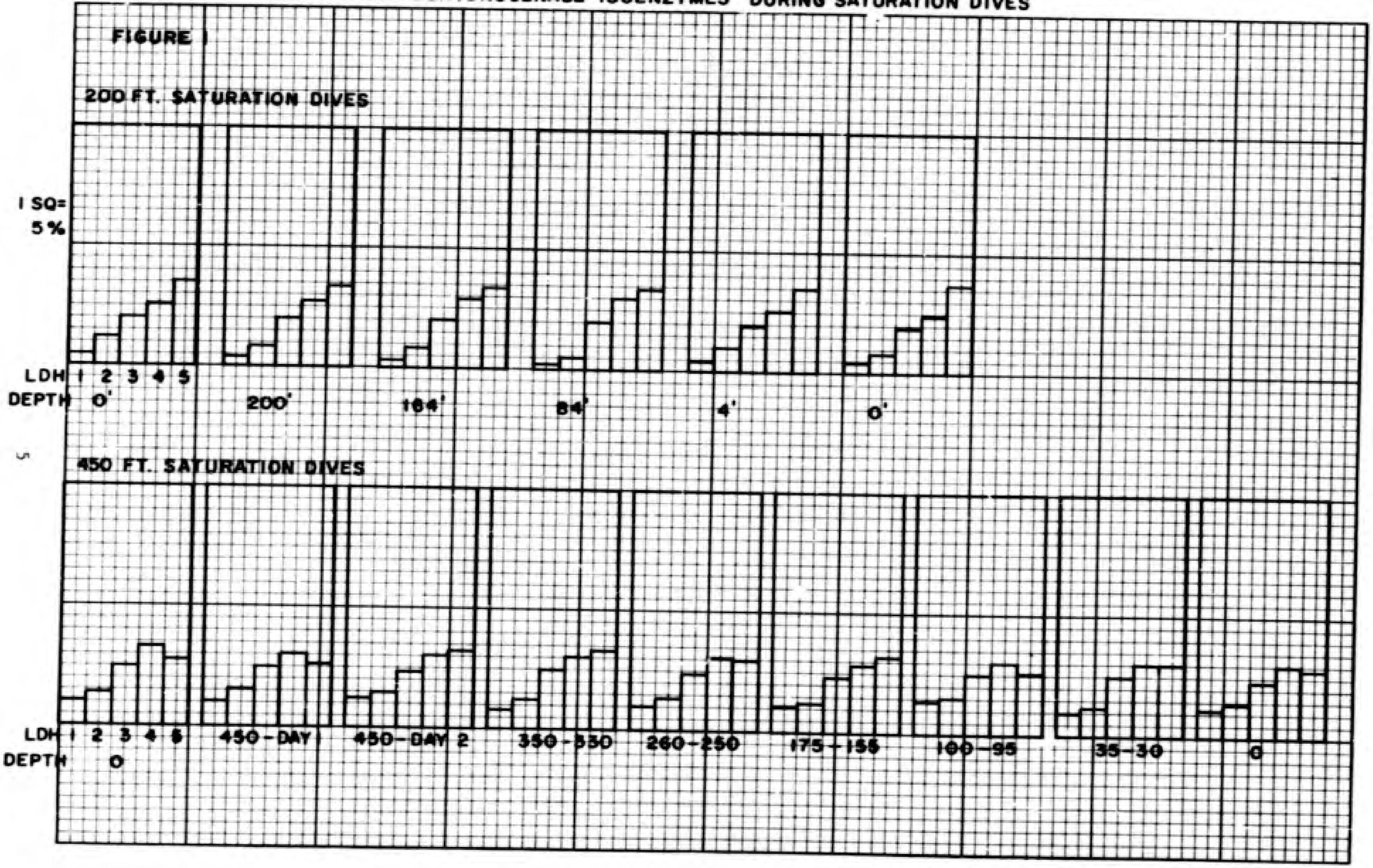
200 foot	8 subjects	48 samples
450 foot	24 subjects	30 samples
600 foot	5 subjects	40 samples
825 foot	5 subjects	40 samples

In contradistinction to the reported increase of the total LDH during SEALAB II (2), no significant change was noted during any of these exposures. During the 200 and 450 foot saturations the isoenzyme distributions remained normal (Fig. 1). However, a definite increase in LDH_5 (myocardial fraction) was found during the 600 and 825 foot exposures (Fig 2.). This increase would ordinarily mean that damage to the myocardium had taken place, but in this case no firm conclusions can be drawn for several reasons. First, it was discovered, shortly after the 825 foot exposure that the dye used in staining the electrophoretograms was defective. The second post-dive sample was done using a new dye mix and was normal in distribution, while all the others, including the pre-dive samples showed the abnormal pattern. This may or maynot have been the cause for the change in the distribution late in the 600 foot dive. Secondly, all specimens were refrigerated prior to analysis and it is possible that cold may change the isoenzyme distribution.

Further work in this area is planned during SEALAB III.

LACTIC ACID DEHYDROGENASE ISOENZYMES DURING SATURATION DIVES

FIGURE I



LACTIC ACID DEHYDROGENASE ISOENZYMES DURING SATURATION DIVES

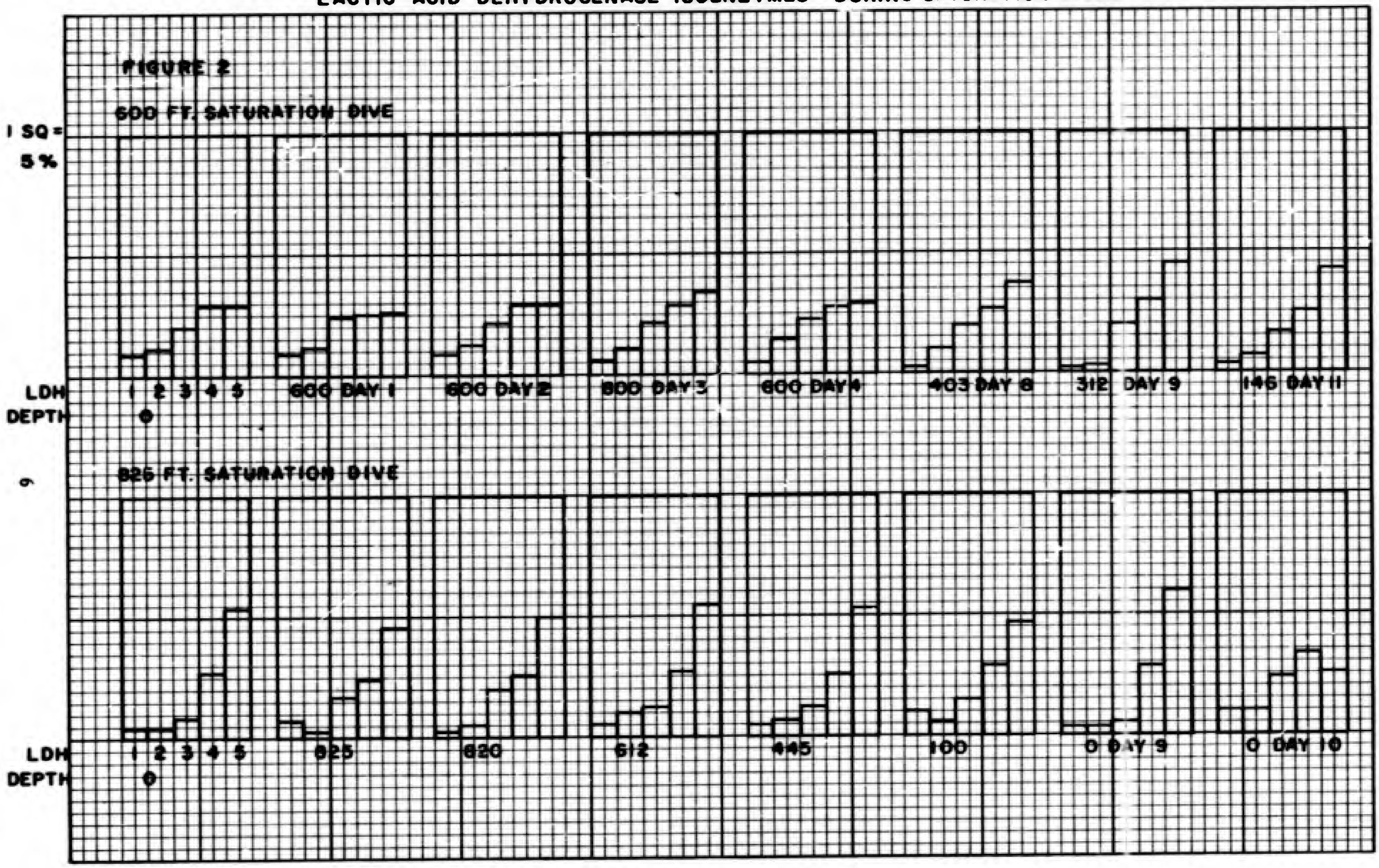


FIGURE 2

HAPTOGLOBINS

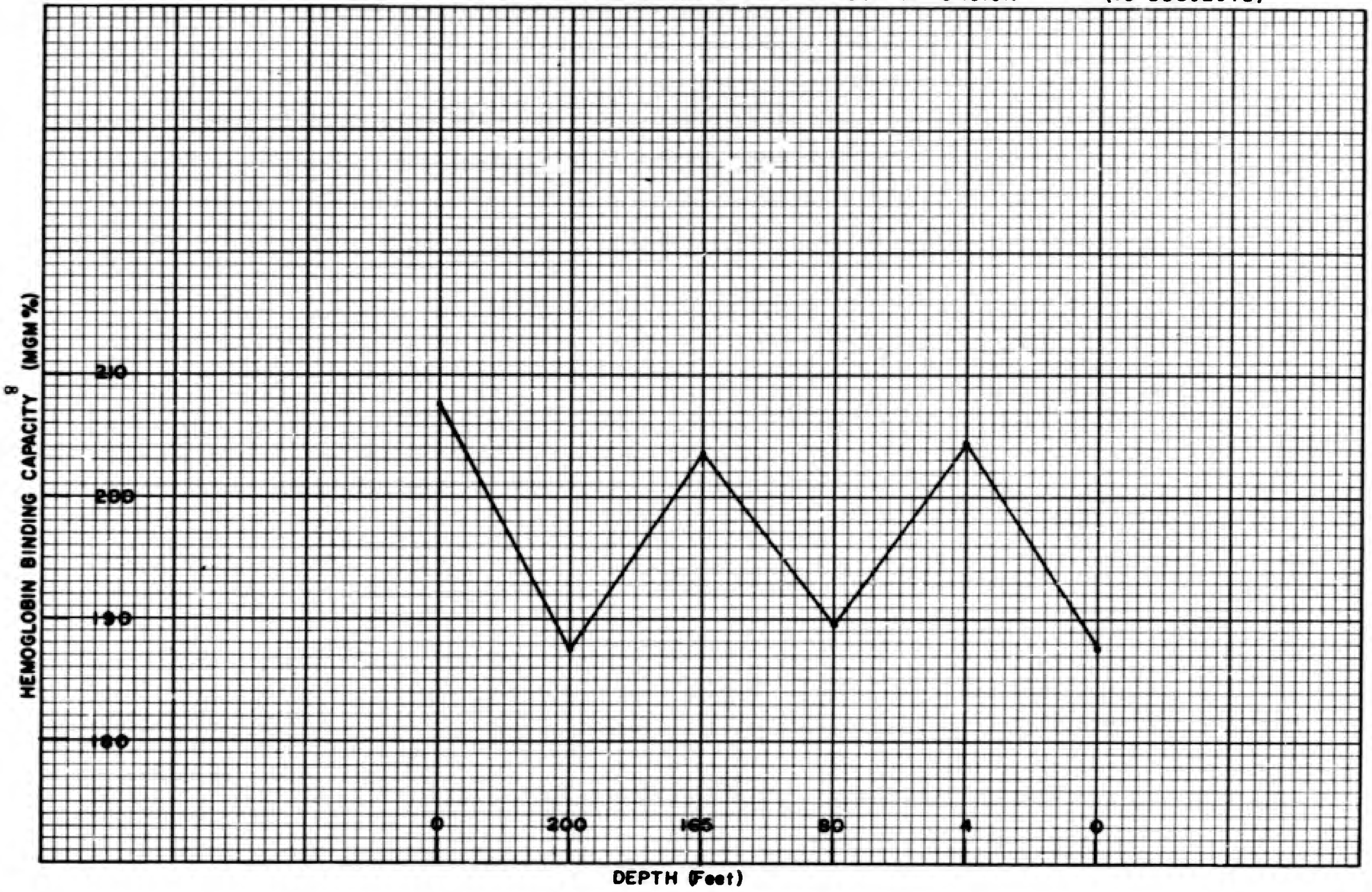
The investigation of serum haptoglobin levels was undertaken as another means of determining whether hemolysis was occurring in these slightly hyperoxic exposures. A fall in the hemoglobin binding capacity of haptoglobin indicates that hemolysis has taken place.

The serum from venous blood samples was analysed in RADM CALVER's physical Chemistry Laboratory at the Naval Medical Research Unit on the following numbers of subjects.

200 foot	18 subjects	84 samples
450 foot	24 subjects	168 samples
600 foot	5 subjects	90 samples
825 foot	5 subjects	45 samples

There were no significant changes noted during either the 200 or 825 foot exposures (figs 1 & 2). During the 450 and 600 foot exposures, however, there was a rise in the haptoglobin levels on the 3-4 day of each dive (Fig 3&4). These elevated levels persisted throughout the entire 450 foot exposures and immediate post-dive samples. The levels during the 600 foot exposure tended, during the last 2 days of decompression, to drop and post-dive were at the same level as the pre-dive samples.

The important conclusion that can be reached from these findings is that no hemolysis occurred during these exposures. The rise in the hemoglobin binding capacity during the 450 and 600 foot exposures is, at this time, unexplainable. High levels of haptoglobins are known to occur during inflammatory processes but there was no other evidence many of these subjects of such a process. No correlation was found between the types of haptoglobins and the changes. Further work will attempt to provide an explanation for these findings.

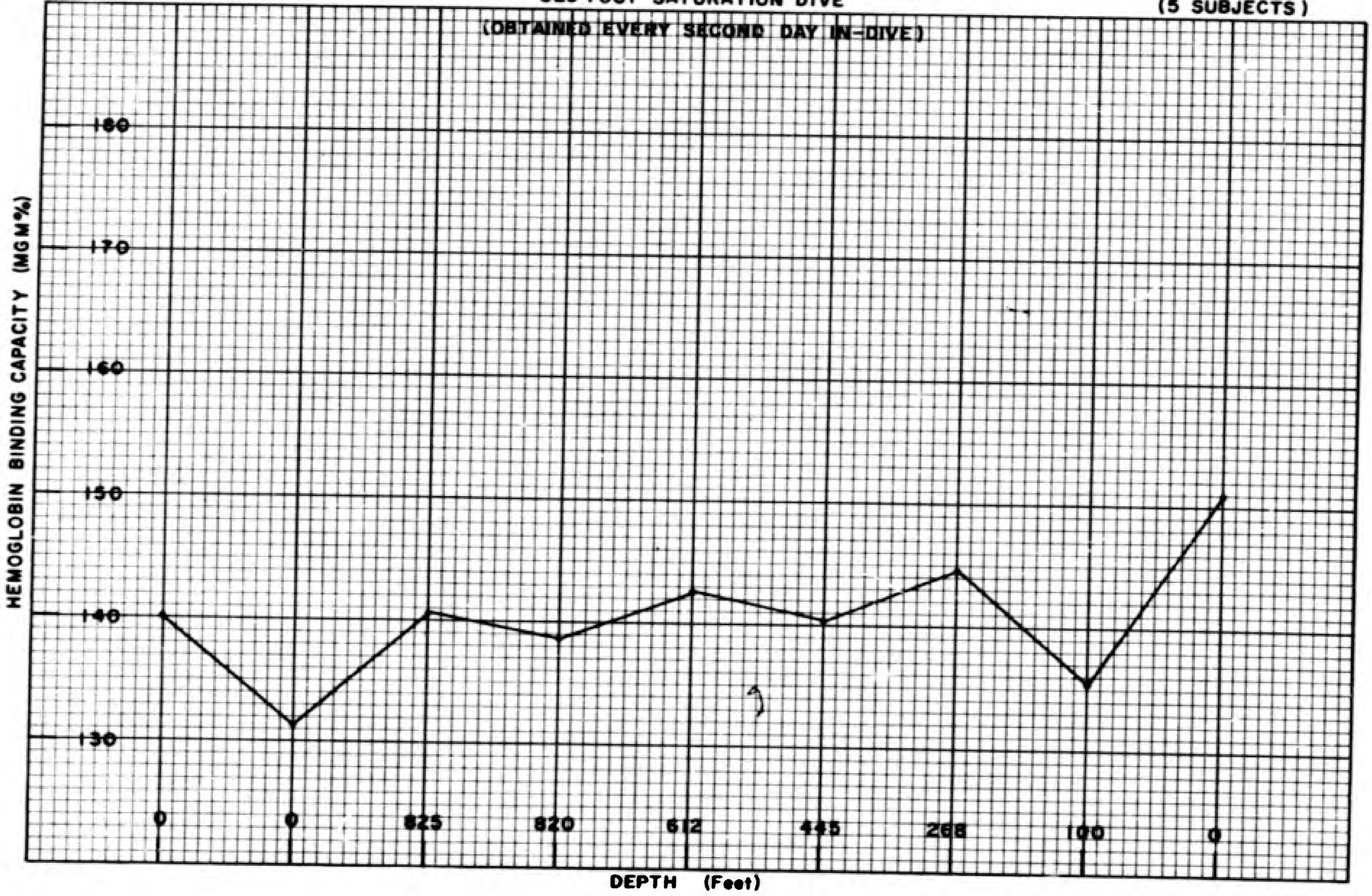


(FIGURE I) 200 FOOT SATURATION DIVES WITH 300 FOOT EXCURSION (18 SUBJECTS)

(FIGURE 2)

825 FOOT SATURATION DIVE (5 SUBJECTS)

(OBTAINED EVERY SECOND DAY IN-DIVE)

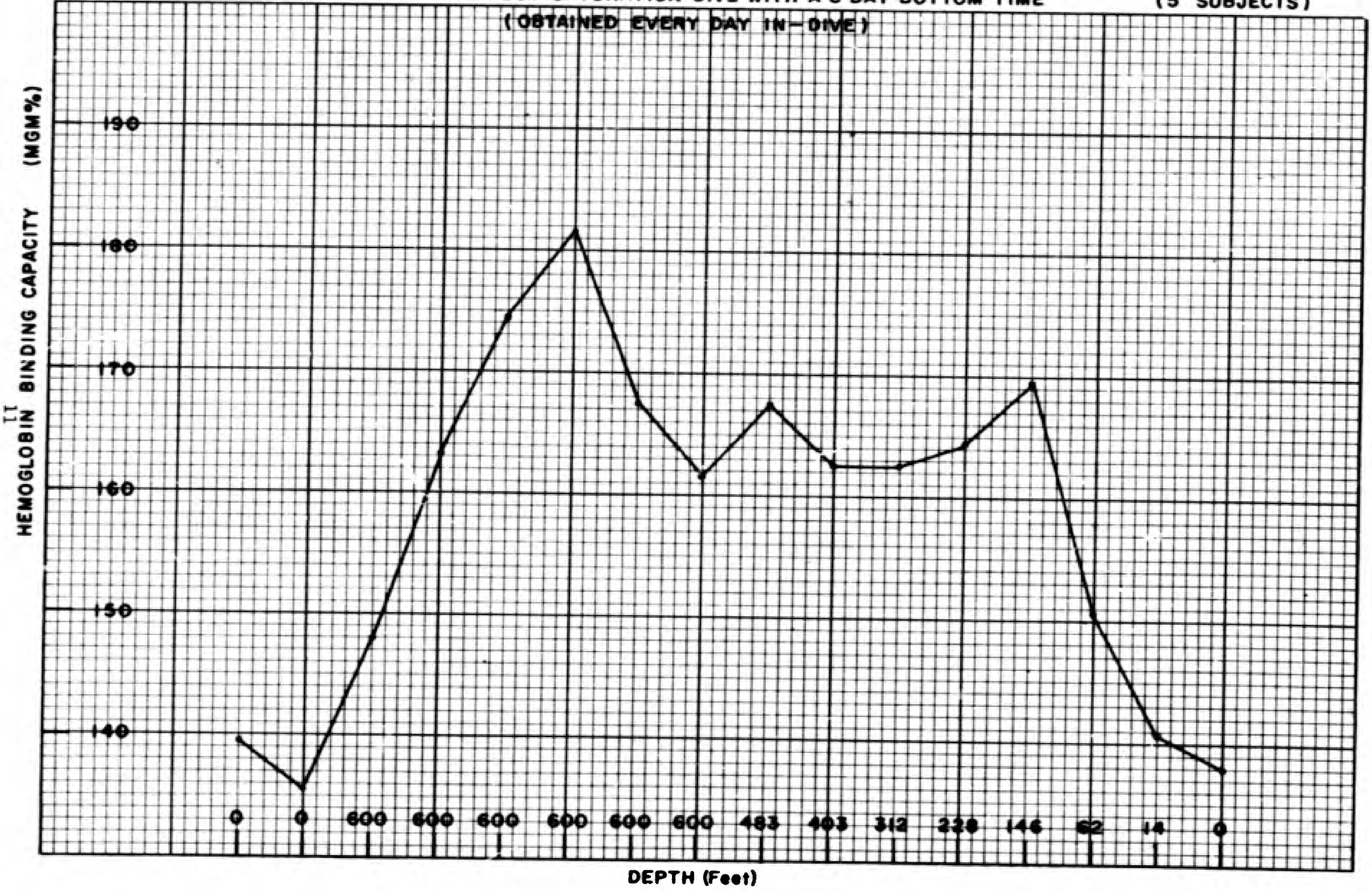


(FIGURE 3) 450 FOOT SATURATION DIVES WITH 600 FOOT EXCURSION (23 SUBJECTS)

(FIGURE 4)

600 FOOT SATURATION DIVE WITH A 6 DAY BOTTOM TIME (5 SUBJECTS)

(OBTAINED EVERY DAY IN-DIVE)



BLOOD CARBON MONOXIDE STUDIES

A study was undertaken to determine the carboxyhemoglobin levels of subjects during long saturation dives. Such a study was considered desirable for the following reasons: First of all, elevated levels of carbon monoxide were reported in the habitat atmosphere of SEALAB II (2). Concurrent with this elevation there was a marked increase in the incidence of severe headaches among the aquanauts. Despite this experience it has never been satisfactorily resolved whether the physiologic effects of carbon monoxide are dependent upon its partial pressure or upon its percentage concentration. Secondly, the effect of a slightly hyperoxic state upon the affinity of hemoglobin for carbon monoxide is unknown. Thirdly, the degradation of the heme molecule is known to produce carbon monoxide as a metabolic byproduct. It was considered important to know whether this process represented a significant and serious source of atmospheric contamination of carbon monoxide during long, deep saturation dives. Lastly, determination of carboxyhemoglobin levels in man has been shown to be a sensitive test for detection of the presence of intravascular hemolysis in man.

In order to investigate this area, specimens of whole blood were analyzed for carbon monoxide by the Physical Chemistry Laboratory of the Naval Medical Research Institute, under the direction of Dr. F. RODKEY and LCDR R. ENGEL, MC, USNR. Chamber gas samples were obtained at the same time that the blood samples were drawn. These gas samples were analysed by the Chemistry Division of the Naval Research Laboratory.

The following number of specimens was obtained during each series of saturation dives:

200 ft.	12 subjects	72 samples
450 ft.	20 subjects	180 samples
600 ft.	5 subjects	90 samples
825 ft.	5 subjects	50 samples

On the basis of the data obtained it appears that the following statements can be made. First, there is no evidence of intravascular hemolysis resulting from these prolonged exposures to a slightly hyperoxic environment. Atmospheric levels of carbon monoxide rose steadily throughout the dives. This was probably due to the metabolic production of carbon monoxide. Metabolic production of carbon monoxide does not appear to be of significant quantity to produce dangerously high levels of carbon monoxide over a two week exposure period. Blood carboxyhemoglobin levels of smokers and non-smokers were found to equilibrate after approximately 24 hours confinement in a hyperbaric chamber.

Next, it appears that the saturation of hemoglobin with carbon monoxide is directly related to the partial pressure of carbon monoxide in the atmosphere. Lastly, the slight degree of hyperoxia present during these dives did not appear to appreciably alter the affinity of hemoglobin for carbon monoxide.

This study will be continued during SEALAB III to better delineate this area during a 2 month exposure period.

BLOOD COAGULABILITY STUDIES

Changes in bleeding and clotting times have been noted in animal experiments at extremely high pressures (4). During a 600 foot saturation dive with 6 days of bottom time, a study was therefore undertaken to investigate blood coagulability in men exposed to high pressures of a helium-oxygen atmosphere.

The procedures of this study included a standard bleeding time using an ear lobe puncture, and a standard three tube (Lee White) coagulation time. Five subjects were studied pre-dive, post-dive, twice at 600 feet, and three times during the decompression. All tests were performed by a physician.

No changes in either bleeding time or coagulation time could be demonstrated during a 6 day exposure to 600 feet.

BLOOD LIPID STUDIES

During an 825 foot saturation exposure blood specimens were obtained from 5 subjects for a study of stress reaction as reflected by changes in the blood lipids. Analysis of the samples is being performed by the Environmental Stress Laboratory of the Naval Medical Research Institute for individual phopholipids, lipoprotein distribution, neutral lipids and haptoglobin levels. Blood samples were obtained at 1800 hours after a six hour fasting period pre- and post-dive, and every other day in-dive.

No results as yet available for inclusion in this report. Results of these studies will be presented in the final report of these saturation dives.

URINALYSIS

Freshly voided urine specimens were collected at least once pre- and post-dive, and daily in-dive at approximately 1800 hours. These specimens were decompressed along with the blood samples and the following tests performed by Laboratory Technician Hospital Corpsmen attached to the Deep Submergence Systems Project Technical Office and to the Experimental Diving Unit.

a. Appearance

b. pH

c. Glucose

d. Protein

e. Occult Blood

f. Microscopic examination of centrifuged specimens

The number of subjects studied during each series of dives was:

200 feet	12 subjects	24 samples
450 feet	32 subjects	360 samples
600 feet	5 subjects	90 samples

Urinalyses remained within normal limits throughout the above saturation exposures. No changes were found which might have resulted from these deep saturation dives.

FLUID INTAKE AND OUTPUT

It has been reported that two subjects experienced a marked diuresis during a 650 foot dry saturation dive (1). This diuresis dramatically disappeared during decompression.

Diuresis during water immersion is a well recognized phenomenon. A 10% decrease in plasma volume has been reported during a six hour period of immersion (3). Changes in intravascular fluid volume could conceivably alter the rate of inert gas uptake and elimination, and thus affect decompression. Therefore, during two 450 foot saturation dives with 600 foot excursions, eight subjects measured and recorded their fluid intake and urinary output for the entire in-dive period. Intake and output measurements were also obtained for the 24 hour period immediately pre- and post-dive. Fluid intake was estimated by knowing the capacity of cups, soda cans, etc. Urinary output was measured with an ordinary measuring cup.

The results of this study showed a definite decrease of fluid intake throughout the in-dive period. Urinary output decreased during the initial 24 hour in-dive period. However, during the remaining in-dive period, output was generally slightly greater than the volume of fluid intake. In these dives there was certainly no sudden diuresis upon compression.

It is felt that the decreases in fluid intake and increases in urine output resulted from the very high humidity during these dives which markedly reduced insensible water loss.

BLOOD PRESSURE AND PULSE

Bradycardia has been reported to occur in divers during deep saturation exposures (1). Therefore the pulse rates and blood pressures of eight subjects were measured throughout two 450 foot saturation dives.

Blood pressures were taken with a standard aneroid sphygmomanometer. Radial pulse rates were counted for 30 seconds and doubled to obtain a one minute pulse rate. All measurements were made by only one person and with the subject lying supine. Both blood pressure and pulse rate were measured every four hours in-dive and every 4 hours during the 24 hour period immediately pre-dive.

No changes could be demonstrated in either the blood pressure or pulse rate of these subjects, other than those which might be expected to result from the limited degree of activity permitted by chamber confinement.

VENTILATORY DYNAMICS STUDY

Because of the need for deep diving operations by the U.S. Navy it is necessary to know the limitations which are imposed upon human respiration by breathing high pressure helium-oxygen mixtures. There is little information presently available concerning the effects on the ventilatory dynamics of men breathing dense mixtures of helium and oxygen.

Increased work of breathing and increased airway resistance may be expected to result from the greater density of gas. In practical diving the additional resistance in the tubes and valves of the diving equipment has to be taken into account. These further increase the total respiratory resistance and hence the total respiratory work. As man dives deeper, the acceptable breathing resistance of diving equipment must become progressively less in order that adequate ventilation and pulmonary gas exchanged can be maintained.

The primary objective of this study was to quantitate the increase in pulmonary resistance occurring while breathing helium-oxygen at high pressures. Such quantitation would better define the acceptable resistances of diving equipment.

A secondary objective was to examine the ventilatory effects of breathing neon at depth. Neon is an inert gas of low narcotic potency and offers possible advantages in multiple gas decompression from deep helium dives.

The basic equipment used was a low resistance wedge spirometer, Model 270 (Med-Science Electronics, Inc.) used without CO_2 absorbent. A smooth-bore breathing tube, 2" in diameter, and a large bore mouthpiece were used to maintain the low resistance characteristics of the system. Esophageal balloons, 1.2 cm. in width and 10 cm. in length, were affixed over the distal end of an 80 cm. length of polyethylene catheter. Multiple small holes had been made in the length of the catheter covered by the balloon. The pressure difference between the mouthpiece airway and the esophagus was measured with a Sanborn differential pressure transducer. The electrical signals for volume, flow and the differential pressure were fed simultaneously into a Model 150 four channel Sanborn recorder.

Volume calibration was performed prior to each use by injecting and withdrawing 7,000 cc of gas into the Wedge with a 1,000 cc syringe. Both volume and flow were also electronically calibrated. Flow calibration was checked by calculating the slope of volume change. The pressure transducer was calibrated with a water manometer before each use.

Seven normal male divers served as subjects for the entire study. Measurements of only lung volumes and forced expired volumes were obtained on three additional divers.

Measurements were obtained on each subject who participated in the entire study while breathing quietly, during deep and fast respiration and while performing three forced maximum expirations. After these maneuvers had been performed, the subject continued breathing from the Wedge and a gas sample was taken from the mouthpiece for analysis.

Breathing mixtures used pre- and post-dive were 30% oxygen, balance helium; 30% oxygen, balance nitrogen; and 30% oxygen, balance sulfurhexafluoride. Measurements of static pressure volume properties of the lungs were made while the subject breathed room air. At depth, the breathing mixtures were either the chamber atmosphere (which consisted of 0.3 atmospheres of oxygen, 1.2 atmospheres or less of nitrogen, with the balance helium) or pure neon with 0.35 atmospheres of oxygen.

The same experimental procedure was followed at depth as pre- and post-dive, with the exception that static pressure-volume curves were not measured in-dive. Measurements were obtained on the subjects participating in the entire study in the following sequence:

a. 24 hours pre-dive (7 subjects).

b. At 825 feet breathing the chamber atmosphere and breathing neon-oxygen. (4 subjects).

c. At 750 feet breathing the chamber atmosphere (4 subjects).

d. At 600 feet breathing the chamber atmosphere and neon-oxygen (7 subjects).

e. At 450 feet breathing the chamber atmosphere and neon-oxygen (7 subjects).

f. At 300 feet breathing the chamber atmosphere and neon-oxygen (7 subjects).

g. At 150 feet breathing the chamber atmosphere and neon-oxygen (7 subjects).

h. 2-3 hours post-dive (7 subjects).

In order to change from one gas mixture to another, the Wedge was filled with ten liters of the gas to be used. The subject then performed a series of maximum expiratory vital capacities to the atmosphere and maximum inspiratory vital capacities from the gas filled Wedge in order to wash out the lungs. After the final wash-out breath the Spirometer was left filled with 7-1/2 liters of the gas mixture, and the subject performed the maneuvers of the experiment.

The following data is, or will be, available from the measurements obtained on each of the seven subjects at each depth, breathing each of the gas mixtures.

a. Vital Capacity.

b. Forced Expired Volume in 1.0 second.

c. Maximum expiratory flow rate.

d. Volume at maximum expiratory flow rate.

e. Maximum mid-expiratory flow rate.

f. Inspiratory Reserve Volume.

g. Expiratory Reserve Volume.

h. Volume - Flow loops and their interpretation.

i. Dynamic Compliances.

j. Pressure - Volume loops and their interpretation.

k. Pulmonary resistance.

l. Work of breathing.

m. Isovolume pressure - Flow curves.

n. Static pressure - Volume curves, pre- and post-dive.

The following data and calculations are available on one subject pre-dive and from 825 feet to the surface, and on two subjects pre-dive and from 600 feet to the surface:

a. Vital capacity.

b. Forced expired volume in 1.0 second.

c. Maximum expiratory flow rate.

d. Volume at maximum expiratory flow rate.

e. Maximum mid-expiratory flow rate.

f. Volume - flow loops and their interpretation.

Most of the above information has not yet been extracted from the raw data. The Deep Submergence Systems Project Technical Office Medical Department, together with LCDR N. ANTHONISEN, MC, USNR, of the Environmental Stress Division, of the Naval Medical Research Institute, are presently engaged in the data analysis required to complete this study. Consequently, only a few results are presented in this report.

Results:

There was a small (3-6%) increase in the vital capacity of the subjects while at depth. Post-dive vital capacities were also noted to be slightly greater than pre-dive. (Figure 1).

There was a progressive, linear decrease in the 1.0 second maximum expired volume from sea level to 825 feet while breathing helium-oxygen. At 825 feet this decrement amounted to 27% of the control value. (Figure 2) Maximum expiratory flow rate fell to 50% of surface value at 825 feet. (Figure 3) The volume at which peak flow occurred was noted to lessen as gas density increased.(Figure 4) Maximum mid-expiratory flow rate progressively fell to 35% of the sea level value at 26 atmospheres while breathing helium-oxygen. (Figure 5).

Calculated maximum breathing capacity was found to decrease to 70% of the sea level value at 825 feet. (Figure 6).

The average dynamic compliances for 3 subjects breathing helium-oxygen mixtures at rest and at increased ventilatory volumes are presented in Table (1).

TABLE 1

DYNAMIC PULMONARY COMPLIANCES OF THREE SUBJECTS BREATHING HELIUM-OXYGEN

Depth	C_L during tidal breathing L/cm H_2O	C_L during increased ventilatory volumes L/cm. H_2O
Surface (pre-dive)	.255	.232
150'	.199	.151
300'	.215	.267
450'	.203	.197
600'	.215	.181
Surface (post-dive)	.200	.193

There was no apparent change in pulmonary dynamic compliance in these subjects with increasing depth and length of exposure to a hyperbaric helium-oxygen environment.

Both inspiratory and expiratory pulmonary resistances rose with increase in gas density. Figure (7) presents the average increase in pulmonary resistance during resting ventilation, measured at a volume of 600 cc. During quiet tidal breathing, average inspiratory pulmonary resistance rose to 3.2 cm H_2O at 450 feet from a control value of 1.5 cm. At 600 feet, inspiratory resistance fell slightly to 2.5 cm. of H_2O. Expiratory resistance at sea level breathing 30% oxygen in helium was 1.85 cm of H_2O, and it increased to 5.2 cm. H_2O at 600 feet.

At elevated ventilatory volumes, mean inspiratory resistance did not appear to appreciably change from that present during resting ventilation. (Figure 8). Expiratory resistance increased linearly to 6.65 cm H_2O from sea level values of 1.75 cm.

Discussion:

Only fragmentary pieces of information are presently available from this study as considerable data analysis remains to be done.

During some of the early 200 and 450 foot saturation dives performed at the Experimental Diving Unit, pre- and post-dive measurements of vital capacity were obtained. Small decreases (2-3%) in the post-dive vital capacity were noted. Some investigators have reported precipitous falls in vital capacity during exposure to high pressures of helium-oxygen. (2).

Neither in-dive or post-dive decreases in vital capacity were detected in this present study, but rather small increases were observed. Small increases in vital capacity in-dive and post-dive have previously been reported (1, 12). The increase is not readily explained, but we feel that high motivation and improvement in performance as a physiological subject may be partly responsible for this phenomenon in our study.

As expected there were progressive decreases in the 1.0 second forced expired volume, maximum expiratory flow rate and maximum mid-expiratory flow rate as gas density increased. The changes noted in these parameters quantitatively agree well with those found by other investigators at 650 feet (1) and predicted by Maio and Fahri (13).

Peak flow occurs progressively earlier in expiration as gas density becomes greater. This phenomenon possibly results from the greater mechanical advantage afforded to the respiratory muscles at full inspiration by breathing denser gas mixtures.

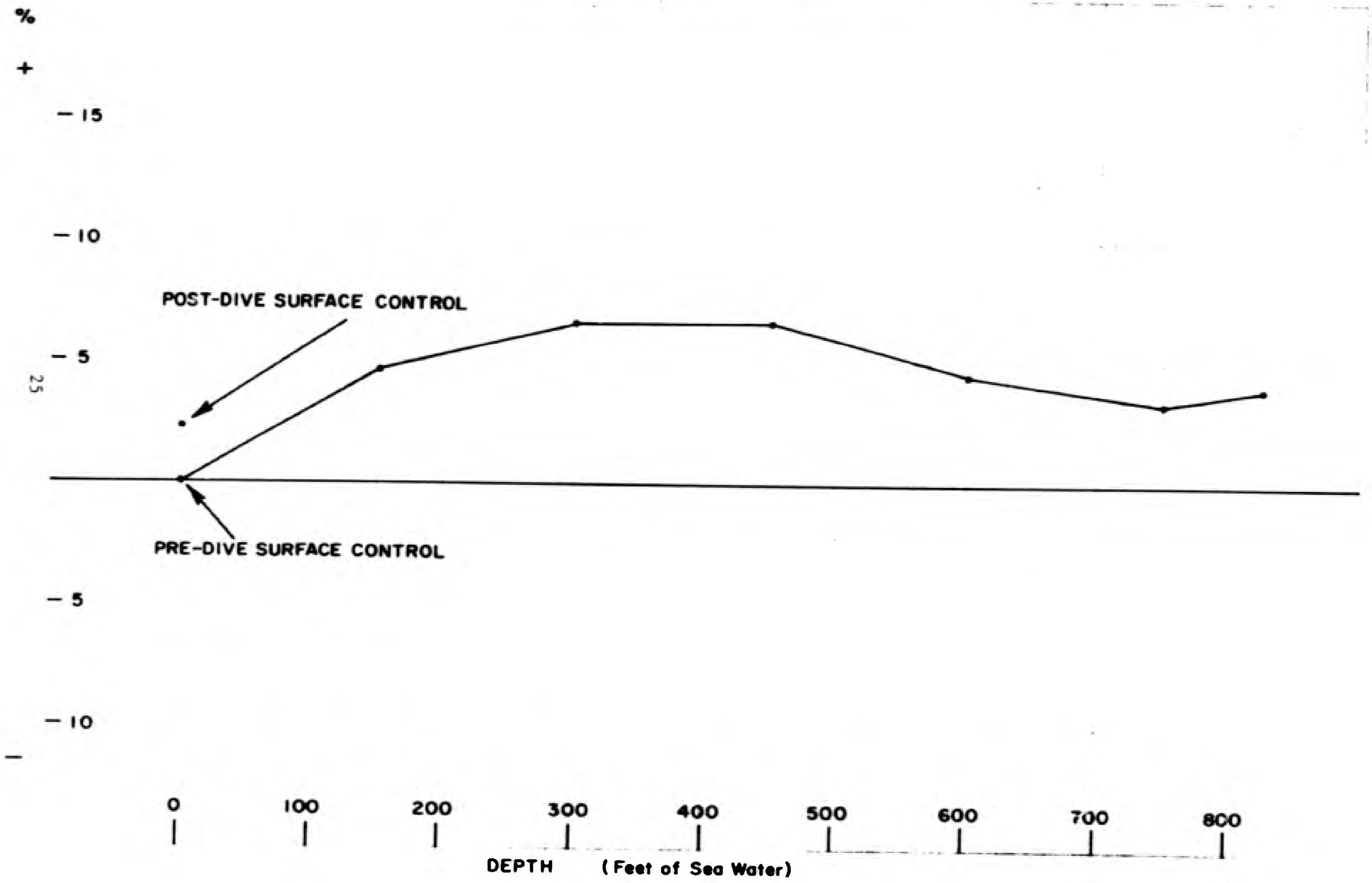
At 825 feet, the calculated maximum breathing capacity had fallen 27% from the pre-dive sea level value obtained during helium-oxygen breathing. This decrement is less than that predicted by Maio and Fahri (13)for breathing a gas mixture roughly five times as dense as that of sea level air. It is possible that this lesser than predicted decrement is attributable to the indirect method of obtaining maximum breathing capacity in our study.

Dynamic pulmonary compliances were not observed to change during and after two weeks of breathing a helium-oxygen atmosphere at pressures up to 19.2 atmospheres. It would appear that the elastic properties of the lungs were not altered by this exposure. Compliance has been reported to decrease in the presence of pulmonary oxygen toxicity (14) We tentatively conclude on the basis of our findings that breathing a slightly hyperoxic helium mixture at pressures up to 19.2 atmospheres does not alter dynamic compliance. Inclusion of the pre- and post-dive static pressure-volume curves and of the data on the four other subjects who participated in the 825 foot dive should support this conclusion.

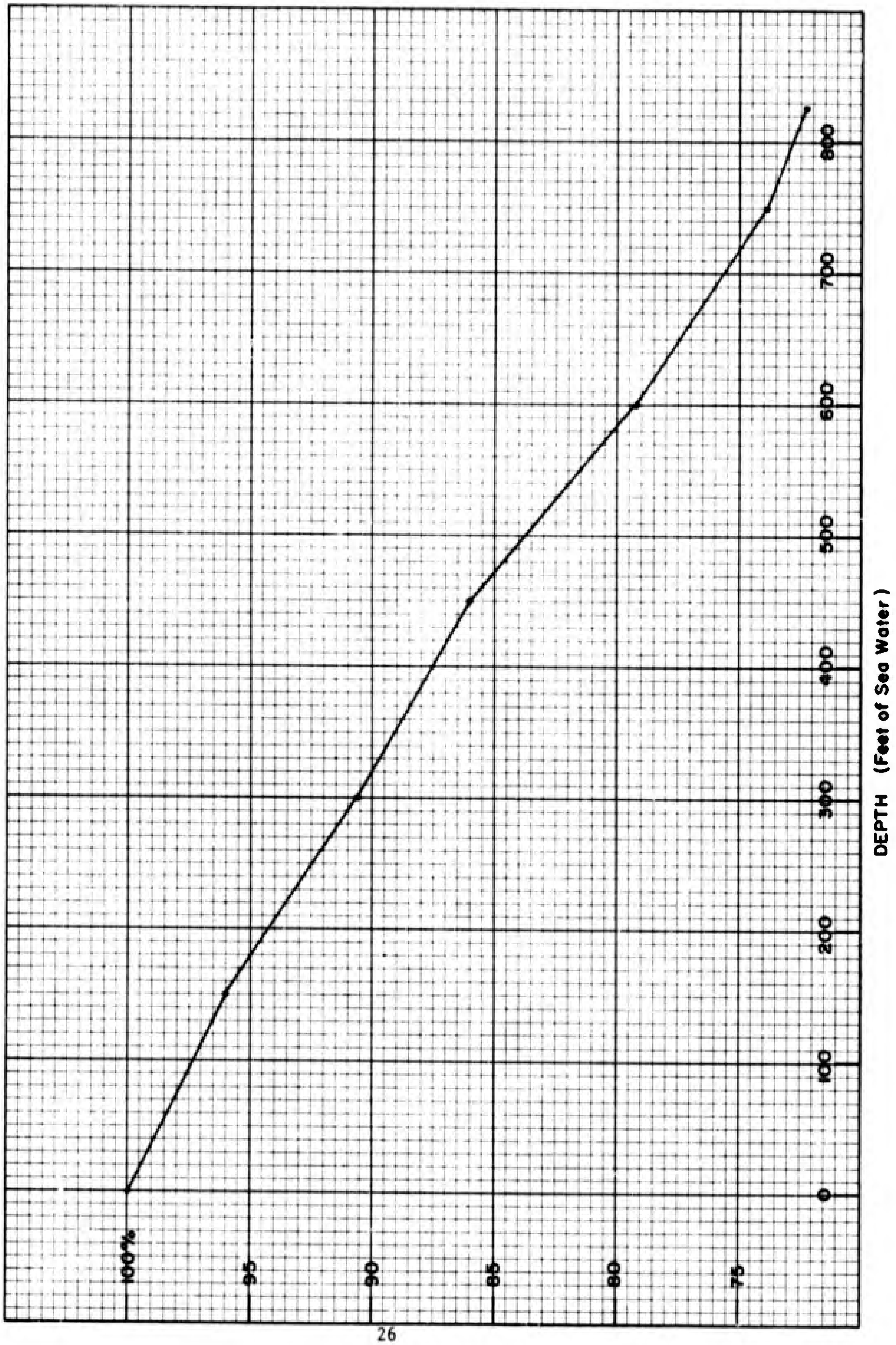
Pulmonary resistive forces appear to increase linearly to 600 feet. Inspiratory resistance, measured at about the mid-point of inspiration during quiet breathing and at three points during deep, fast respiration, was little more than doubled at 600 feet. The rather low value at 600 feet during quiet breathing may be in error. Further analysis and inclusion of the data from the four subjects studied on the 825 foot saturation dive should clarify this point.

As expected, airway resistance in expiration was considerably more affected by the increased density of gas. It has been suggested that increased expiratory resistance during dense gas breathing may be partly due to trapping of gas in the alveoli with consequent partial bronchiolar collapse during expiration (15). Subsequent data analysis will delineate pulmonary resistances at depths of 750 and 825 feet, and expand those findings thus far obtained. Furthermore, the data available on neon breathing in this study may permit us to predict the ventilatory limits in diving with very dense helium mixtures.

VITAL CAPACITY PERCENT CHANGE/DEPTH (FIGURE 1)



$FEV_{1.0}$ PERCENT OF SURFACE CONTROL TO 825' BREATHING $He-O_2$ (FIGURE 2)



MAXIMUM EXPIRATORY FLOW RATE DEPTH WHILE BREATHING $He-O_2$ (FIGURE 3)

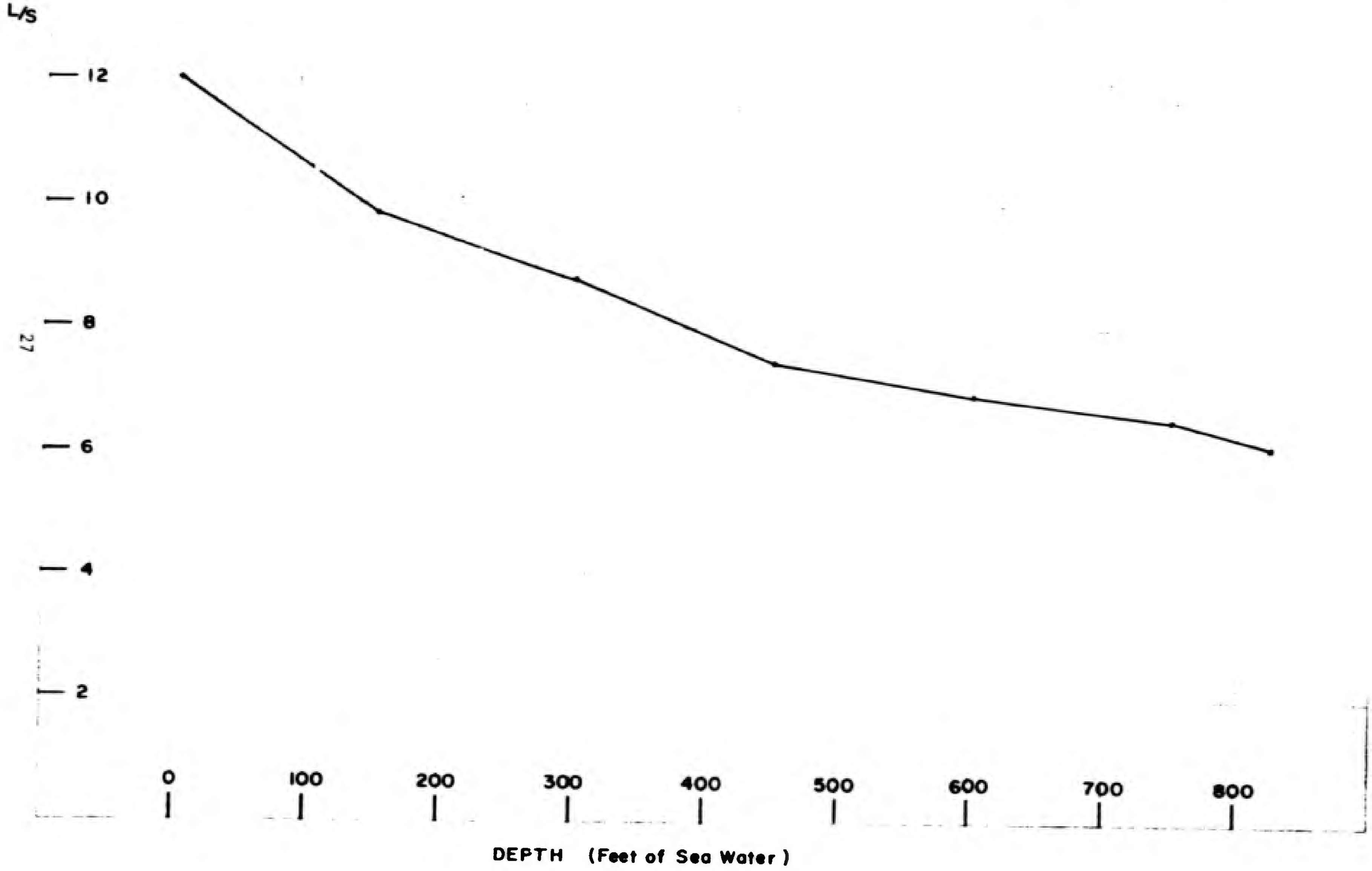
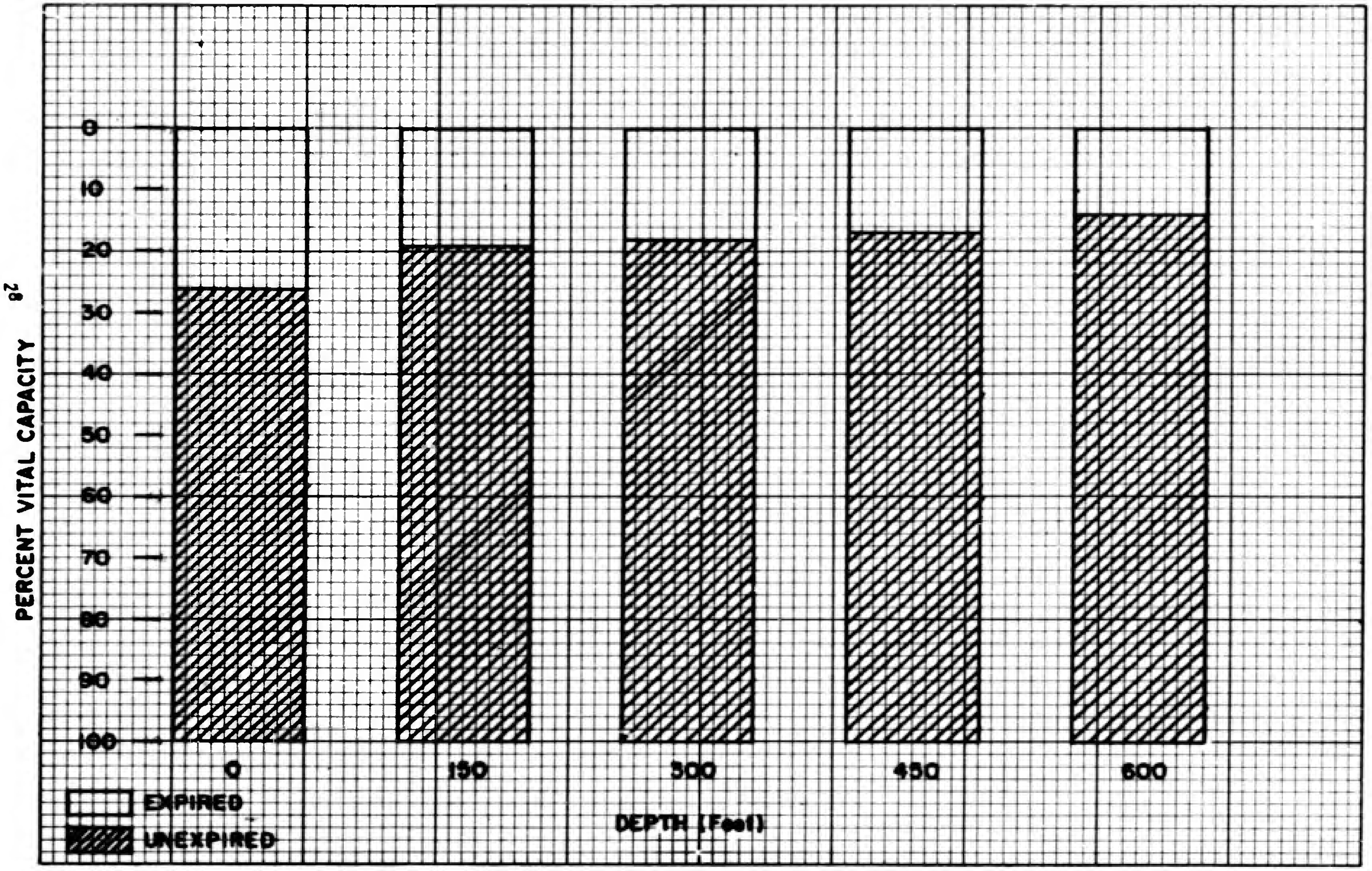


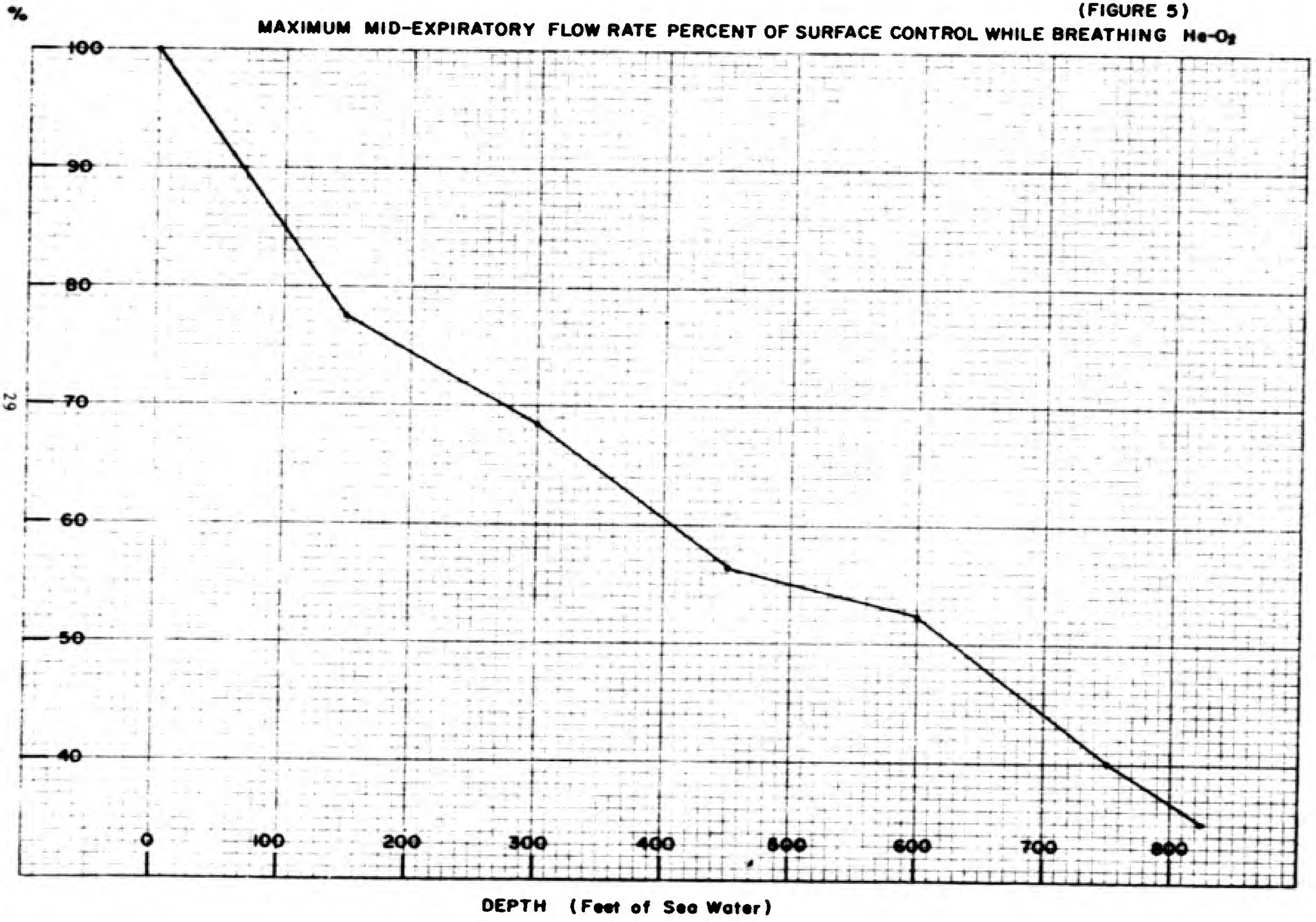
FIGURE 4

THE PERCENT OF VITAL CAPACITY EXPIRED AT WHICH MAXIMUM FLOW OCCURS DURING A F.E.V. BREATHING HeO_2

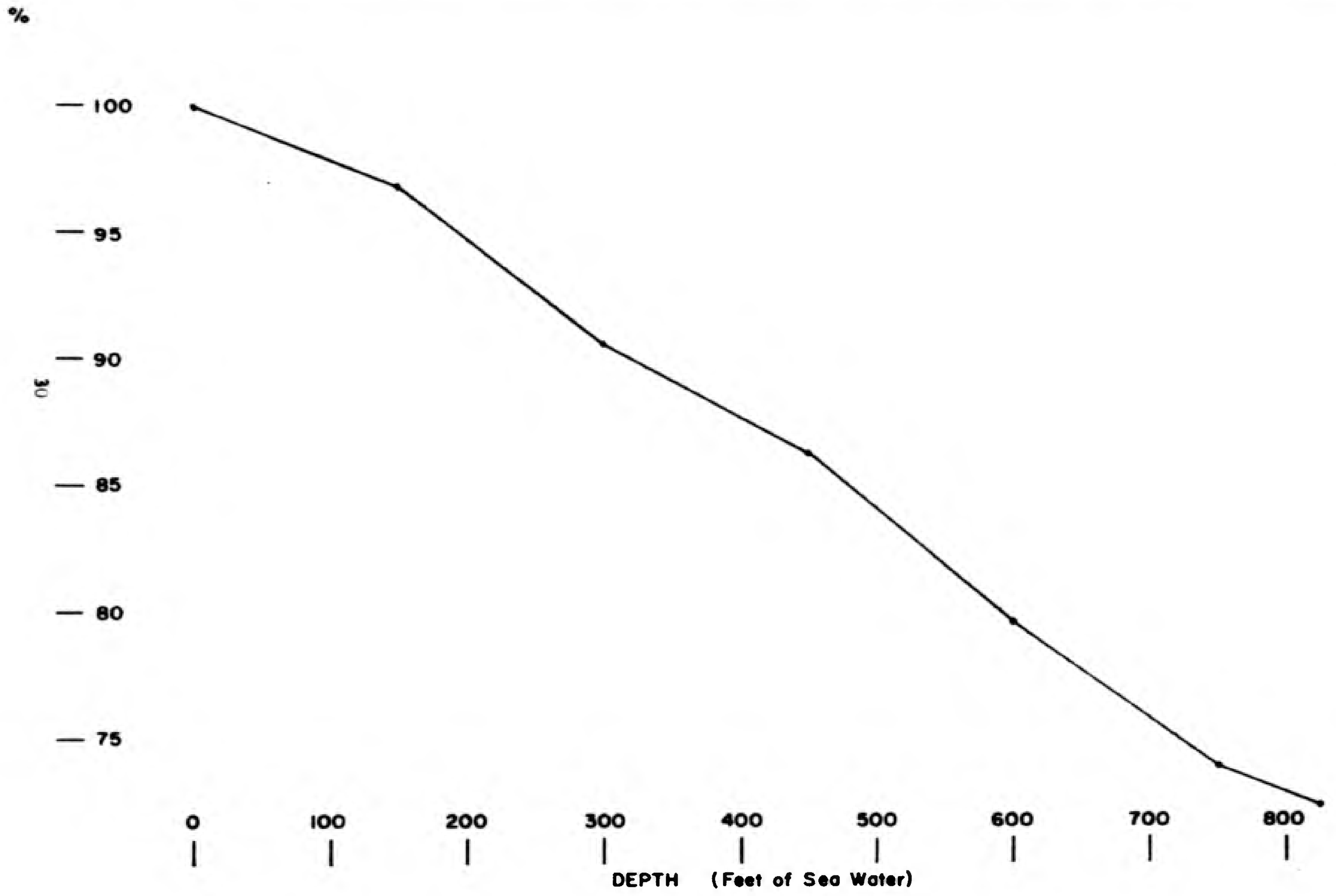


(FIGURE 5)

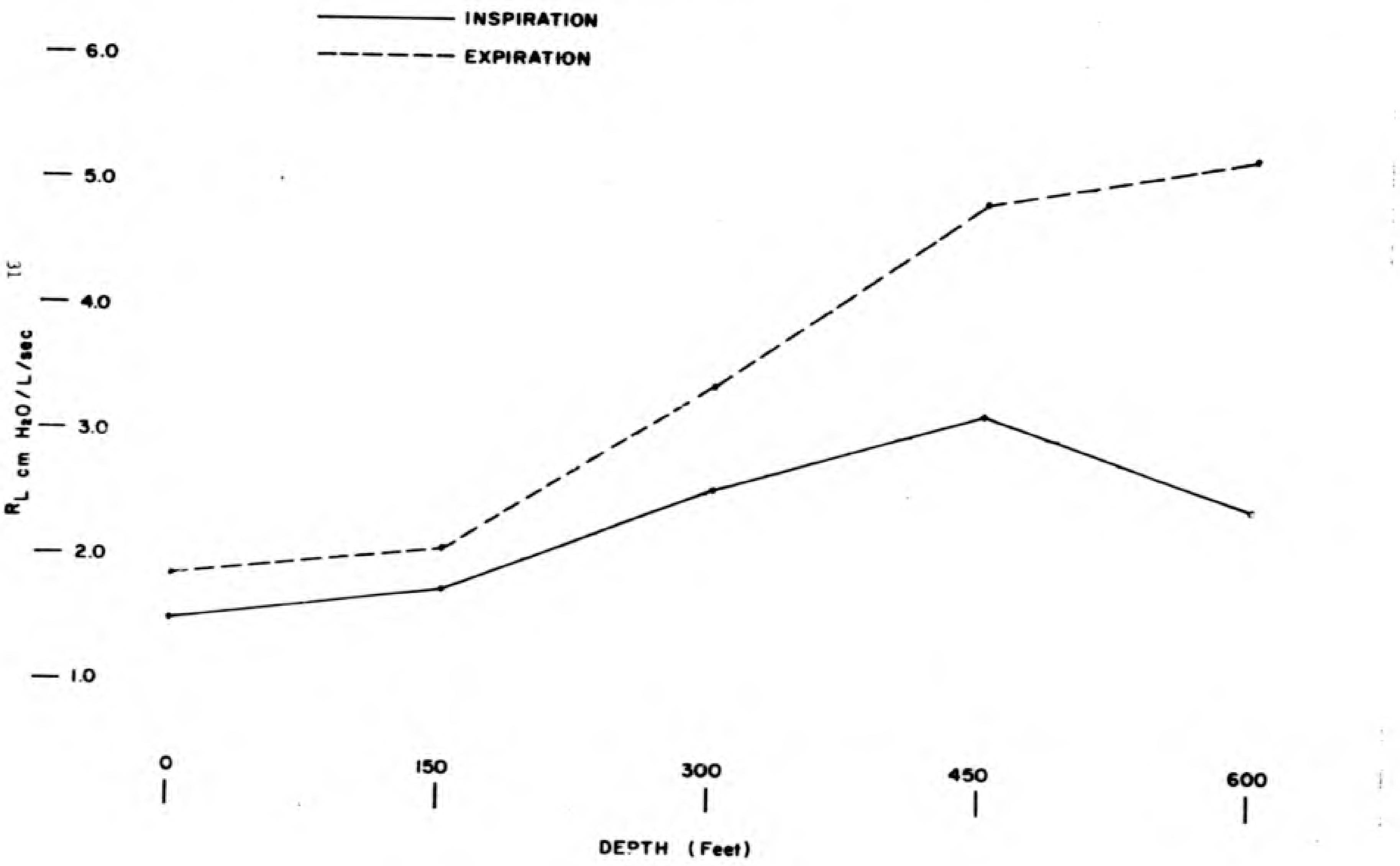
MAXIMUM MID-EXPIRATORY FLOW RATE PERCENT OF SURFACE CONTROL WHILE BREATHING $He\text{-}O_2$



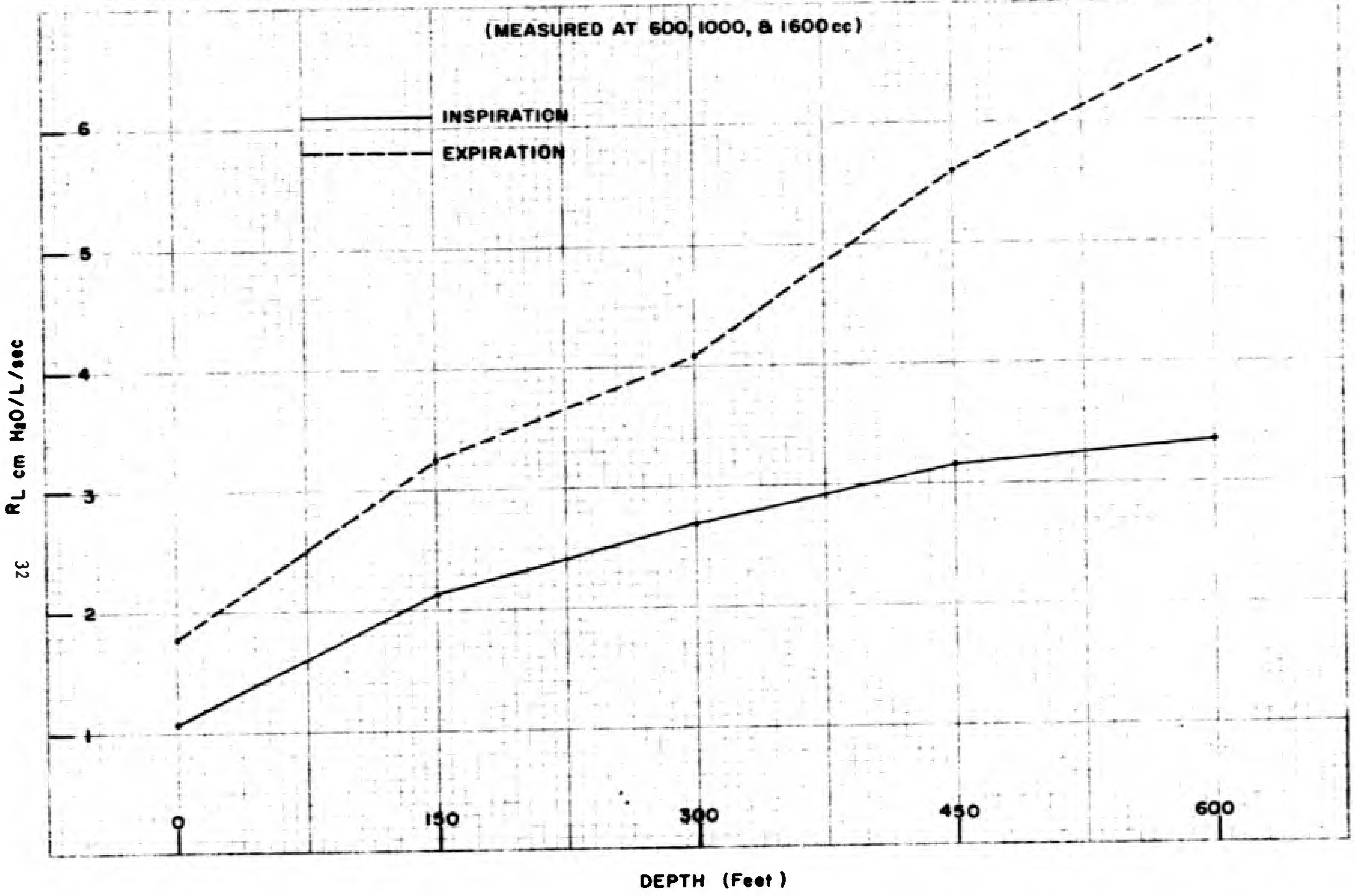
MAXIMUM BREATHING CAPACITY PERCENT OF SURFACE CONTROL WHILE BREATHING $He-O_2$ (FIGURE 6)



MEAN PULMONARY RESISTANCES OF 3 SUBJECTS WHILE QUIETLY BREATHING He-O₂/DEPTH (FIGURE 7)
(MEASURED AT 600 cc)



AVERAGE PULMONARY RESISTANCES OF 3 SUBJECTS BREATHING He-O$_2$ AT HIGH VENTILATORY VOLUMES (FIGURE 8)



EXERCISE STUDY

This study was undertaken to assess cardiopulmonary function during exercise while breathing helium-oxygen mixtures from sea level to depths of 600 feet. It is important to establish man's ability to perform hard, useful work at extreme depths and to seek evidence of changes that may represent physiological limitations. There is as yet, a paucity of information available concerning the physiological changes which occur during sustained heavy work at great depths.

Methods:

Two subjects in excellent physical condition participated in this study. The physical characteristics of these subjects are presented in Table 1.

SUBJECT	J.W.M.	P.A.W.
Height	73"	69"
Weight	190 lbs	153 lbs
Age	27	41
Vital Capacity	6400 cc	5400 cc
Max. Breathing Capacity	204 L/Min	164 L/Min

Table 1. Physical Characteristics of the subjects participating in the Exercise Study

The conditions of physical activity studied were rest, moderate work (450 Kg-m/M) and heavy work (900 Kg-m/M). Each subject was studied pre- and post-dive while breathing 30% oxygen-balance helium and 30% oxygen-balance nitrogen. The measurements obtained at 150, 300, 450, and 600 feet were made while the subject was breathing the chamber atmosphere which consisted of 0.3 atmospheres of oxygen, 1.2 or less atmospheres of nitrogen, balance helium.

Exercise was performed by pedaling a Monarch bicycle ergometer at a constant rate in time with a metronome. A Collins Triple-J exercise valve and mouthpiece were used for breathing mixture administration. Expired gas was directed from the breathing valve through 2-1/2 inch smooth bore tubing, into a dry, rotary gasometer, and then into a 10 liter mixing chamber. At sea level while breathing air at ventilatory volumes of 70 L/min, inspiratory resistance was 1 cm. of H_2O, and during expiration 1.8 cm. of H_2O. Ventilatory volume measurements were taken and recorded at one minute intervals in all the states studied. Respiratory frequency was measured and recorded on a minute by minute basis by means of a hand counter.

Mixed expired oxygen was sampled by a calibrated polarographic high output oxygen sensor which was mounted in the distal end of the mixing chamber. A constant recording of oxygen tension was made on a Gilsen multichannel recorder. Mixed expired carbon dioxide was continuously sampled from the mixing chamber, through the chamber wall and to either a calibrated Beckman LB-1 or Beckman IR 215 infrared carbon dioxide analyzer. Output from the carbon dioxide amplifier was connected to a Gilsen recorder. Electrodes were affixed to the subject's precordial region and heart rate continuously monitored by means of an electrocardiogram and recorded on the Gilsen.

The following general procedure was followed. After the electrodes had been attached, the subject rested quietly for twenty minutes. After resting state measurements had been obtained, the subject performed first the moderate and then the heavy work. All work states were of fifteen minutes duration. For the first ten minutes of the work period, the subject was allowed to reach a "steady-state" status. The physiologic measurements presented in this report are those measurements obtained during the final five minute steady-state period breathing helium-oxygen.

The following data and calculations were obtained from the measurements made on each subject during each condition:

Ventilatory Volume
Respiratory Frequency
Tidal Volume
Alveolar Ventilation
Oxygen Consumption
Carbon Dioxide Production
Respiratory Exchange Quotient
Alveolar Carbon Dioxide Tension
Alveolar Oxygen Tension
Heart Rate

Results: (Tables 2 and 3).

A. Ventilation

Respiratory minute volume during rest, moderate and heavy work remained constant within each activity level from sea level to 600 feet. (Figures 1 and 2) Both divers showed a decrease in average respiratory frequency and an increase in tidal volume from sea level to 150 feet in all activity states. From 150 to 600 feet, both respiratory frequency and tidal volume were unchanged. (Figures 3, 4, 5 and 6).

B. Oxygen Consumption and Carbon Dioxide Production

One subject's (J.W.M.) (age 27) oxygen consumption and carbon dioxide production (Figures 7 and 8) did not appear to be affected by the increased ambient pressures, either in the resting state or during work. The other subject (P.A.W.)(age 41) showed no definite changes attributable to the increasing depth in his oxygen consumption or carbon dioxide production during rest or moderate work. During heavy work though, both oxygen consumption and carbon dioxide production was seen to progressively increase from 300 feet to the 600 foot depth. (Figures 9 and 10).

C. Alveolar Gases

J.W.M.'s alveolar carbon dioxide tension showed only minor changes at all the depths studied during rest and with exercise. (Figure 11). At both rest and moderate work, P.A.W. showed no major changes in alveolar carbon dioxide tension. P_{ACO2} during hard work was not affected by increased gas density except at 600 feet. At this depth, P_{ACO2} rose to 47.2 mm Hg, a 7 mm increase over that seen at shallower depths. (Figure 12).

D. Heart Rate

Heart rate increased linearly with increasing work load. No changes were noted though that could be attributed to the increase in ambient pressure.

Discussion:

Helium at high pressure may possess pharmacological properties, and stress and relative inactivity may affect cardiopulmonary function in exercise, but the predominant variable of this experimental situation was the progressive increase in the density of the breathing medium. The increased work of breathing a dense gas may produce changes in ventilatory response, oxygen consumption, alveolar carbon dioxide production and heart rate during exercise.

A. Ventilation:

Impaired pulmonary ventilation may result from breathing dense gas mixtures. It is impressive that men can respire more than 70L/min of a helium-oxygen mixture for prolonged periods at 600 feet. Within each activity level in this study, respiratory minute volume appears little affected by the increased density of gas.

From 150 feet to 600 feet, tidal volume and respiratory frequency did not seem to be influenced by the increasing ambient pressures. The initial decrease in rate of respiration and increase in tidal volume from sea level to 150 feet is characteristic of the breathing pattern reported for divers adjusted to high pressures (8).

B. Oxygen Consumption and Carbon Dioxide Production:

An increase in the work of breathing should reflect itself by an increase in oxygen uptake. In this study, J.W.M. did not demonstrate any apparent increases in oxygen utilization for any activity level from the surface to 600 feet. P.A.W. maintained a constant oxygen consumption during the resting state and during moderate work at all depths. His apparent progressive increase in oxygen uptake during heavy work at depths greater than 300 feet is quite likely the result of increased work of breathing at high ventilatory volumes. This subject was the smaller of the two physically dissimilar men, and would probably be more affected at high work loads by increased gas density.

Changes in the carbon dioxide production of both subjects with exercise paralleled the changes seen in oxygen uptake, which supports the validity of measurements.

C. Alveolar Gases:

Except when P.A.W. performed hard work at the 600 foot depth, carbon dioxide retention was not observed. At 600 feet during heavy work, this subject's carbon dioxide production was over 3 L/min, while respiratory minute volume was not increased. Therefore an elevation in alveolar carbon dioxide tension was most likely present.

Other investigators (1) have found significant increases in the alveolar carbon dioxide tension of subjects exercising at considerably lower work levels while breathing helium-oxygen mixtures at 650 feet. The two most likely reasons for obtaining false low measurements of P_{ACO_2} are: (1) faulty carbon dioxide analysis; (2) gross underestimation of physiologic dead space in exercise. It is felt that inaccurate CO_2 analysis was unlikely in this study. We can assume that values for P_{ACO_2} in the resting state are valid as they were measured on the surface by means of end-tidal sampling and CO_2 analysis. The assumption of the knowledge of the subject's dead space during exercise, which enters into our calculations of alveolar carbon dioxide tension, was based on the dead space of the breathing valve (300 cc) and on an estimated physiologic dead space V_D based on the average tidal volume.

It is also possible that the alveolar carbon dioxide tensions found by other investigators are falsely high. (1) These investigators utilized end-tidal sampling during exercise to determine P_{ACO_2}. This method has been reported to give erroneously high values for alveolar carbon dioxide tension in the exercise state. (11).

D. Heart Rate:

Bradycardia has been reported in resting subjects at depths of 650 feet. This phenomenon could not be demonstrated in this study. With exercise at depth, heart rate responded in essentially the same manner as at sea level, suggesting that there is no special cardiovascular stress resulting from moderate and heavy work to depths of 600 feet.

Conclusions and Recommendations:

1. The evidence obtained from these two subjects indicates that man, breathing helium-oxygen mixtures, can perform strenuous work at depths to 600 feet without hypoventilation, significant carbon dioxide retention or additional cardiovascular stress.

2. An attempt is being made to include additional subjects in this study to depths of 600 feet. This will hopefully confirm the findings presented in this report and provide more data for statistical analysis.

3. A problematical area in this study was the determination of the actual physiologic dead space in the exercising subject breathing a high density gas. The DEEP SUBMERGENCE SYSTEMS PROJECT TECHNICAL OFFICE plans to undertake a study to clarify this area.

DEPTH (feet)	WORKLLOAD Kg-M/min	V_e L/min. BTPS	RESP. FREQ	TIDAL VOLUME cc	OXYGEN CONSUMP. L/min STPD	CO_2 PRODUCTION L/min STPD	R	$P_{A_{CO2}}$	Heart Rate
Surface	Rest	9.14	11.7	653	.264	.226	.86	35.8	90
150'	Rest	11.04	10.1	1093	.270	.223	.83	35.6	69
300'	Rest	11.82	11.0	1075	.310	.255	.82	36.8	72
450'	Rest	11.88	10.9	1037	.340	.271	.80	38.2	66
600'	Rest	11.52	9.14	1260	.280	.288	1.02	39.2	70
Surface	450 Kg-m/M	39.5	25.0	1580	1.390	1.227	.88	40.0	132
150'	450 Kg-m/M	43.7	24.2	1806	1.210	1.220	1.0	35.9	117
300'	450 Kg-m/M	42.75	24.4	1752	1.318	1.207	.92	36.9	114
450'	450 kg-m/M	42.75	18.8	2274	1.473	1.501	1.02	42.5	114
600'	450 Kg-m/M	43.36	21.6	2007	1.259	1.283	1.02	37.5	114
Surface	900 Kg-m/M	69.27	33.0	2099	2.393	2.255	.94	40.8	168
150'	900 Kg-m/M	78.57	28.0	2806	2.486	2.134	.86	34.2	--
300'	900 Kg-m/M	76.93	27.0	2849	2.313	2.307	1.0	35.2	162
450'	900 Kg-m/M	70.35	26.8	2625	2.291	2.179	.95	36.5	156
600'	900 Kg-m/M	73.80	27.2	2713	2.170	2.223	1.02	36.2	168

TABLE 2 SUMMARY OF EXERCISE DATA FROM THE SUBJECT J.W.M. BREATHING HELIUM - OXYGEN AT ALL DEPTHS

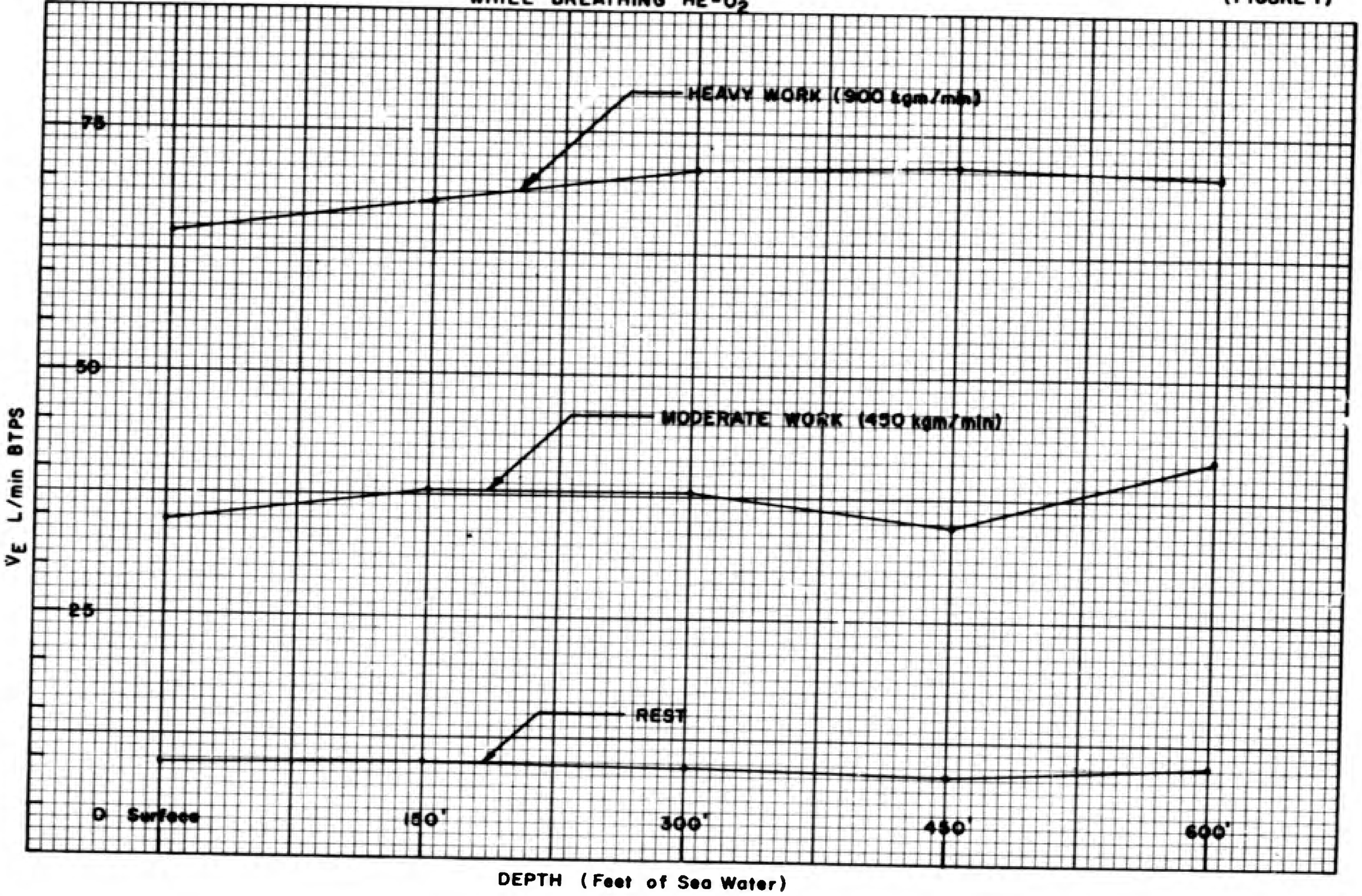
DEPTH (feet)	WORKLOAD Kg-M/min	V_e L/min. BTPS	RESP. FREQ	TIDAL VOLUME cc	OXYGEN CONSUMP. L/min STPD	CO_2 PRODUCTION L/min STPD	R	$P_{A_{CO2}}$	Heart Rate
Surface	**Rest**	9.72	15.8	615	.243	.220	.91	37.6	54
150'	**Rest**	10.0	12.6	.794	.271	.220	.81	36.0	58
300'	**Rest**	9.65	13.0	650	.308	.225	.73	35.5	54
450'	**Rest**	8.86	11.0	805	.281	.241	.86	42.3	54
600'	**Rest**	10.16	10.6	958	.328	.272	.83	37.6	54
Surface	**450 Kg-m/M**	34.55	22.6	1529	1.318	1.216	.93	41.6	105
150'	**450 Kg-m/M**	37.78	19.8	1908	1.193	1.165	.98	36.4	120
300'	**450 Kg-m/M**	37.83	19.8	1911	1.315	1.385	1.05	40.4	100
450'	**450 kg-m/M**	34.43	17.4	1979	1.211	1.263	1.04	41.7	102
600'	**450 Kg-m/M**	38.89	20.4	1906	1.339	1.240	.96	38.1	102
Surface	**900 Kg-m/M**	64.31	29.2	2202	2.461	2.318	.94	38.9	150
150'	**900 Kg-m/M**	67.56	25.0	2702	2.233	2.168	.97	36.5	140
300'	**900 Kg-m/M**	7.122	25.8	2706	2.583	2.669	.103	38.6	150
450'	**900 Kg-m/M**	71.76	27.2	2638	2.677	2.672	.99	40.7	152
600'	**900 Kg-m/M**	71.02	28.4	2501	2.998	3.063	1.02	47.2	156

TABLE 3 SUMMARY OF EXERCISE DATA FROM THE SUBJECT P.A.W. BREATHING HELIUM - OXYGEN AT ALL DEPTHS

(P.A.W)

VENTILATORY VOLUME/DEPTH
WHILE BREATHING HE-O_2

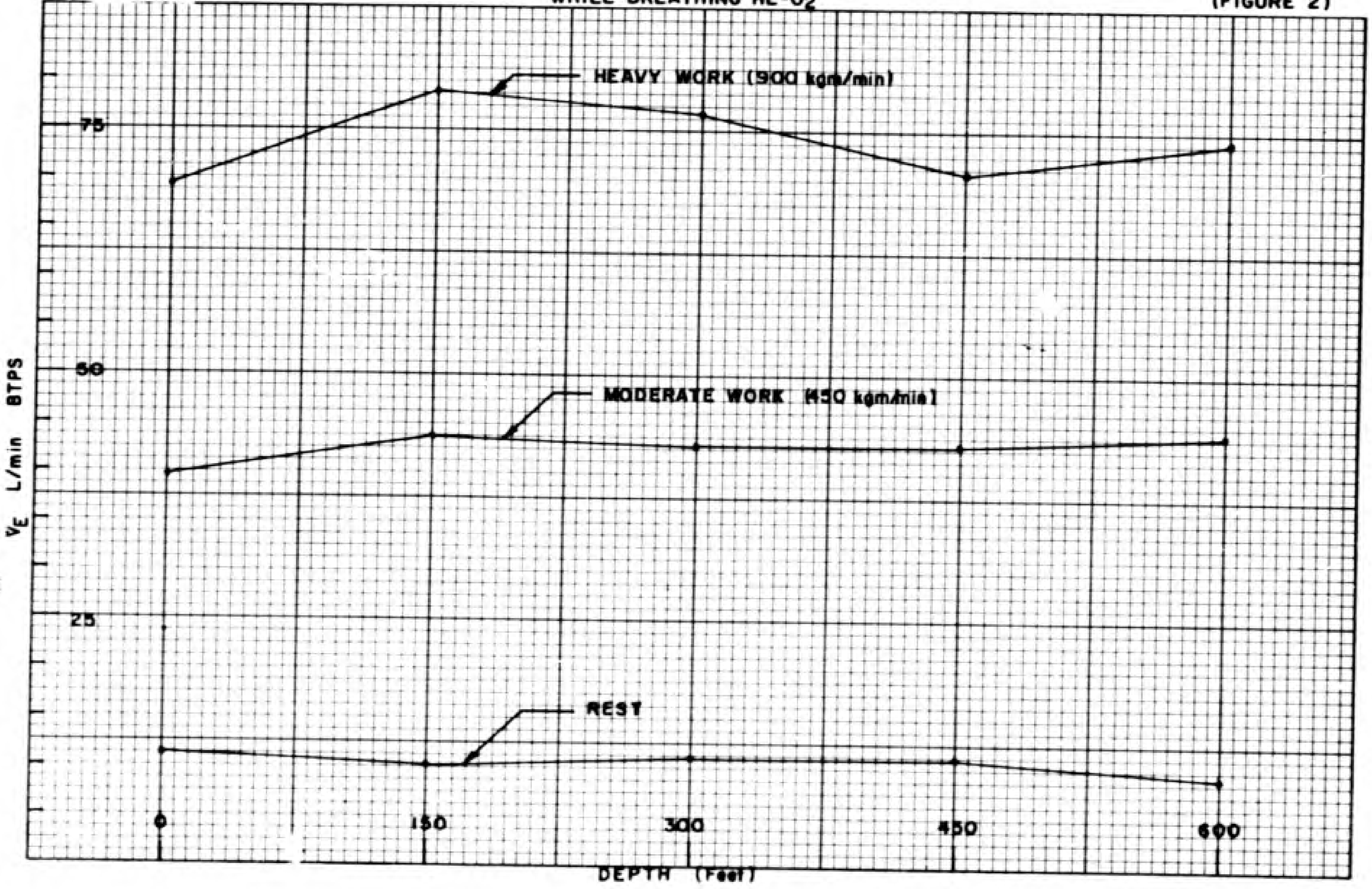
(FIGURE I)



(J.W.M.)

VENTILATORY VOLUME/DEPTH WHILE BREATHING HE-O_2

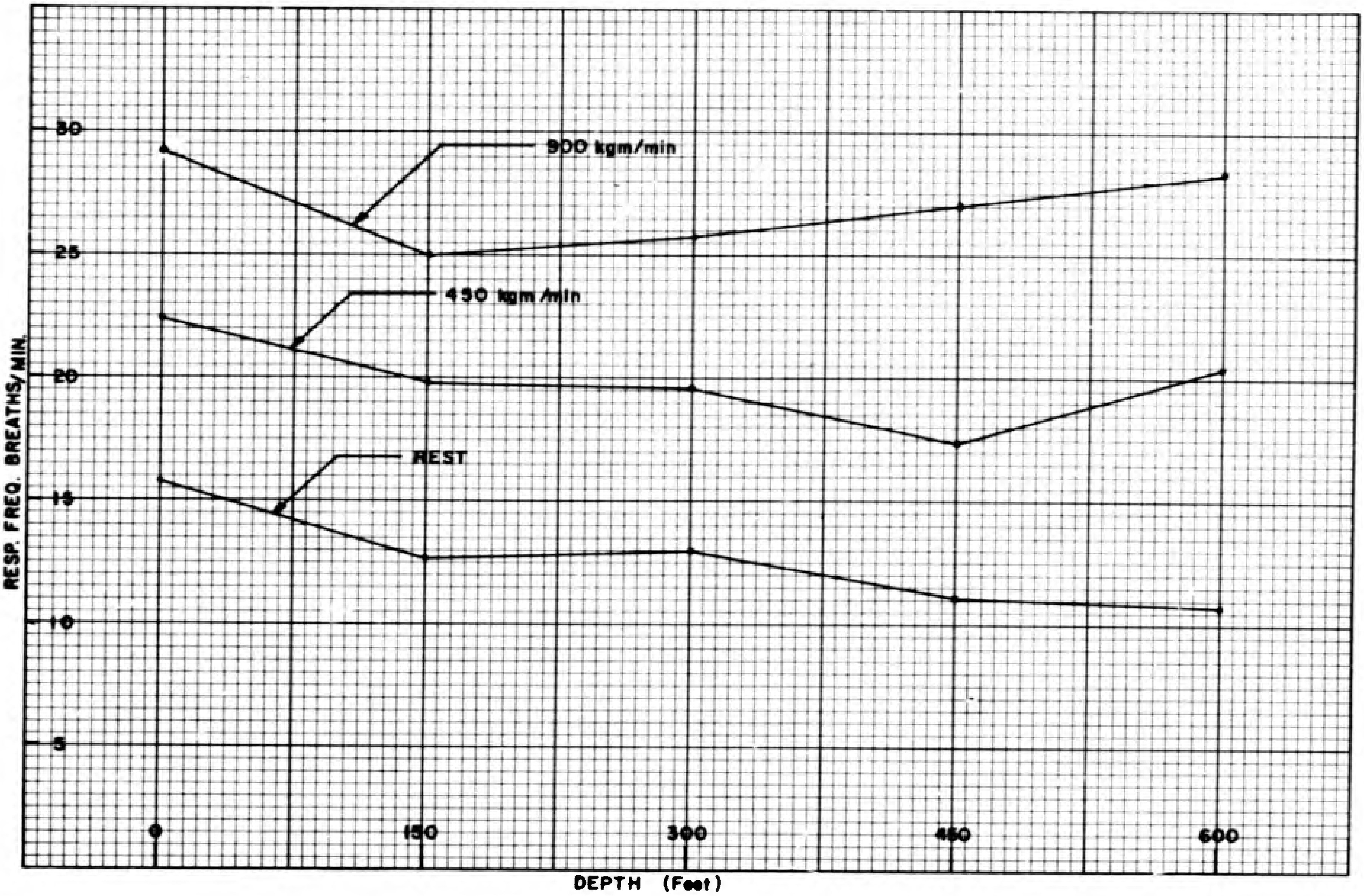
(FIGURE 2)



(P.A.W.)

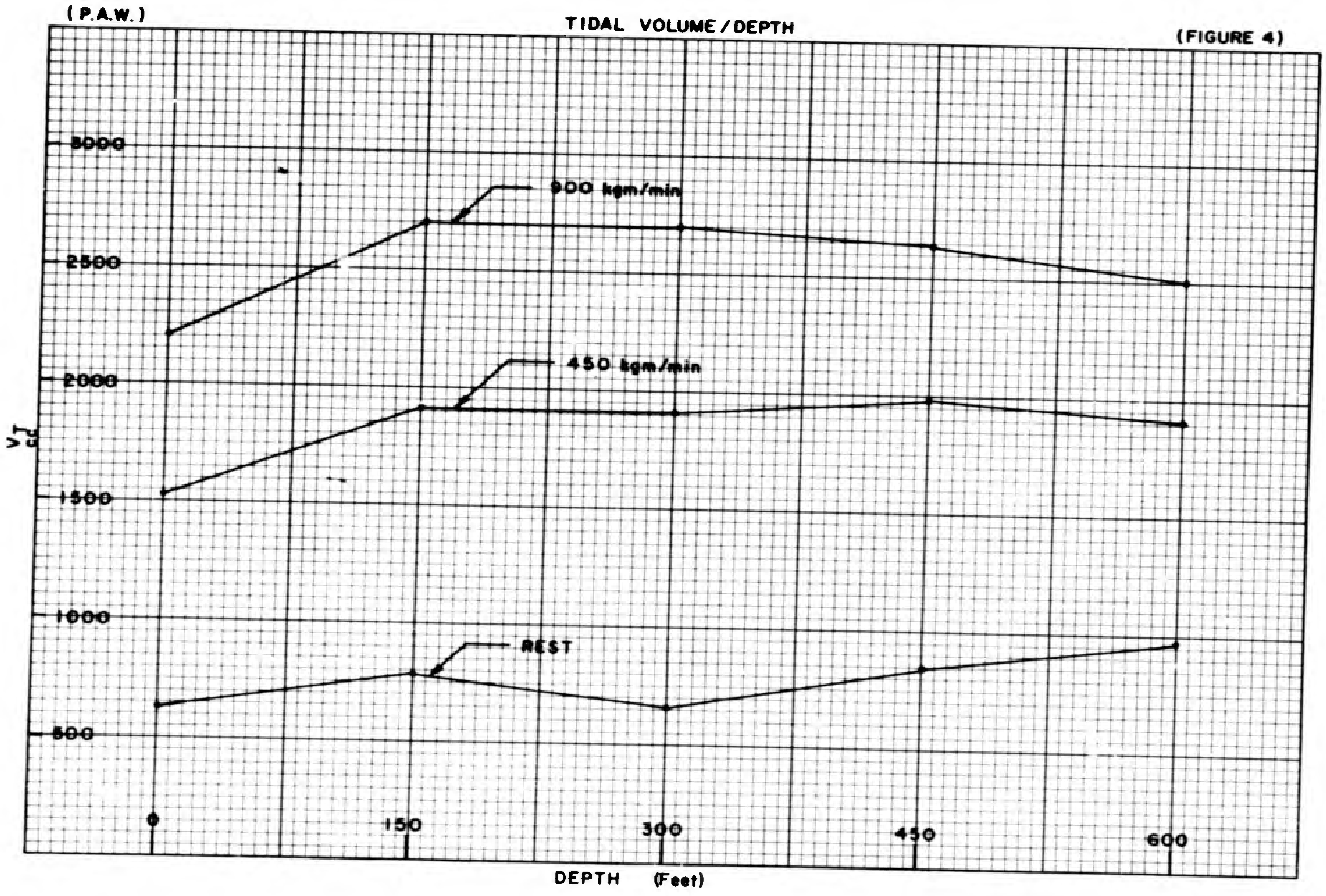
RESPIRATORY FREQUENCY / DEPTH

(FIGURE 3)

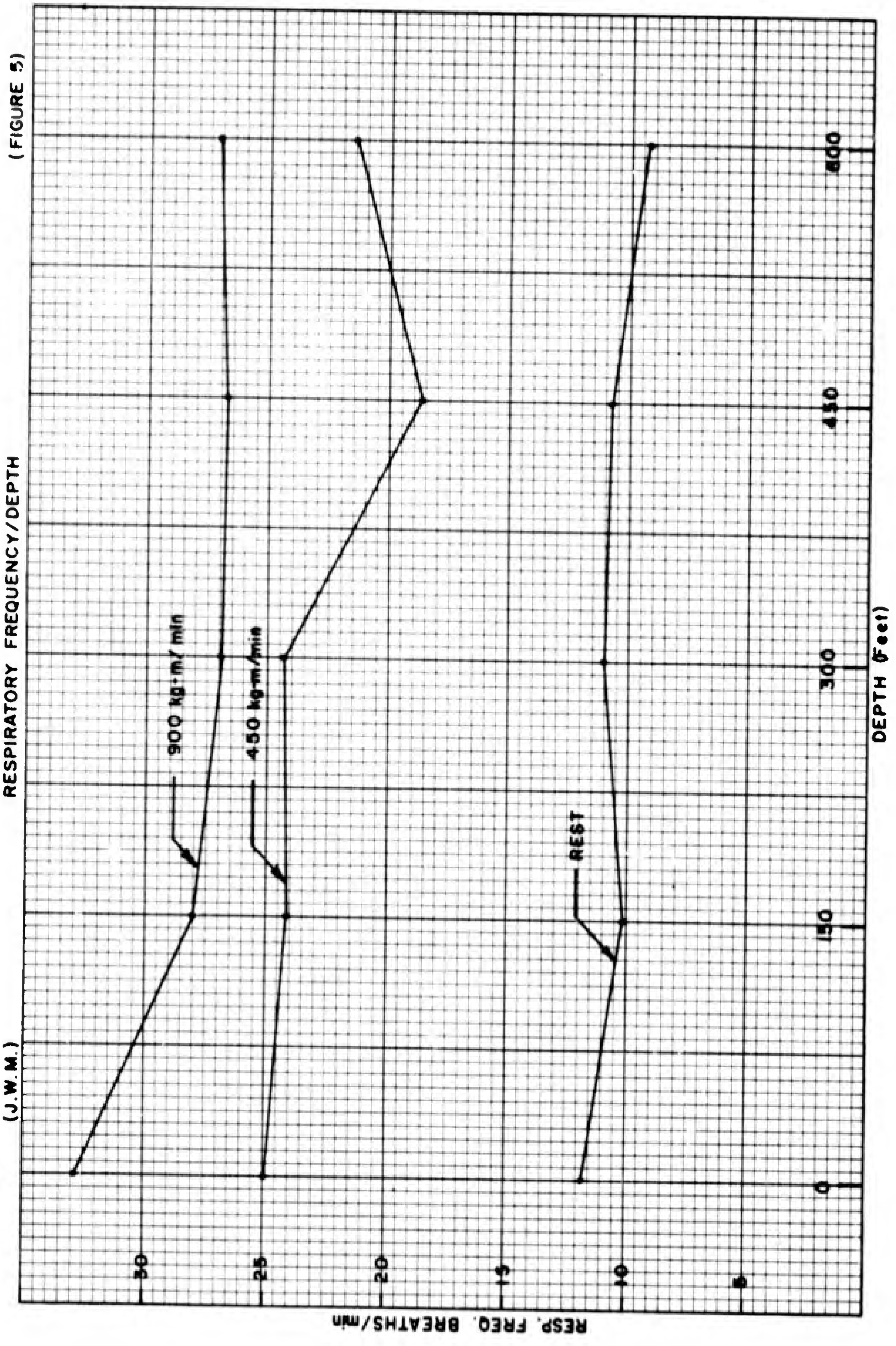


(FIGURE 4)

TIDAL VOLUME / DEPTH



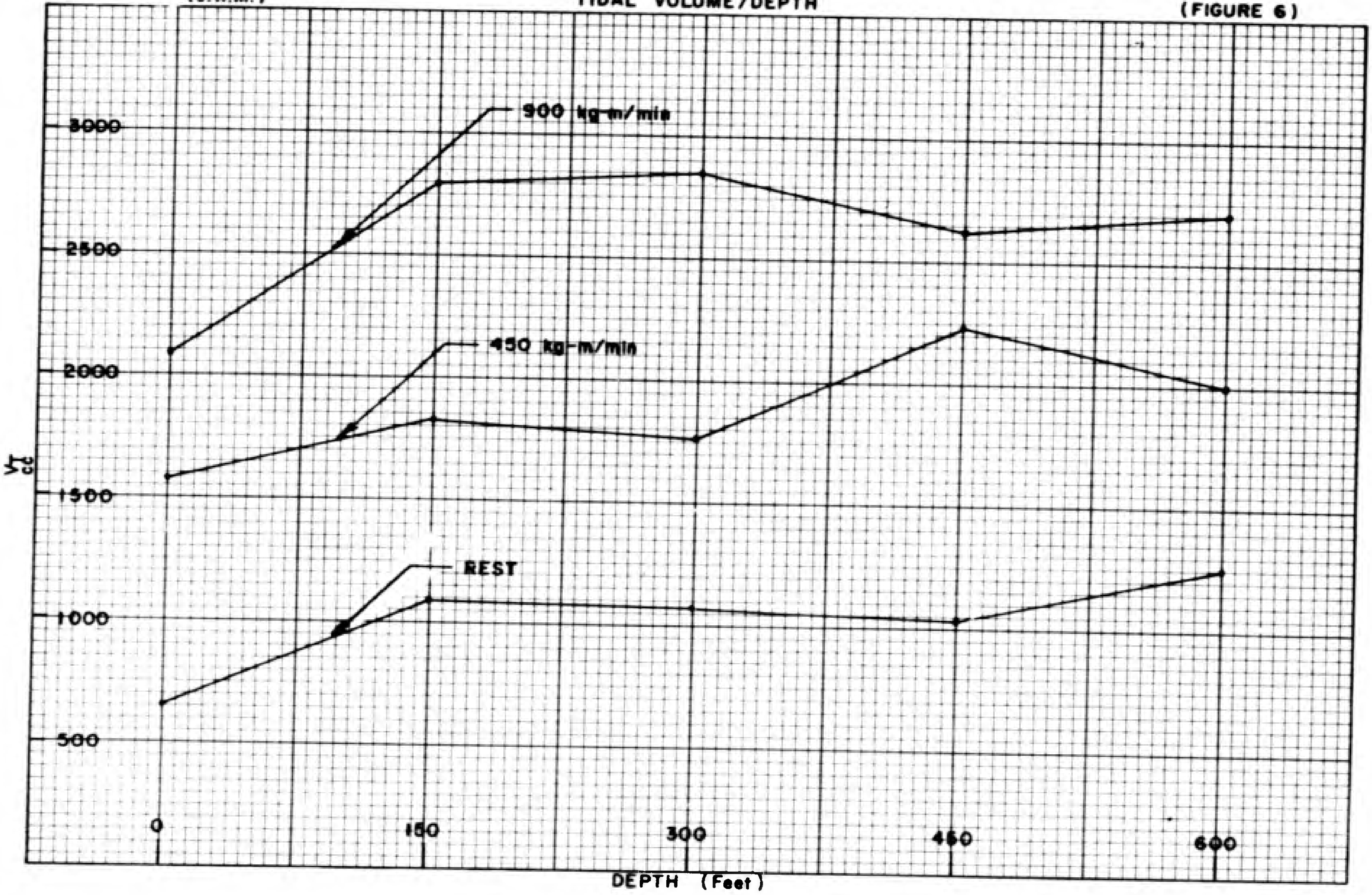
(J.W.M.) RESPIRATORY FREQUENCY/DEPTH (FIGURE 5)



(J.W.M.)

TIDAL VOLUME/DEPTH

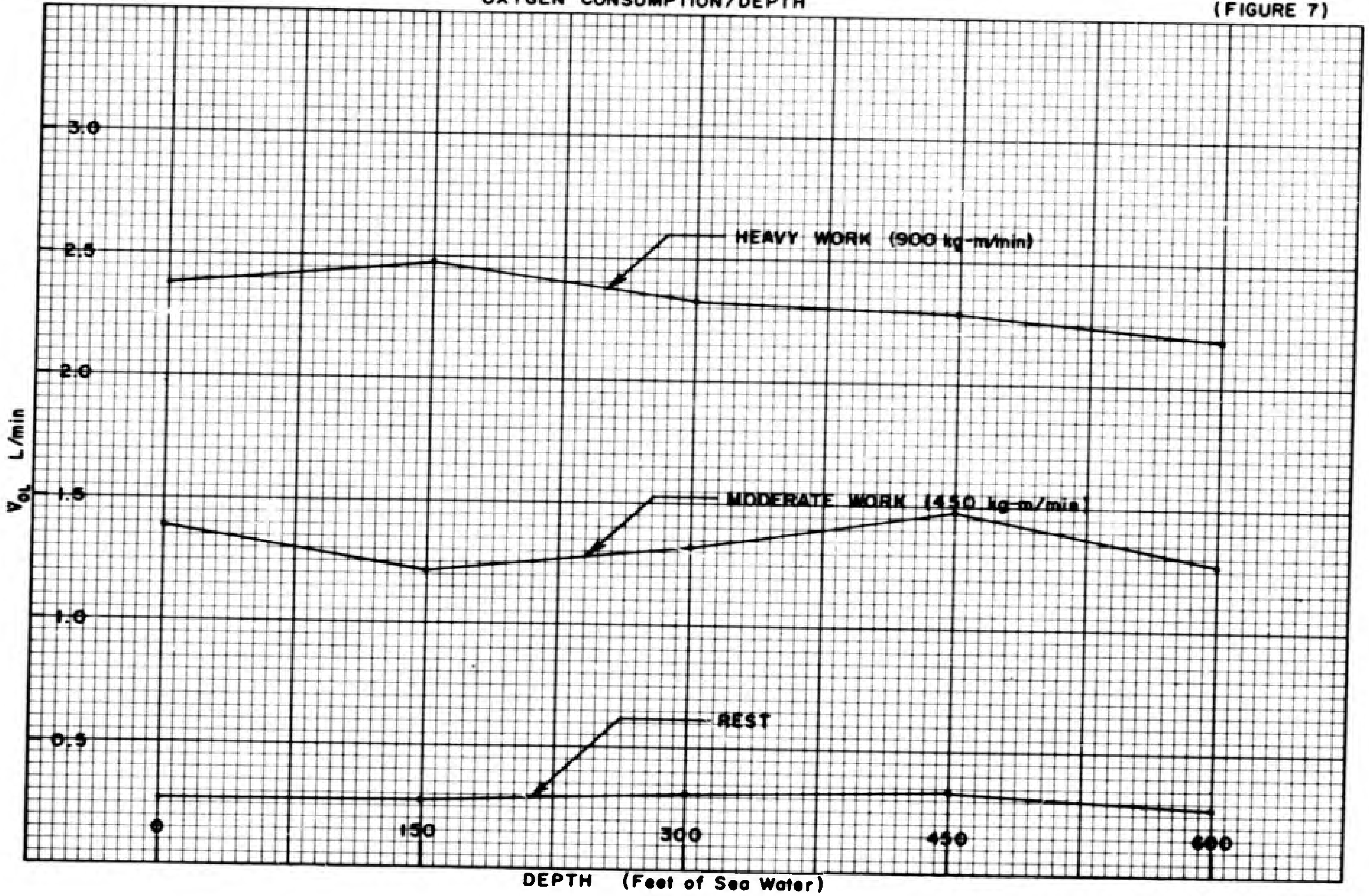
(FIGURE 6)



(J.W.M.)

OXYGEN CONSUMPTION/DEPTH

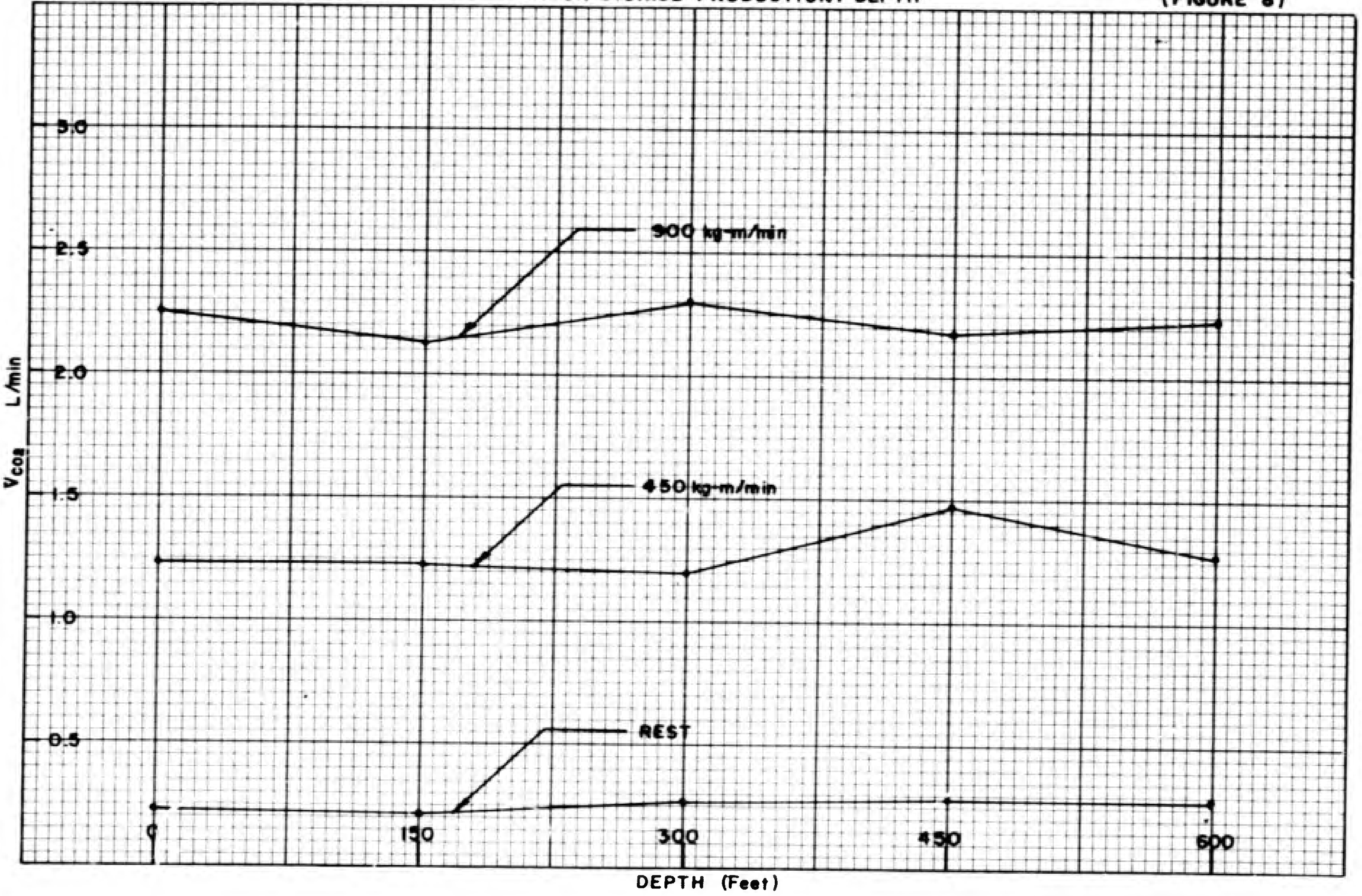
(FIGURE 7)



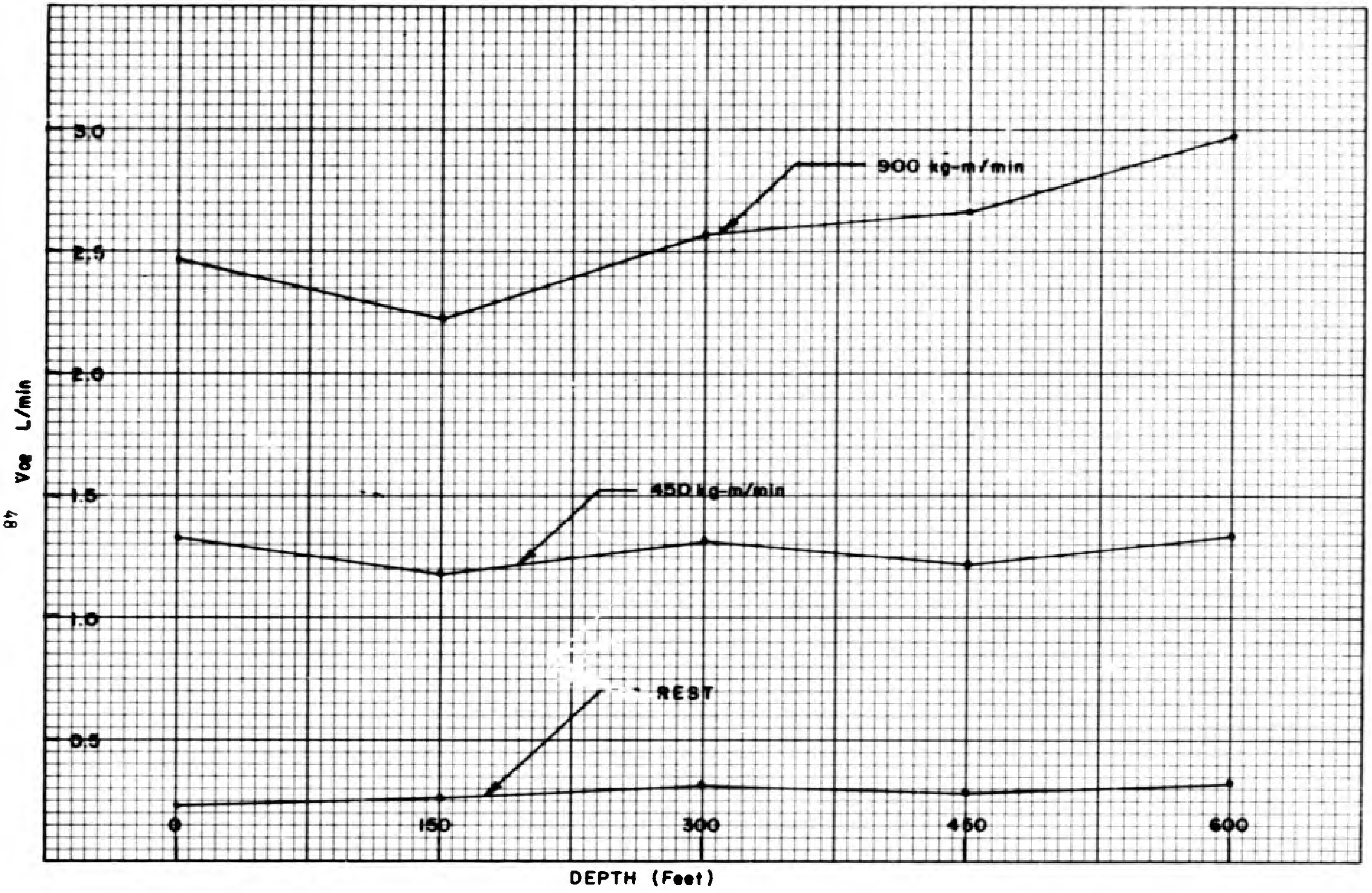
(J.W.M)

CARBON DIOXIDE PRODUCTION / DEPTH

(FIGURE 8)



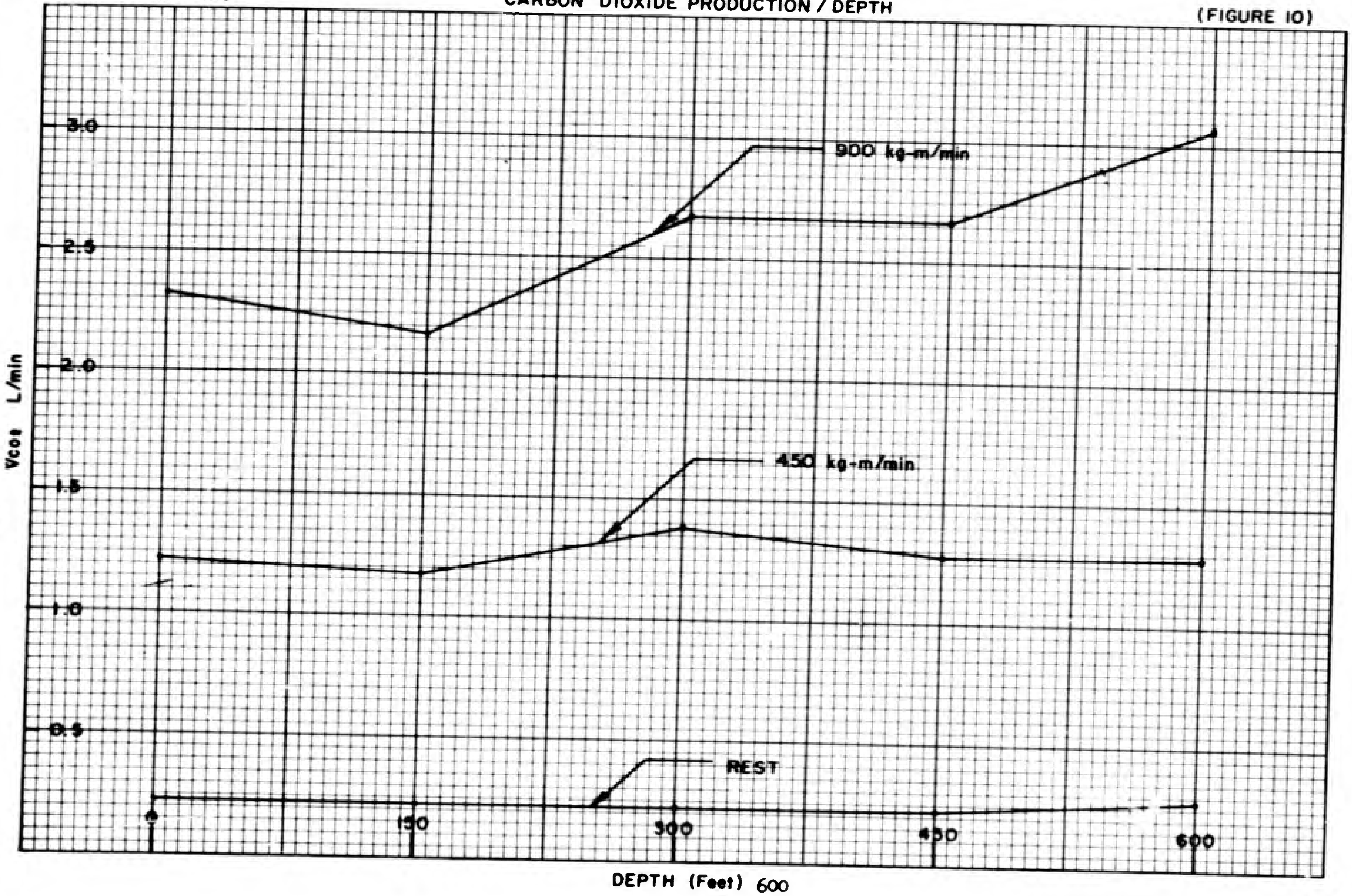
(P.A.W.) OXYGEN CONSUMPTION / DEPTH (FIGURE 9)



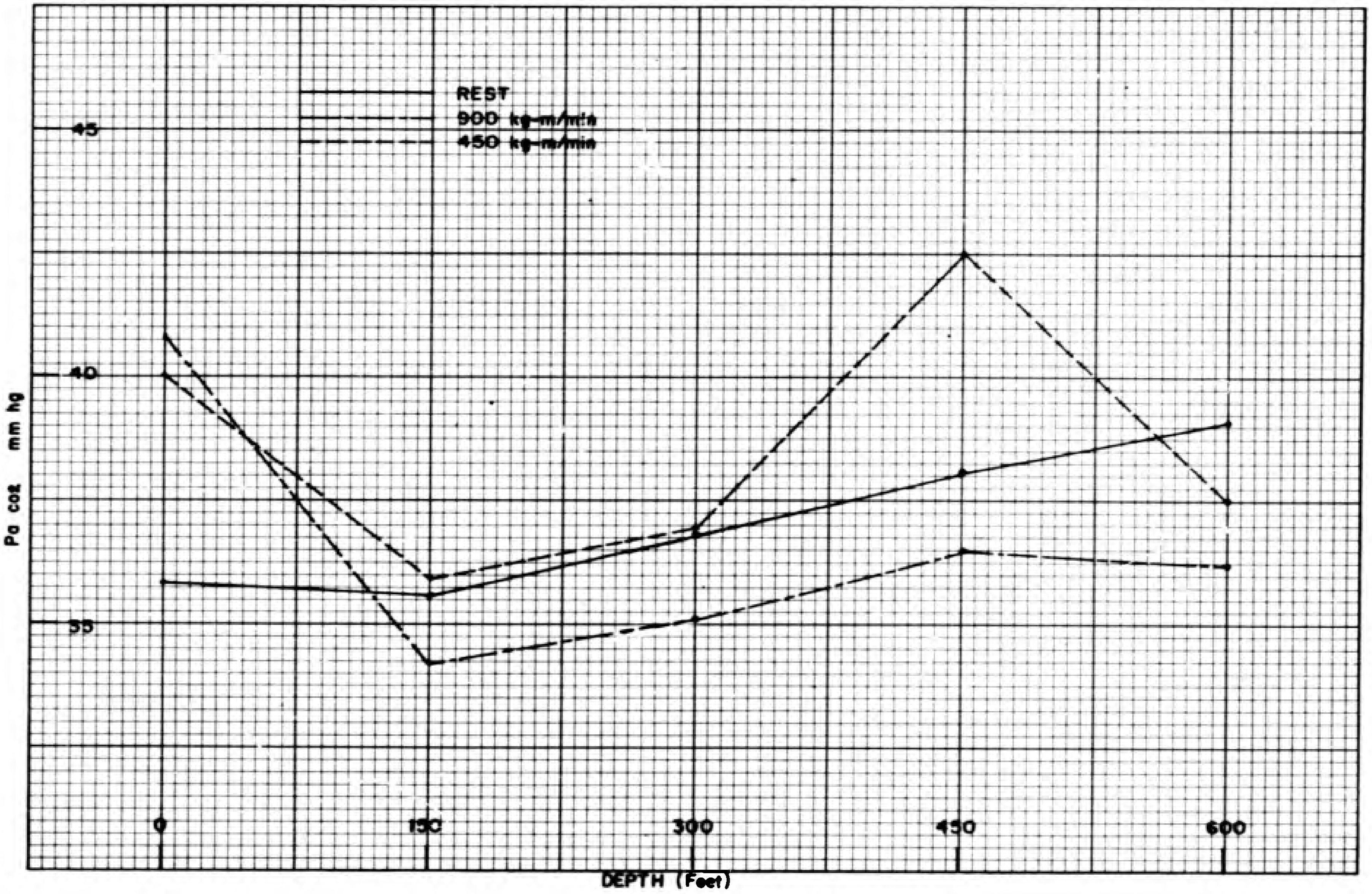
(P.A.W.)

CARBON DIOXIDE PRODUCTION / DEPTH

(FIGURE 10)



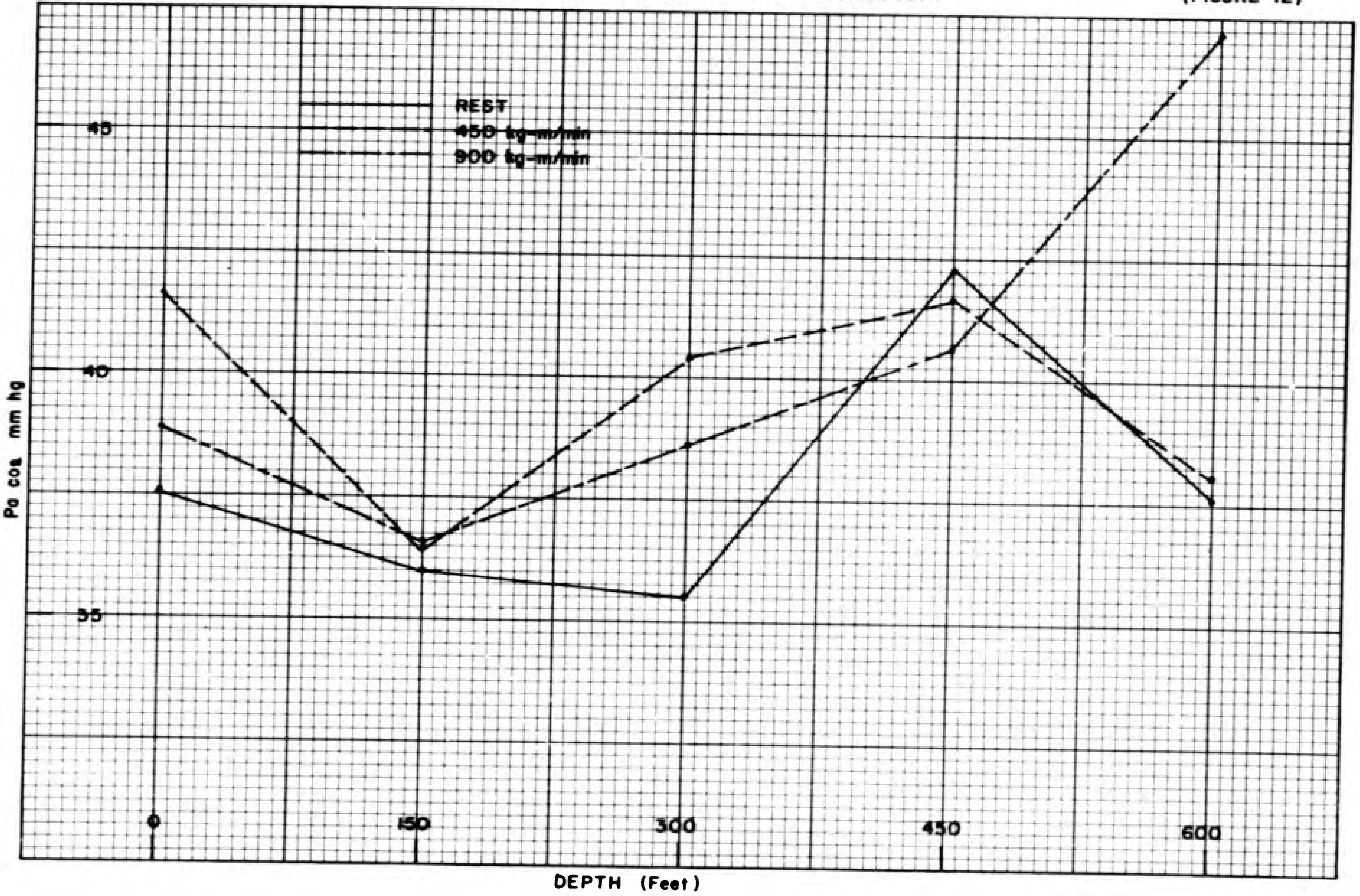
(J.W.M.) ALVEOLAR CARBON DIOXIDE TENSION/DEPTH (FIGURE II)



(P.A.W.)

ALVEOLAR CARBON DIOXIDE TENSION/DEPT

(FIGURE 12)



HUMAN PERFORMANCE EVALUATION PROGRAM

Background: Under the direction of DSSP and ONR, Lieutenant T. Berghage, MSC, USN, at the U.S. Navy Experimental Diving Unit, has for the past year been testing SEALAB III divers on a variety of performance tests. These measures are being taken in an attempt to assess and quantify the ability of man to perform cognitive and perceptual motor functions in extreme hyperbaric environments. By administering these synthetic tasks in a laboratory situation, it will be possible for the divers to concentrate completely on real work in the open sea experiment.

Procedure: Four areas of human performance have been investigated. The selection of these areas was based upon the types of task that will be required of SEALAB III divers. No attempt has been made to obtain highly sophisticated measures of primary human abilities. This degree of complexity is being explored under another DSSP program. For each ability area a single performance test was selected, based upon consideration of easy administration and test durability. The following are descriptions of the actual tests used and what they are reported to measure:

1. Bennett Hand-Tool Dexterity Test. A measure of proficiency in the use of wrenches and screwdrivers. On the left-hand upright of the metal frame are mounted four bolts of each of three sizes. The task is to take apart the twelve fastenings and to reassemble the nuts, washers, and bolts in the right-hand upright.

2. Purdue Pegboard. (Developed by Science Research Associates, 1943) as a measure of fine finger dexterity involving two hand coordination. Only the assembly subtest is being used in the SEALAB III laboratory experiments. An assembly sequence consists of a pin, washer, collar, and washer using right, left, right, and left hands. The score is the number of parts assembled in 60 seconds.

3. Digit Symbol Test. As a test of associative memory the Digit Symbol Test is to be found in a large variety of intelligence scales, the most formidable being

the Wechsler Adult Intelligence Scale. The subject is required to associate certain symbols with certain other symbols, and the speed and accuracy with which he does it serve as a measure of his intellectual ability. Administration of the test takes 90 seconds.

4. Tapping Test. Used to measure the speed of voluntary hand wrist and arm movement. Its inclusion in the experiment was primarily as a measure of the retarding effects of water viscosity on hand and arm movement. The test consists of two 4 1/2" square stainless steel plates mounted on a wooden base eleven inches apart. The subject taps, as fast as possible, alternate plates with a metal stylus. The performance score consists of the total number of contacts in a thirty second time period.

Results: Because of wide variability between divers in their level of motivation and their ability to adapt to stressful hyperbaric environment, it is very difficult to draw firm conclusions from the present data. However, 518 data points have been collected and some general trends have been observed and are outlined below and in the enclosed table:

1. Performance in the water was less effective than on dry land in all four tasks. The following mean decrements have been observed in the water.

a.	Hand Tool Dexterity	24%
b.	Purdue Pegboard	16%
c.	Digit Symbol	14%
d.	Speed of Tapping	14%

2. As the divers proceed to depth the performance picture becomes less clear and variations between individuals increase. There is a very gradual non-specific **decrease in measured performance at the rate of about** 1-1/2 percent per 100 feet. As would be expected, the associative memory task showed the greatest decrement while the fine motor dexterity showed the least.

All of the above findings are very tentative and far from firm conclusions, but indications are that man can effectively perform down to depths of 1,000 feet and beyond.

DIVER PERFORMANCE DURING SEALAB
PRESSURE CHAMBER EXPERIMENTS

		SURFACE (DRY)			10 feet			200 feet			300 feet			400 feet			450 feet			600 feet			825 feet			1025 feet		
		N	X	SE	N	X	SE	N	X	SE	N	X	SE	N	X	SE	N	X	SE	N	X	SE	N	X	SE	N	X	SE
HAND TOOL DEXTERITY (TIME IN MIN.)	NAVY ENLIST.	20	6.5	.3	18	7.8	.5	3	9.2	.8	10	8.0	.6	5.	9.5	.7	7	8.9	.5.	14	9.0	.7	0	-	-	0	-	-
	OFFICERS + CIVILIANS	24	6.6	.3	24	8.4	.4	9	1[illegible].5	.8	8	9.7	.7	0	-	-	10	10.1	.9	7	7.9	.7	0	-	-	0	-	-
PURDUE PEGBOARD (PARTS ASSEMBLED)	NAVY ENLIST.	21	35.3	1.2	18	31.5	1.3	3	28.3	2.6	10	27.7	1.8	4	30.8	3.2	8	25.5	2.1	14	26.0	2.1	2	33.7	2.0	2	37.0	2 5
	OFFICERS + CIVILIANS	24	35.5	1.0	24	28.3	1.4	9	24.0	1.1	8	22.9	2.0	0	-	-	11	25.9	1.1	7	28.4	2.1	0	-	-	0	-	-
DIGIT SYMBOL TEST (SYMBOLS COMPLETED)	NAVY ENLIST.	22	53.1	1.6	12	47.8	3.3	0	-	-	7	47.6	4.0	0	-	-	3	36.7	3.8	12	41/6	4.3	2	47.7	3.7	2	47.5	4.5
	OFFICERS + CIVILIANS	23	61.6	2.3	24	51.1	2.7	9	64.4	4.9	7	45.3	3.0	0	-	-	11	55.0	4.9	6	49.2	4.2	0	-	-	0	-	-
SPEED OF TAPPING (CONTACTS MADE)	NAVY ENLIST.	11	65.1	3.1	10	55.1	4.0	3	52.0	9.6	3	48.7	4.7	2	55.5	9.5	6	55.3	3.0	2	64.0	2.0	0	-	-	0	-	-
	OFFICERS+ CIVILIANS	9	69.9	3.0	8	60.9	2.9	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-

HUMAN LEARNING AND MEMORY STUDY

Experienced Navy divers from the SEALAB program learned a memory task under ambient and hyperbaric conditions in order to study the effects of high pressure and HeO_2 on information processing in man. The task consisted of ten series of numbers paired with pertinent diving and salvage information, such as depth and time of dive and weight and volume of a sunken vessel. The numbers were 3, 4 and 5 digits in length. The divers were given five minutes in which to learn the paired items on a study sheet, and two minutes to complete two practice sheets, using the study sheet as a guide. The divers were then retested for memory thirty seconds, five minutes, and sixty minutes later. The tests were administered on the surface, and at simulated depths of approximately 100, 600 and 825 feet. The divers breathed HeO_2 at all depths. The study was conducted by an experimental psychologist of the Experimental Diving Unit, Lieutenant R. Biersner, MSC, USN.

The results (see enclosed Table A) indicate that long-term memory (measured sixty minutes after original learning) is significantly altered at great depths on HeO_2. Early studies revealed no significant differences in error scores obtained from the thirty second and five minute retesting sessions under any depth or surface condition, prompting the elimination of the thirty second retesting sessions from later experiments. Moreover, no differences were found between surface control and depth control (100 feet) conditions. The data from these two control conditions have been combined on the enclosed table. This table further shows that short-term memory (retested five minutes after learning) varied little under any of the testing conditions. Only long-term memory changed, and did so only at great depths.

The significant effect, therefore, is a latent one, and does not represent a general learning or memory deficit. It is possible that this change is related to stress or motivational factors, but it is more likely due to some physiological effect of high pressure or HeO_2.

Although the divers showed a significant memory change at 825 feet, this was noticeably less than that shown at 600 feet. This probably reflects a sampling error related to the small number of divers tested at this depth.

This study suggests that long-term information processing in man is highly unstable at great depths on HeO_2. Divers cannot be expected to remember newly learned information for extended periods of time under such conditions. If the situation requires divers to do so, then as little delay as possible should intervene between the learning and performance of the new response.

TABLE A

Mean Error Scores of Divers under Various Conditions

Depth at Which Tested	Time Retested after Original Learning	
	5 mins.	60 mins.
Control Conditions (Surface and 100 feet)	35.0	30.4
600 feet	33.6	86.8
825 feet	26.1	58.2

VISUAL STUDIES

A study of the visual function of divers during an 825 foot saturation dive was conducted by LT J. **KELLEY**, MC, USNR, of the Experimental Diving Unit. This experiment was designed to detect defects in visual function which might result from the high inert gas partial pressure and from the effects of living in a confined enviroment for prolonged periods.

Knowledge of the size, shape, color and luminosity of objects in the environment, along with their position and movements in space in relation to other objects and to the observer, is obtained by means of sight. These results are obtained by series of complex neurophysiological and motor processes.

Visual changes have previously been reported in the presence of inert gas narcosis. During nitrogen narcosis the frequency at which a flickering light is perceived as being steady (flicker fusion) is less than that in the un-narcotized subject. (6) Some investigators have predicted the onset of mild helium narcosis at a depth of 450 feet and the presence of severe helium narcosis at 1350 feet, the effects of which would be equivalent to air breathing at 300 feet. (7)

A decrement in visual acuity and tendency toward esotropia have been reported in individuals serving aboard submarines. (16) It has been suggested that this phenomenon is related to the limited range for viewing objects, thus the eyes are always accomodating and always converging, a circumstance which may cause a relatively fixed posturing of the crystalline lens in an accomodative state and a neuromuscular tendency to over convergence.

METHODS:

Simplicity, testing time and instrument limitation were considerations in these preliminary tests. All tests were performed on the surface prior to the dive, at 825 feet, at 600 feet and post-dive. Four normal male subjects participated in this study.

1. Extra ocular muscle function, with varying degrees of neural pathway complexity was studied, including examination of optokinetic nystagmus, ductions, ductions with red glass, Maddox wing test, prism fusion test and Worth four-dot test.

2. Visual acuity was examined 20 feet and 14 inches.

3. Visual fields were studied on a portable hand perimeter (white 1 mm object) and with the Amsler Grid.

4. Pupil size and accommodation were measured as an indication of the tone of the intrinsic muscles.

5. H-R-R pseudoisochromatic plates were used to determine color vision.

6. The regeneration of retinal pigment was timed after staring at a 100 watt bulb for 60 seconds (after image).

RESULTS:

Statistical Significance was estimated by the Wilcoxen Matched-Pairs Signed-Rank Test.

1. Visual Acuity (20 feet) - Armed Forces Clinical Visual Acuity Test Chart.

   Results: No significant change. All acuities were 20/20 or better.

2. Visual Acuity (14 inches) - American Optical Company Standard Chart.

   Results: All read V=.50D print.

3. Color Vision - H-R-R Pseudoisochromatic Plates

   Results: Plates 1-6 were all read correctly

4. Optokinetic Nystagmus - This was inducted with 1 1/2 inch wide tape marked as a standard drum. Results were recorded as Normal, Reduced, or Absent.

   Results: All Normal

5. a. Ductions: The subject follows a light with both eyes and the light is moved along three meridians.

   b. Duction with Red Glass: Same as (a) with a red lens over one eye.

   Results: No diplopia induced.

6. Maddox Wing: The subject reports the scale reading to nearest whole number.

   Results: All readings were within the normal range

7. Prism Fusion: The subject attempted to maintain fusion while prisms of varying sizes were interposed, oriented first base-in, then base-out.

   Results: No significant change was noted at depth. Greater ability to maintain fusion was seen in the second surface trial, probably showing some learning effect.

8. Titmus Stereopsis.

Results: All nine test patterns were labeled correctly at each obseration.

9. Pupil size: This was estimated with a comparator card in millimeters.

Results: Surface range 7mm-3mm. Range at depth, 6mm-3mm.

10. Accommodation: Subject focuses on V=.50D letter with both eyes. The distance at which the object becomes blurred is recorded in inches.

Results: Surface: Range 5.75 - 3.5; Range at depth: 3.75-3.5.

11. Peripheral Fields: The subject held a hand perimeter with 15 cm. radius and was tested in six meridians with a 1 mm. white object.

Results: A 2% reduction in fields was found at depth but was not statistically significant

12. Central Fields: Standard questions were asked of the first Amsler Grid.

Results: No abnormalities reported.

13. After Image: The subject attempted to read the 20/20 line on the Snellen Chart after staring at a 100 watt pressure shielded bulb.

Results: Wide individual variation was noted.

DISCUSSION:

Firm conclusions cannot be made on the basis of only 4 subjects. However, it is tentatively concluded that visual functions are not affected by helium-oxygen mixtures to depths of 825 feet. Moreover, there is no evidence that visual acuity was impaired by 2 weeks of chamber confinement.

These studies will be continued to increase the number of subjects and body of data to provide for more accurate statistical analysis.

AUDIOGRAMS

Beacuse of several recent cases of decreased auditory acuity following deep experimental dives, including one case of permanent bilateral deafness, it was considered essential to have baseline audiograms on all subjects before they made saturation dives. Standard audiograms using frequencies of 250 cps through 6000 cps were obtained on all subjects pre- and post-dive.

There has been no evidence on any of these subject's audiograms of a decrement in post-dive audiotory acuity. Although no problems have arisen during the DSSPTO saturation dives, it is recommended that a recent audiogram be available on each diver.

PRELIMINARY RESULTS OF MICROBIOLOGICAL SAMPLES OBTAINED DURING SEALAB III SATURATION DIVES AT THE EXPERIMENTAL DIVING UNIT

Series of bacteriological samples were obtained from subjects during saturation diving operations. Analysis of the specimens and data organization were performed by the Microbiology Division of the Naval Medical Research Institute. The objectives of this study were:

1. To determine if an alteration in the normal body microflora occurred under the conditions of pressure, the gases breathed, the restricted environment, and the wet suit excursions.
2. To investigate whether the diving conditions induced or favored direct effects on the microflora, such as medically important changes in pathogenicity or antibiotic sensitivity.
3. To study if transfer of microorganisms occurred among personnel. This could become particularly important if careful and thorough prior screening for carriers of pathogens is not done.
4. To study if alterations in susceptibility and resistance to infection occurred both during and after the exposure to the underwater environments. There is evidence both from Antarctic and Polaris personnel that such alterations do occur.
5. To determine if clinically undiagnosed chronic infections might be activated by DSSP conditions; this is also being studied in the laboratory using experimental animals.
6. To determine if a build-up of microorganisms within the habitat occurred.

Experiment Procedure:

The sampling areas selected for evaluation of the human microflora were the nose, oropharynx, skin, ear, and anus.

Samplings were obtained with moistened sterile cotton swabs in 10% skim milk suspensions which were immediately frozen at -60° C on removal from the chamber. Primary platings of serial dilutions of reconstituted, frozen, stored specimens were made to nine selected differential and enrichment media under both aerobic and anaerobic conditions. Identifications were based upon morphological and tinctorial characteristics along with selected biochemical tests and determinations of hemolytic, coagulase, bile solubility and fermentative activities where indicated. Selected isolates were examined for possible alteration in antibiotic sensitivity patterns. Bacteriological examination of four saturation dives required in excess of 13,200 primary platings.

The first two saturation dives studied were conducted at 450 feet with a 600 foot wet-pot excursion on the second day. Decompressions were completed on the ninth day. The next two dives were conducted at 200 feet with 300 foot wet-pot excursions on the second day and completion of decompression on the fourth day. The last dive studied was to 600 feet, with five subjects for six days bottom stay and seven days of decompression. There were no excursion dives during this saturation dive. Bacteriological examination of the specimens obtained from this dive has not yet been completed and therefore is not included in this report.

Results and Discussion

In general, during both nine-day saturation dives at 450 feet, the total aerobic and anaerobic bacterial population of skin and ear samples increased sharply following excursion to 600 feet. The peak values were obtained on the third and fourth days. This was followed by a general return towards pre-dive values during the latter stages of decompression. Total aerobic and anaerobic populations of oropharynx and nasal samples remained relatively constant throughout both dives. (Figure 1).

During Dive No. 1, subjects 2 and 4 were found on the second day, to be harboring moderate numbers of organisms morphologically resembling Pneumococci in the oropharynx. The total numbers present in subject #2 increased up to the fifth day with the development of upper respiratory symptoms; the numbers thereafter decreased during the last days of decompression. Strains from both subjects were penicillin and optochin resistant (ethylhydrocuprecine hydrochloride [pneumochin]). At the same time, subjects #3 and 4, on the fourth and fifth days respectively, were found to be harboring large numbers of typical Escherichia coli in the oropharynx. These disappeared during the decompression period.

While *E. coli* was not observed in samples obtained during Dive # 2, ear specimens did reveal the presence of three other gram negative species of possible fecal origin (*Pseudomonas aeruginosa*, *Aerobacter aerogenes*, and *Bacterium anitratum*). Total numbers, primarily *Pseudomonas aeruginosa*, increased steadily to values of 10^8 organism/ml of sample by the sixth day. Subject #1 also harbored moderate number of *Pseudomonas aeruginosa* throughout the dive in his nasal specimens.

Potentially pathogenic Staphylococci were not found in any specimen obtained during the first 450 foot dive. However, in Dive #2, subject #4 was found to be a nasal carrier of a Staphylococcus which was mannite and coagulase positive, properties generally associated with pathogenicity. Subject #2 carried a mannite positive, coagulase *negative* strain in his *pre-dive nasal specimen*; but the organism recovered after his wet-pot excursion was coagulase *positive*. Maximum numbers of Staphylococcus were recovered during the third to sixth day (fifth day for subject #4). (Subjects #1 and #3 did not show the presence of pathogenic Staphylococci during any sampling interval.) (Figure 2).

Following Dive #2, water samples taken from the wet pot showed a very high concentration of both typical *E. coli* and fecal streptococci, indicating a build-up of fecal pollution. Subject #3 showed a build-up of gram negative bacilli from ear samples which reached 10^8 organisms by the sixth day. (Figure 3).

During Dives #3 and #4 (fourth day, 200 feet with 300 foot excursion) the total numbers of aerobic and anaerobic flora from skin and ear samples showed the same tendency to *increase sharply* following wet pot excursion. Nasal and oropharyngeal samples gave fairly uniform values through the runs.

Pathogenic Staphylococci again were found in Dive #3 in all post excursion specimens from subject #3. None of the other subjects showed the presence of this strain during the short sampling interval. (Figure 4).

Subject #1 in Dive #4, developed an external ear infection with Pseudomonas aeruginosa as the only isolate. Total numbers of Pseudomonas rose sharply - again following excursion - and reached a maximum of 10^7/ml on the fourth day. (Figure 5).

In Dive #4, Subject #1, was found to harbor a pathogenic Staphylococci in his pre-dive nasal specimen. Subsequently, from subject #3, previously negative, a mannite and coagulase positive strain was found in his nasal specimens following wet pot excursion. Both subjects showed increasing numbers of Staphylococci for the next two days. (Figure 6).

Generally, the recovery of yeast, molds, and fungi from skin and ear samples of all dives was sporadic, with numbers being extremely small.

With regard to the fecal specimens, the values obtained throughout all dives on the specimens were within the numerical range of usual aerobic and anaerobic enteric flora. Some tendency towards higher values was observed in a few subjects during the third to fifth day of saturation, but because of the sporadic number of samples obtained, no definite trend was apparent. Enteric pathogens (Shigella, Salmonella, etc.) were not encountered in any specimen.

Summary:

The epidemiological and bacteriological data so far derived from the four saturation dives sampled may be prudently interpreted as follows:

1. The introduction of a potentially pathogenic Staphylococcus strain into the habitat by an asymptomatic carrier apparently occurred in Dive #2, subject #4.

2. Person-to-person transfer, or person-to-habitat-to-person transfer of Staphylococcus, Pseudomonas and E. coli may have occurred.

3. It appears possible that the replacement of a coagulase negative Staphylococcus strain by a coagulase positive strain may have taken place (Dive #2).

4. A penicillin and optochin resistant organism morphologically resembling Pneumococci appeared, increased in numbers, and was associated with some clinical symptoms (Dive #1).

5. The increase in total numbers of potentially pathogenic organisms following wet pot excursion was observed. Although the numbers usually tended to return toward the normal pre-dive values during excursion, it cannot be assumed that a similar return will be obtained under other saturation conditions where longer periods of exposure under increased pressures may be required. The effects are not known even empirically.

6. It is felt that these data, obviously permitting only tentative conclusions, may indicate that as diving/undersea living conditions become more stressful, more definitive interactions of medical importance may occur between microorganisms and subjects.

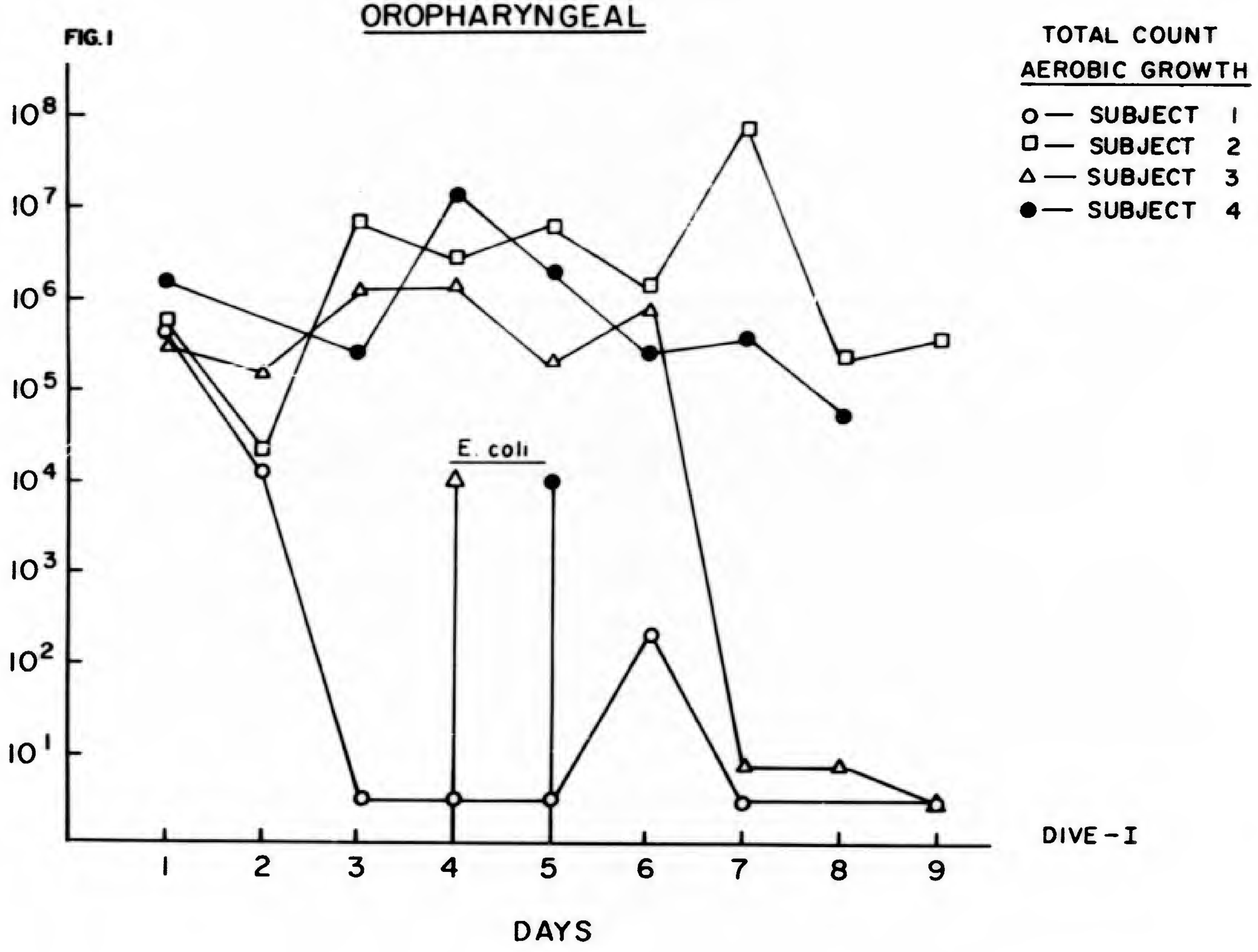
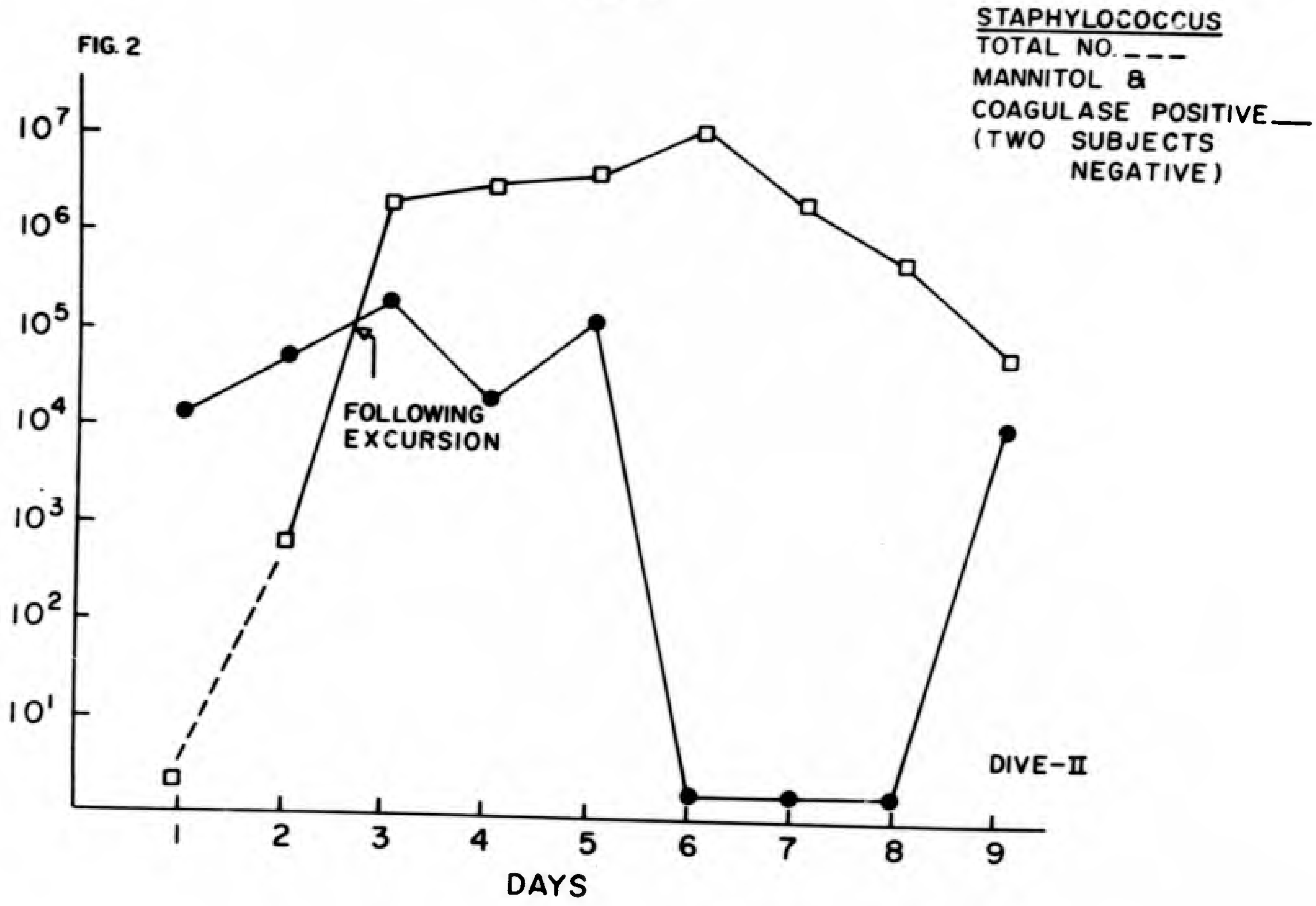


FIG. I

OROPHARYNGEAL

NOSE

FIG. 2


STAPHYLOCOCCUS
TOTAL NO. ---
MANNITOL &
COAGULASE POSITIVE —
(TWO SUBJECTS
NEGATIVE)
10^7
10^6
10^5
10^4
10^3
10^2
10^1
FOLLOWING
EXCURSION
DIVE-II
1
2
3
4
5
6
7
8
9
DAYS

EAR

GRAM-NEGATIVE BACILLI

FIG. 3

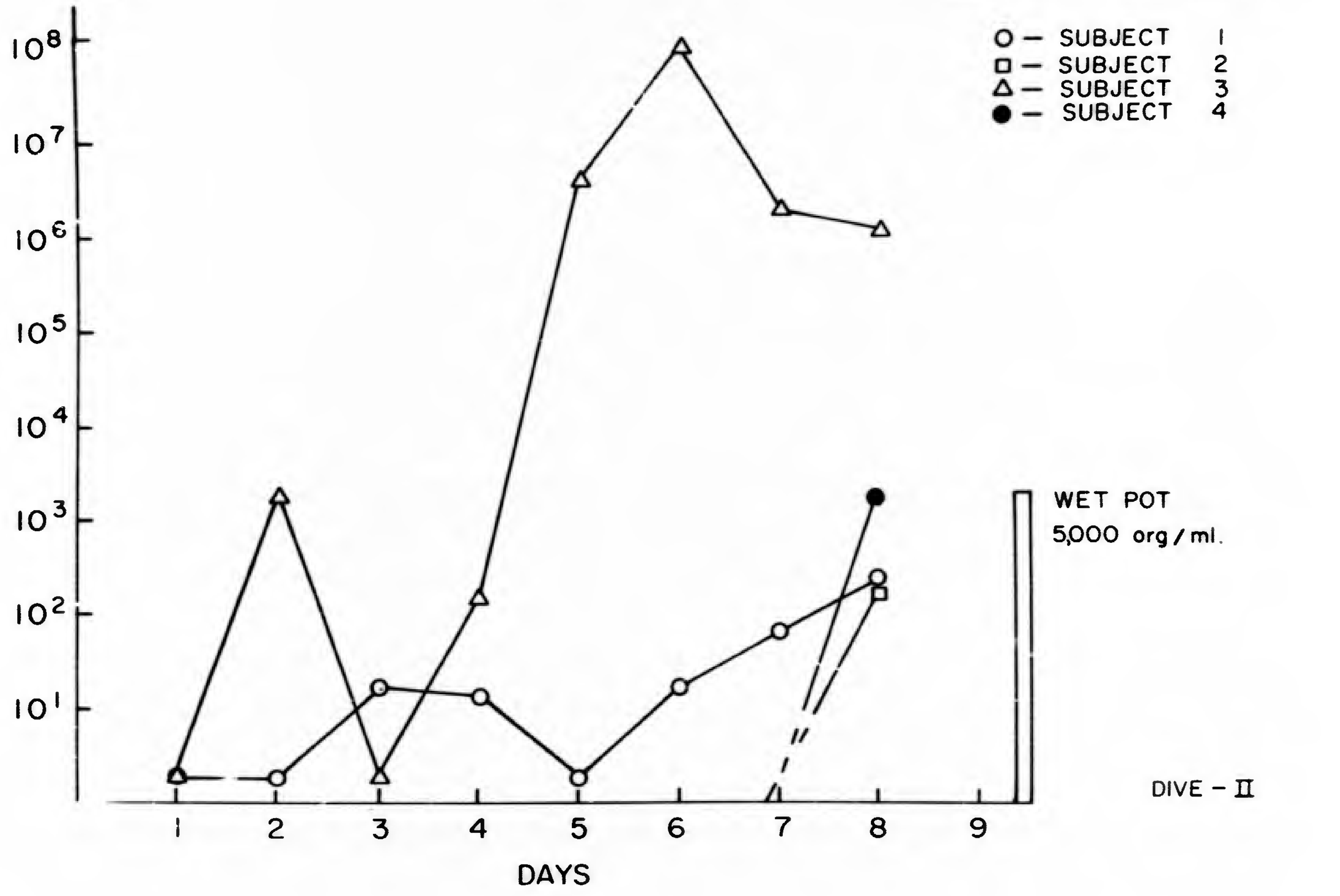
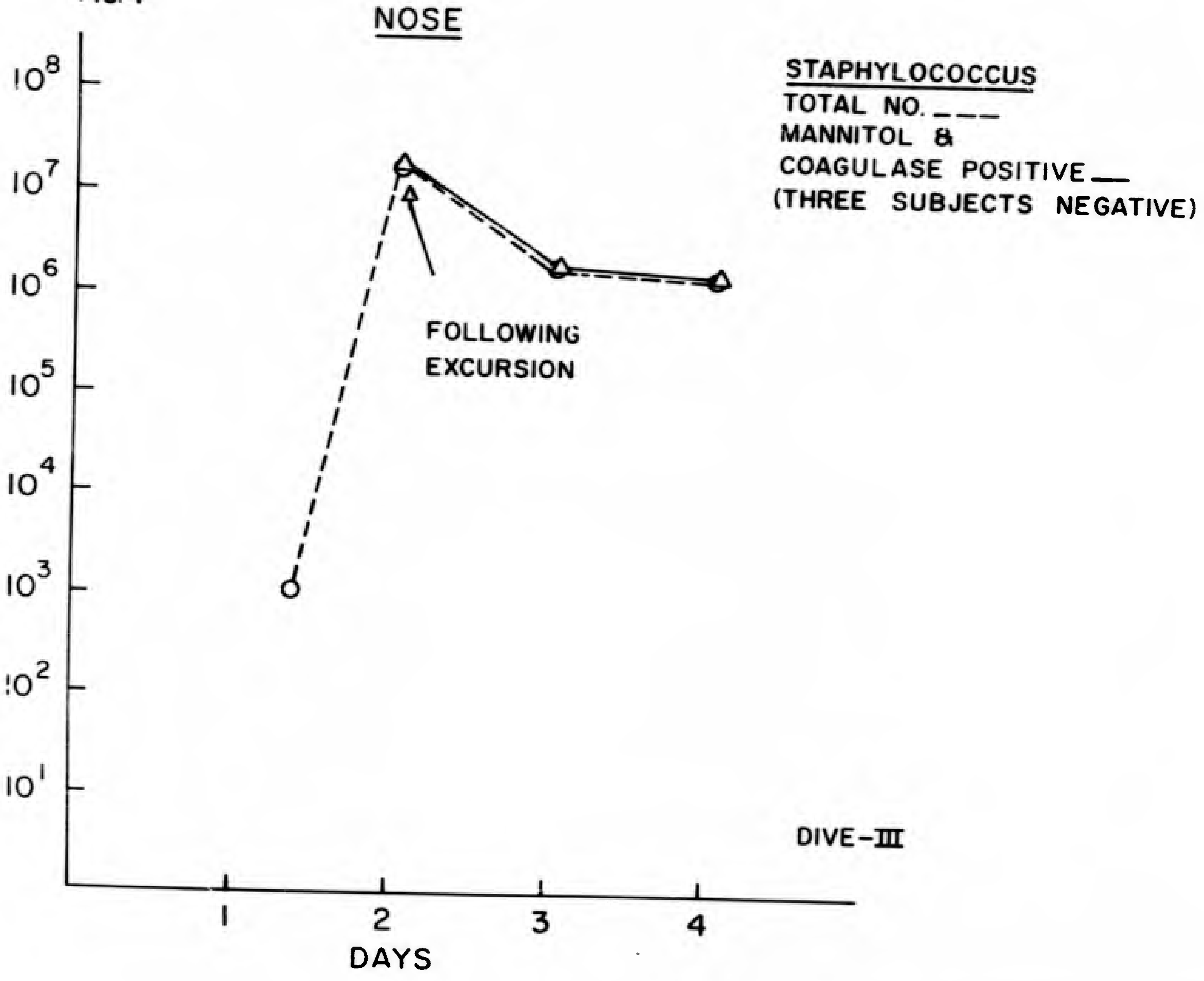


FIG. 4


NOSE
STAPHYLOCOCCUS
TOTAL NO. ---
MANNITOL &
COAGULASE POSITIVE —
(THREE SUBJECTS NEGATIVE)
FOLLOWING EXCURSION
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
1
2
3
4
DAYS
DIVE-III

EAR

FIG. 5

PSEUDOMONAS

(THREE SUBJECTS NEGATIVE)

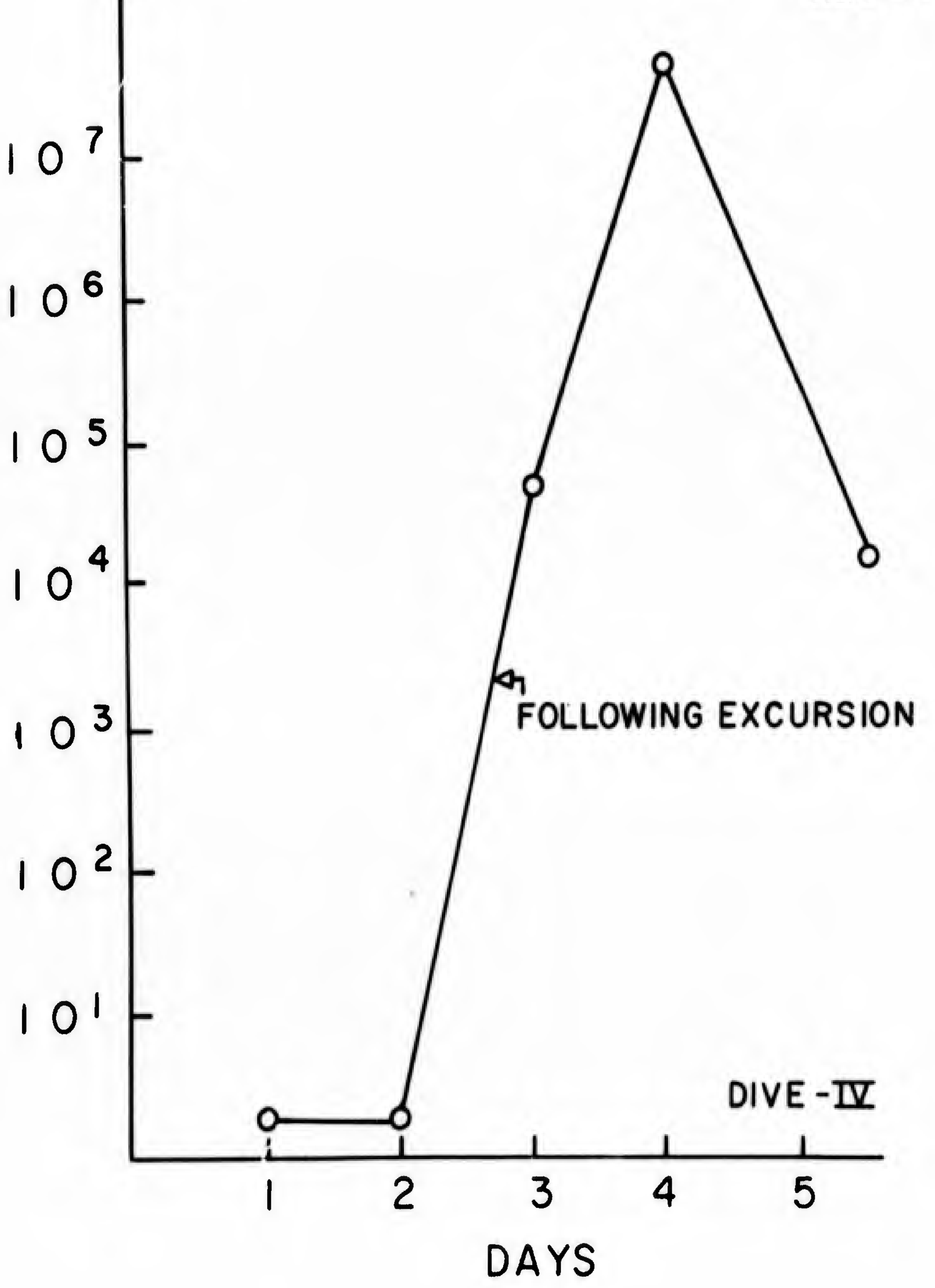
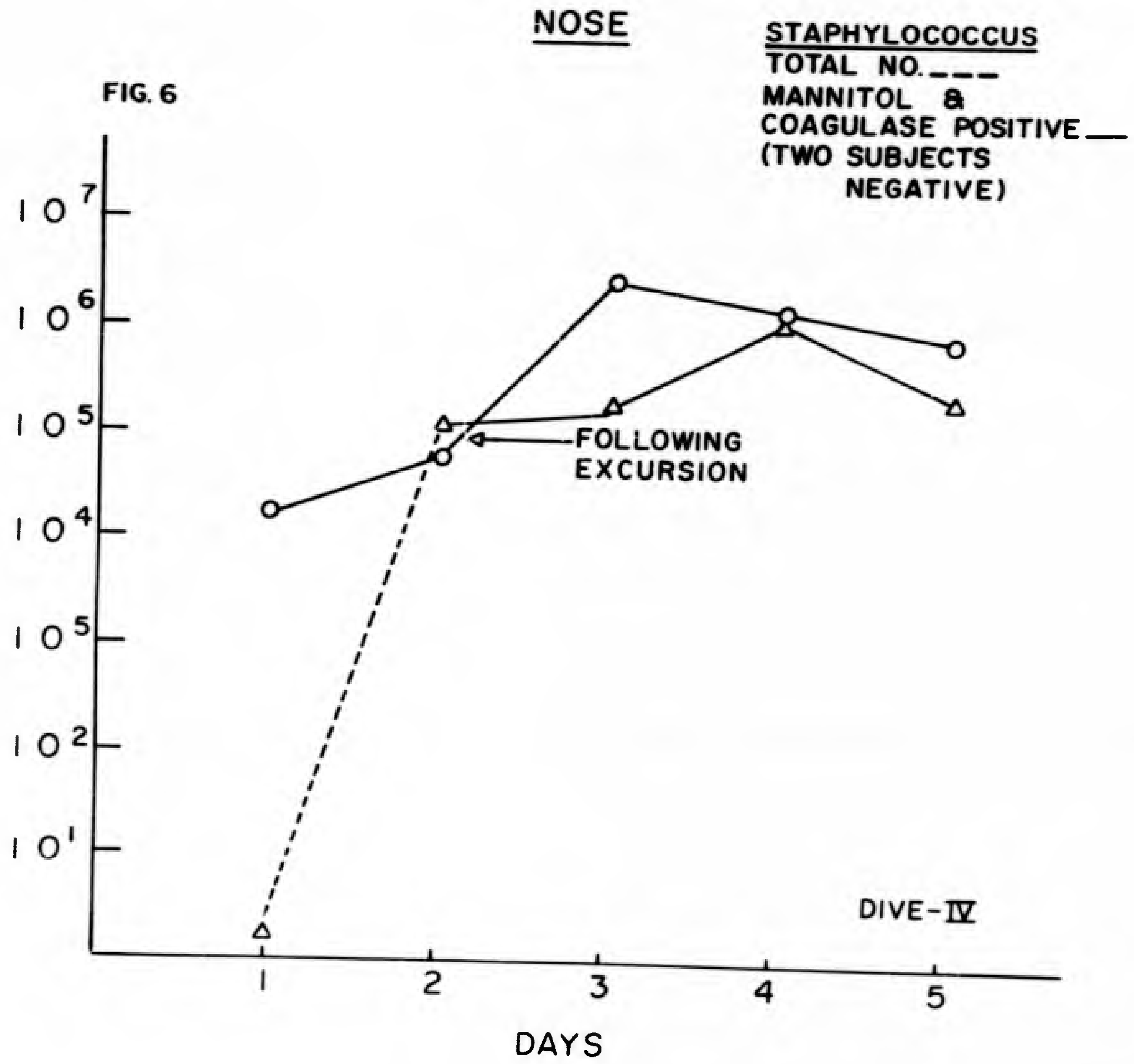


FIG. 6


NOSE
STAPHYLOCOCCUS
TOTAL NO. ---
MANNITOL &
COAGULASE POSITIVE —
(TWO SUBJECTS
NEGATIVE)
10^7
10^6
10^5
10^4
10^5
10^2
10^1
FOLLOWING
EXCURSION
DIVE-IV
1
2
3
4
5
DAYS

BIBLIOGRAPHY

1. Hamilton, R.W., J.B. MacInnis, A.P. Noble, H.R. Schriener: Saturation Diving at 650 feet. Ocean Systems Inc., Tech. Memo B-411, March 1966

2. Hock, R.J., G.F. Bond, W.F. Mazzone: Physiological Evaluation of SEALAB II; Effects of Two Weeks Exposure to an Undersea 7-Atmosphere Helium-Oxygen Environment. U.S. Navy DSSP Report, 11 DEC 1966

3. McCALLEY, M: Body Fluid Volumes and the Renal Response of Human Subjects to Water Immersion. Aero. Med. Res. Lab. Tech. Rep 65-115, Aug 1965.

4. Steiner, R.D.: Naval Medical Research Institute, Personal Communication, 1967

5. Pauli, D.C., G.P. Clapper: Project SEALAB Report - An Experimental 45 day Undersea Saturation Dive at 205 feet. ONR Rep ACR-124, 8 Mar 1967

6. Bennett, P.B., A.V.C. Cross: Alterations in the Fusion Frequency of Flicker Correlated with Electro-Encephalogram Changes at Increased Partial Pressures of Nitrogen. Jour. Physiol. 151:28-29, 1960

7. Bennett, P.B.: The Aetiology of Compressed Air Intoxication and Inert Gas Narcosis. Pergamon Press, Oxford, 1966

8. Schaeffer, K.E.: Panel Discussion, Physiological Performance at Extreme Pressures. Proc. Third Sympos. on Underwater Physiology, P.389, Ed. C.J. Lambertson, Williams & Wilkins, Balt. 1967.

9. Asmussen, E., M. Nielsen: Physiological Dead Space and Alveolar Gas Pressures at Rest and During Muscular Exercise. Acta. Physiol. Scand. 38:1-21, 1956

10. Lambertson, C.J., et.al.: Respiratory and Cerebral Circulatory Control During Exercise at .21 and 2.0 Atmospheres Inspired PO_2. J. Appl. Physiol. 14: 966-982, 1959.

11. Asmussen, E.: Muscular Exercise. Handbook of Physiology, Respiration, Vol II., Chap 36. Ed.. W.O. Fenn & H. Rahn, Amer. Physiol Soc., Wash.D.C. 1965.

12. Dougherty, J.H. Jr., K.E. Schaeffer: Pulmonary Functions During Saturation-Excursion Dives Breathing Air. Aerospace Med. 39:289-292, 1968

13. Maio, D.A., L. E. Fahri: Effect of Gas Density on Mechanics of Breathing J. Appl. Physiol. 23: 687-693, NOV 1967

14. Fisher, A.B., R. Hyde: Effects of Oxygen at 2-Atmospheres on Lung Mechanics of Normal Men. Fed. Proc. 26: 522, 1967

15. Buhlmann, A.A.: Respiratory Resistance with Hyperbaric Gas Mixtures. Proc. Second Sympos. on Underwater Physiology, pp 98-107., Ed. C.J. Lambertson & L. J. Greenbaum, Pub. No. 1811, Nat. Acad. Sci., Wash.D. C. 1963.

16. Schwartz, I., N.E. Sandberg: The Effect of Time in Submarine Service on Vision, U.S.N. Submarine Medical Res. Lab. Rep No. 253, 30 Aug 1954

BLANK PAGE

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Deep Submergence System Project Technical Office 139 Sylvester Road, Ballast Point San Diego, California 92106	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b GROUP N. A.

3. REPORT TITLE
RESULTS OF PHYSIOLOGIC STUDIES CONDUCTED DURING CHAMBER SATURATION DIVES FROM 200 FEET TO 825 FEET, A PRELIMINARY REPORT

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
INTERIM February 1967 to May 1968

5. AUTHOR(S) (Last name, first name, initial)
BRADLEY, LCDR Mark E., MC, USN
VOROSMARTI, LCDR James Jr., MC, USN
LINAWEAVER, CDR Paul G. Jr., MC, USN

6. REPORT DATE 1 May 1968	7a. TOTAL NO. OF PAGES 77	7b. NO. OF REFS 16
8a. CONTRACT OR GRANT NO. b. PROJECT NO. S4607-001 c. TASK NO. 11897 d. SUB TASK NO. 50-1	9a. ORIGINATOR'S REPORT NUMBER(S) DSSP-TO RESEARCH REPORT 1-68 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) NONE	

10. XXXXXXXXXXXXXXXXXXXXXXX DISTRIBUTION STATEMENT
NO. 1. DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

11. SUPPLEMENTARY NOTES NONE	12. SPONSORING MILITARY ACTIVITY Deep Submergence System Project (PM-11) 6900 Wisconsin Avenue Chevy Chase, Maryland 20015

13. ABSTRACT There has been relatively little investigation of the environmental effects of living at depths greater than 300 feet. That data which is available has usually been obtained during brief exposures to depth and on only a few subjects. In the past, conclusions that man could live and effectively work without detrimental effects to himself in a helium-oxygen environment at great depth have often been empirically derived.

From February 1967 to May 1968, The DEEP SUBMERGENCE SYSTEMS PROJECT TECHNICAL OFFICE conducted a series of saturation dives at the U.S. NAVY EXPERIMENTAL DIVING UNIT. These dives were designed to train and select aquanauts for the open sea SEALAB III experiments as well as to measure the psychophysiological effects on man's ability to work at great depths. The psychophysiological research program during these dives was conducted by the DEEP SUBMERGENCE SYSTEMS PROJECT TECHNICAL OFFICE MEDICAL DEPARTMENT with the assistance of the EXPERIMENTAL DIVING UNIT, the NAVAL MEDICAL RESEARCH INSTITUTE, BETHESDA NAVAL HOSPITAL and the NAVAL RESEARCH LABORATORY. A wide variety of hematological, biochemical, cardiopulmonary and psychometric studies were made to determine whether changes occured during exposures to helium-oxygen atmospheres at great depths.

The data in this preliminary report was obtained during 14 saturation dives, ranging in depth from 200 feet to 825 feet. Phychological studies were conducted during "wet" excursion dives to depths of 300, 600, 825 and 1025 feet. Over 25,000 biomedical observations and measurements were obtained in the course of these dives.

In general the results indicate that man can effectively, safely work at depths

DD FORM 1 JAN 64 1473

(1)

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Saturation-excursion diving						
Helium-oxygen environment						
Man-in-the-sea						
Hyperbaric physiology						
Exercise physiology						
Physiology						
Mechanics of breathing						

UCTIONS

1. ORIGINATING ACTIVITY: Enter the name and add of the contractor, subcontractor, grantee, Department c fense activity or other organization *(corporate author)* the report.

2a. REPORT SECURITY CLASSIFICATION: Enter th all security classification of the report. Indicate whethe "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
_______________________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
_______________________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
_______________________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS), (S), (C), or (U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.

②

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*

2a. REPORT SECURITY CLASSIFICATION

2b. GROUP

3. REPORT TITLE

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(Last name, first name, initial)*

6. REPORT DATE

7a. TOTAL NO. OF PAGES

7b. NO. OF REFS

8a. CONTRACT OR GRANT NO.

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. AVAILABILITY/LIMITATION NOTICES

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT continued . . .

up to 825 feet saturated. Some decrement in cognitive and neuromuscular ability was found as well as in certain pulmonary ventilatory parameters.

(3)

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT

INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. **REPORT DATE:** Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.

8*a*. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
__________________________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
__________________________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
__________________________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.