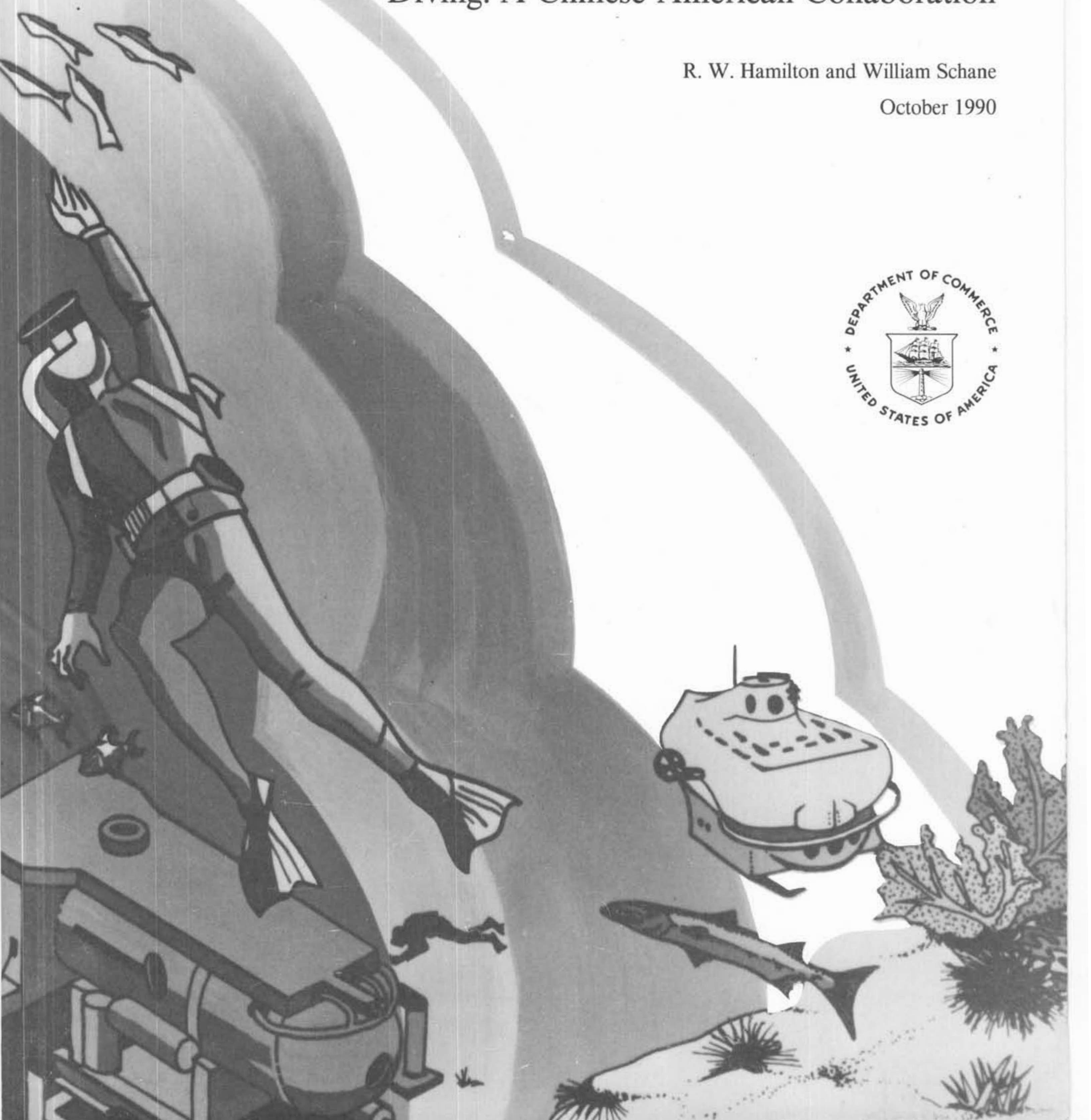
NATIONAL UNDERSEA RESEARCH PROGRAM Technical Report 90-1

Chisat I, Extension and Validation of NOAA's REPEX Procedures for Habitat Diving: A Chinese-American Collaboration

R. W. Hamilton and William Schane

October 1990



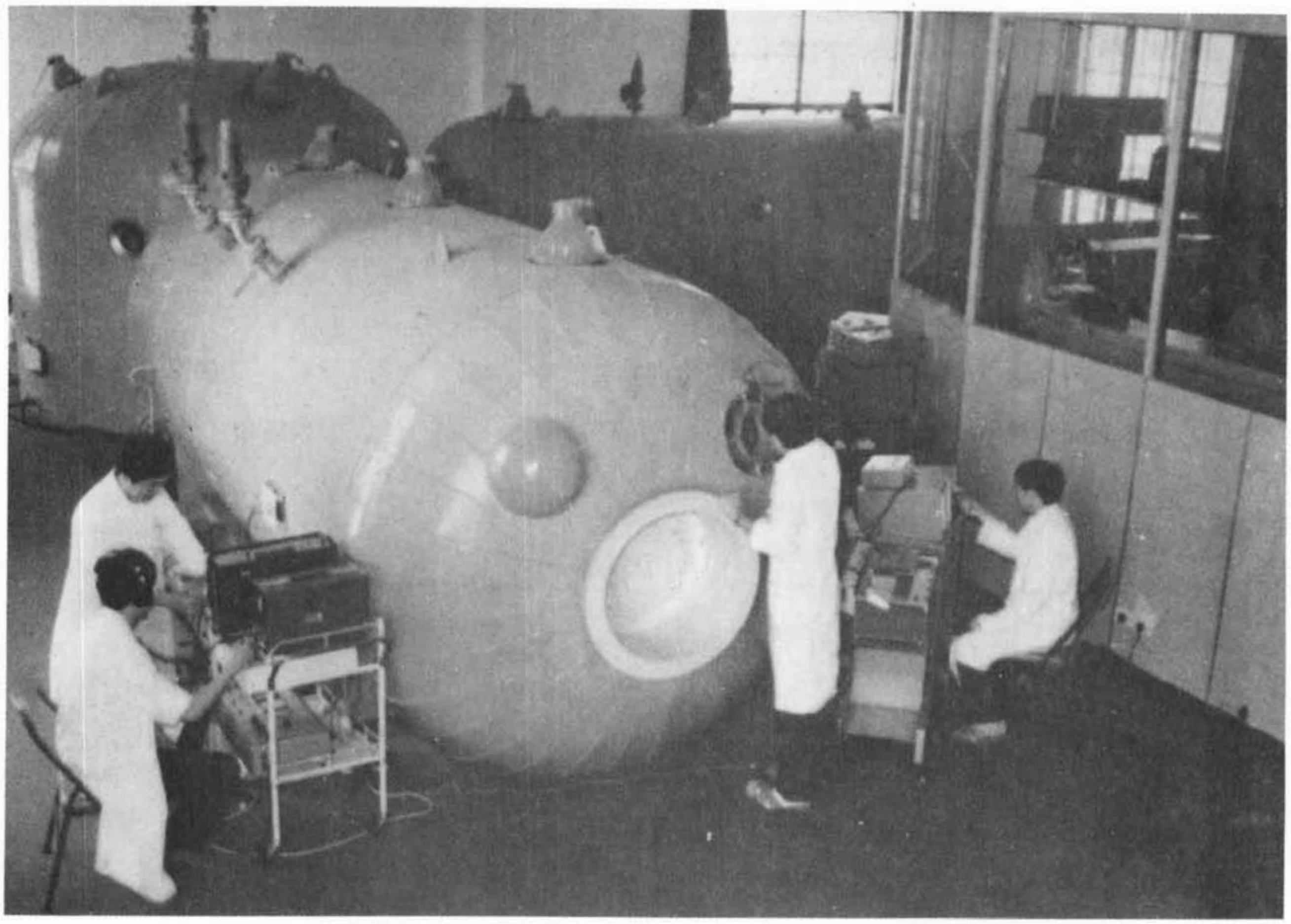
NATIONAL UNDERSEA RESEARCH PROGRAM Technical Report 90-1

Chisat I, Extension and Validation of NOAA's REPEX Procedures for Habitat Diving: A Chinese-American Collaboration

R. W. Hamilton and William Schane

October 1990

U.S. DEPARTMENT OF COMMERCE
Robert A. Mosbacher, Secretary
National Oceanic and Atmospheric Administration
John A. Knauss, Under Secretary
Oceanic and Atmospheric Research
Alan R. Thomas, Acting Assistant Administrator
Office of Undersea Research
David B. Duane, Director



FRONTISPIECE

Diving simulation facility of Chinese Underwater Technology Institute, Shanghai. The divers in Chisat I lived and performed physiological monitoring in the chamber at left and did their pressure excursions in the "igloo" portion of the "wet" chamber at far left. (photo from cover of the quarterly Ocean Technology 6(3) 1987 Sept. (in Chinese))

FOREWORD

The National Oceanic and Atmospheric Administration (NOAA) has the largest diving complement of any civilian Federal agency. Under the aegis of NOAA's Undersea Research Program (NURP), the agency also directly assists a large cadre of marine research scientists to conduct their scientific activities under the sea. This research is accomplished using manned submersibles, remotely operated vehicles, and compressed-air scuba, mixed-gas, and saturation mode diving. Additionally, the NURP assists all divers of the nation through research undertaken in accordance with the terms of Sec. 21(e) of the Outer Continental Shelf Lands Act of 1978 (PL 95-372; 43 USC 1331 *et seq*.). This statute requires NOAA, under authority delegated by the Secretary of Commerce, to "...conduct studies of underwater diving techniques and equipment suitable for protection of human safety and improvement of diver performance. Such studies shall include, but need not be limited to, decompression and excursion table development and improvements and all aspects of diver physiological restraints and protective gear for exposure to hostile environments."

The Technical Report series published by the NURP is intended to provide the marine community with the results of NURP-sponsored research, in greater detail, by presenting all of the relevant data developed in the course of the research. Results reported in NURP's Technical Report series may be preliminary or require further development, refinement, or validation, and this additional research may be beyond the scope or mission of NURP. Accordingly, the reports in this series do not carry any endorsement or approbation on the part of the NURP, nor can the NURP accept any liability for damage resulting from incorrect or incomplete information.

During late 1988 NURP had the opportunity to participate in a unique collaborative project with the Chinese Underwater Technology Institute (CUTI) in Shanghai. Dr. R. W. Hamilton, principal investigator of the research grant that resulted in the Repex tables and report (Technical Reports 88-1A and 88-1B), was invited to be a co-investigator in a simulated nitrox saturation dive project at CUTI. The project was designated Chisat I and was designed as a verification and extension of capability of the Repex method. Dr. Hamilton was accompanied by co-investigator Dr. William Schane, physician for the NURP *Aquarius* and earlier *Hydro-Lab* operations. Their participation was supported by NURP, but since the cost of the experiment was borne primarily by CUTI and its sponsors, Chisat I was highly cost-effective for NURP.

Chisat I's main accomplishment was to perform additional validation testing of Repex procedures for repetitive excursion diving, oxygen tolerance, and saturation decompression. Perhaps more important was the extension of capability provided by laboratory validation of the algorithm used for generating the Repex excursion procedures, supplementing earlier testing of the tables themselves. This enables "custom" excursion patterns for specific projects to be developed with greater confidence; such procedures are required for some already planned *Aquarius* missions.

This report, published as presented to NOAA, was submitted under the requirements of award number NA88-D-UR106. Comments on the report are welcome. Send them to:

Director
National Undersea Research Program, NOAA
1335 East-West Highway, Room 5262
Silver Spring, MD 20910

Silver Spring, Maryland
October 1990

David B. Duane
Director

PREFACE

This report covers a collaborative experiment performed in Shanghai at the Chinese Underwater Technology Institute in October of 1988. A preliminary report was presented at the Undersea and Hyperbaric Medical Society meeting in June of 1989, which by coincidence was precisely at the time of the "hardline" crackdown on demonstrators in Tiananmen Square in Beijing (text of that presentation is included in the appendix). As is evidenced by its date, the completion of this final report has been delayed, for all the usual reasons. We have retained the material as it was (or would have been) before Tiananmen.

In the early stages of production we decided to prepare the report with materials and information we had on hand on return to the US from Shanghai, and not to attempt to fill in blanks by correspondence. This decision was based first on the long turnaround time for an exchange of letters (on the order of one month) but also because to seek additional data from the individual investigators for work that did not belong to us in the first place seemed inappropriate. In retrospect there would have been enough time for a few letters, but we still feel the approach we used was best. Thus some data reported here was kindly supplied by the investigators who collected it. It is reported in a provisional way, but we make no claim to it or for that matter for its correctness. Any points of uncertainty are mentioned in the text; if there are errors, we apologize. We acknowledge with gratitude the splendid cooperation of all our CUTI colleagues, both for their invaluable help to us in our tasks, but also for their contributions to the project and the report. We have chosen to list their names in the report in the traditional Chinese order with surname first.

The prime mover in this project was Dr. Shi Zhongyuan, head of CUTI, whose persistence to do a collaborative project made this one happen. Others on the CUTI team were especially helpful, including in particular our interpreter Geng Zhongming, our driver You Shengdi, the other senior CUTI members Chen Baosong, Fan Zhenghuan, Gu Zhengzhong, and Zhang Longbao, and of course the divers. The list could go on and on, and we feel guilty about failing to mention many others who should be acknowledged. A nearly complete list of participants is shown on page 12. Also deserving special thanks is a CUTI investigator who missed the experiment, Lee Yuanchen, who was studying in the US at the time and who provided willing assistance to HRL in Tarrytown for half a year before moving on to Duke University. Mr. Lee is still at Duke, and Mr. Geng is now a student at the University of Tennessee. We want to thank also our colleagues at NOAA's Office of Undersea Research, Drs. Bill Busch and David Duane, who willingly provided the support. Thanks also to the HRL staff, Eileen Whitney and Kathryn Hamilton, to Dave Kenyon for his work with DCAP, and to Wayne Gerth for his help with the analysis of the chest plethysmograms.

We are ready to do another one as soon as national politics permits.

TABLE OF CONTENTS

List of Figures

List of Tables

I.
ABSTRACT

Hamilton RW, Schane W. 1990 October. Chisat I, extension and validation of NOAA's new Repex procedures for habitat diving: A Chinese-American collaboration. Research report 90-1. Silver Spring, MD: National Undersea Research Program.

A collaborative experiment between the Chinese Underwater Technology Institute, NOAA's Office of Undersea Research, and Hamilton Research, Ltd., was conducted at CUTI's facility in Shanghai during October 1988. The experimental objectives were to extend the laboratory validation of NOAA's new Repex procedures for habitat diving (NOAA 88-1A and 88-1B). The main objective was to test the Repex decompression algorithm for multiday repetitive excursions computed on a "worst case" basis, but we also further evaluated the longer, deeper repetitive excursions (some with stops), oxygen exposure management, and saturation decompression after excursions, all from the Repex procedures. These objectives were successfully accomplished. Four experienced divers were saturated at 25 msw for 5 days, during which time they did 15 air excursions to depths between 50 and 75 msw, for times up to 240 min. Decompressions from excursions were mostly no-stop, but 5 required stops of durations from 3 to 116 min. Saturation decompression began with the "precursory" ascent following a brief return to 25 msw. Doppler bubble detections showed some bubbles, Spencer Grade II and occasionally III, following excursions and during saturation decompression, especially after muscle flexing. No symptoms of decompression sickness were reported; one diver was more than normally fatigued on one occasion. Oxygen exposure reached its peak at 6 days at 3103 Oxygen Toxicity Units, over 600 more than the Repex limit; the symptoms were mild and transient numb fingertips. No vital capacity changes greater than the normal fluctuations in measurements were seen. An unexpected change in pulmonary blood flow measured with impedance plethysmography showed a flattening of the peak of the pulse curve. This was noticed in 3 of the 4 divers and seemed most prominent during periods of high decompression stress; it could be an indication of bubbles in the pulmonary circulation and requires further study. Additional physiological and psychometric measurements showed anticipated responses. The divers consumed 5000 kcal per day. While these experimental findings are important, perhaps the most significant result was the initiation of effective scientific cooperation between scientists of these two countries in this special field. *Note: The comments on events and relationships were all written prior to the unfortunate situation in Tiananmen Square during 1989 June, and have been left unchanged.*

II. INTRODUCTION

Note: This document was approaching its final form when the unfortunate situation developed in Tiananmen Square during June of 1989. This of course cast a dark cloud over any prospect of future collaboration, but the suggestions for such activity and the relationships described have all been left in this report as they were or we included them as they would have been. The authors' impressions at the time are still valid, and we regard them worth reporting as they were made.

A. Background of the project

Contemporary policy in mainland China encourages the opening up of communication and commerce with the West. In keeping with this, a satellite symposium was held in China during the fall of 1986 in conjunction with the 9th Symposium on Underwater and Hyperbaric Physiology which met in Kobe, Japan. The satellite symposium was held by the Chinese Underwater Technology Institute (CUTI) in Shanghai, and was attended by a number of prominent researchers in diving medicine and physiology from several Western nations. This symposium furnished the face-to-face personal contacts necessary to start planning for future operational and scientific collaboration.

A particularly significant bit of common ground was found to be the area of nitrogen-oxygen ("nitrox") saturation-excursion diving, a technique used for diving from seafloor habitats. CUTI is one of the world's most experienced laboratories in conducting simulations of this type of operation, and this helped generate a special relationship with us as developers of much of NOAA's technology in this area, specifically the NOAA OPS and Repex projects related to excursion techniques for habitat diving, and long association with NOAA's undersea habitat program. CUTI planned a saturation-excursion chamber "dive" for the fall of 1988 and invited the participation of Hamilton Research, Ltd. (HRL). The interest was there, all that remained was a meaningful experimental plan and some way to finance it.

Several concurrent events helped move this along. One was the launching of Aquarius, the new habitat of NOAA's Undersea Research Program (NURP) and the U.S.'s main implementation of habitat diving. Another was the arrangement for a visiting scholar (Lee Yuanchen) from CUTI to study for a year with HRL. Still another event was the publication by NOAA NURP of the Repex reports which provide new repetitive excursion diving capability.

The invitation from CUTI was generous, offering a wide open opportunity for proposing what the U.S. contribution could be, with a good chance for a reasonable idea to be accepted. HRL's interest was in extending the verification of the Repex procedures with more controlled laboratory exposures, and in particular to test the use of the computational algorithm for calculating "custom" excursion decompression tables for specific applications.

A proposal from Hamilton Research was submitted to NURP for funding to cover the participation of R.W. Hamilton in the project, with an invitation passed on from CUTI to include a NOAA participant if possible. The proposal was accepted, and Dr. William Schane was appointed as the NOAA representative. A grant by NURP covered the travel expenses for both investigators, some time for preparation and participation by RWH, and a contribution to the cost of the project for CUTI. In terms of the usual costs of this type of operation this was a token amount, but it helped provide precious foreign exchange funds for CUTI. CUTI covered the living expenses of the U.S. investigators while in China.

From the Chinese end the project was instigated by the head of CUTI, Professor Shi Zhongyuan. This was a familiar type of experiment for CUTI, but this one had as a special objective to promote international cooperation. Funding was obtained from the Ministry of Transport and Communication and the Ministry of Petroleum, two of CUTI's regular sponsors.

It was agreed that CUTI would perform a 5-day nitrox saturation with excursions, and that the excursions and decompressions would be planned by HRL. CUTI would perform physiological measurements during the exposure.

B. Nature of this report

This report is a first person account of our view of the project. It includes our (the authors') data, which dealt almost exclusively with decompression and oxygen management, in as much detail as is immediately possible. We do not anticipate much additional input.

The report also includes an overview of the work of many of our CUTI colleagues. We include that here primarily to provide a better perspective of the project, but do not lay claim to the data. What is said here is based on the best information we could gather at the time of the project. Some of the data is incomplete, and neither the data presentation nor our analysis has been reviewed by the CUTI participants.

We did, however, discuss this report and its approach while we were there. The CUTI people, presumably because of the personal viewpoints expressed, quite properly declined to be listed as authors. It is our plan to prepare--jointly--a more complete paper for a journal such as *Undersea Biomedical Research*. A paper on Chisat presented at the UHMS meeting in Hawaii in 1989 June is included as Appendix D.

Although the CUTI staff were completely open about the Institute's facilities and operations, due to lack of time and language difficulties we were not able to get a thorough briefing on all aspects of the facilities. We have had to fill in some of these details ourselves, and because our report has not been checked by CUTI personnel there may be some inaccuracies. We take full responsibility for any of these, and apologize for any inconvenience they may cause.

C. The Chinese Underwater Technology Institute

To better put the project into perspective, this section reviews the diving research scene in China and at CUTI.

1. Background

a. History

There was not much diving in China before 1949, except for an occasional small group diving in the rivers and lakes. A company was set up in the early 1950's. One of its members, Zhang Ziqua, went to Poland in 1954 and returned with decompression tables that had originated in Russia. He later became the first head of CUTI. Even now the current Chinese diving manual contains Russian air diving tables (Fan, 1982). The Navy developed air tables in 1958, but the commercial tables are more popular. There has never been a great push to get faster decompressions.

The Institute was founded in 1978, just as China was coming out of the Cultural Revolution. It is supported by the Ministry of Communications, which regulates shipping and road traffic in China (but not the railroads), and of the Ministry of Energy, which holds the responsibility for offshore petroleum development. In addition to CUTI and some 10 other agencies the Communications Ministry includes the General Salvage Bureau, which has 3 major ocean salvage and ocean engineering companies, located in Shanghai, Guangzhou, and Yantai. CUTI is tasked to provide technical support for this sister agency and its underwater operations. Likewise CUTI's support of offshore petroleum work is a main part of its mission. Most of the major salvage and offshore activities in China are linked to CUTI.

Before the Institute was founded the center for diving research in China was the Institute of Physiology at Academia Sinica (the Academy of Sciences) in Shanghai. Several of the senior researchers now at CUTI began these investigations there (SZY, CBS, GZZ). A list of the CUTI investigators in Chisat I is given in section II.C.3., below.

b. Organization

CUTI has six major departments, covering physiology and medicine, underwater mechanical engineering, remotely operated vehicles and manipulators, underwater technique, underwater information science, and an underwater engineering company. There are also sections for the hyperbaric laboratory, and for some business ventures that help bring in money. The Hyperbaric Laboratory conducts medical research in hyperbaric oxygen therapy and treats patients with HBO (for income), and has sections for the machine room and the chamber operators. The divers belong to CUTI's underwater engineering company, and support themselves with commercial diving work when not working at the institute.

The Department of Diving Physiology and Medicine has six groups specializing in brain function, brain blood flow, biochemistry, decompression, cold, and respiratory physiology.

The Institute has a total staff of about 300, with some 35 scientists and 70 engineers. About 200 are at the campus at 1500 Long Wu Road where the experiment was held.

c. Economics

Several characteristics of P. R. China as a nation are reflected in CUTI. One prevailing problem of constant concern to individuals, institutes, and the nation itself is the shortage of hard currency. China uses two forms of currency, the local *"renminbi"* or RMB and "FEC" or foreign exchange currency. They have the same nominal value, but only FEC can be exchanged for dollars. The black market value of FEC is said to be roughly twice that of RMB.

CUTI is able to carry on, funded by its regular budget and ongoing businesses for day to day operations, and can call on its Ministries for special activities such as this one; support is easier to get where local currency will suffice, but the Institute is always in need of foreign currency for instruments and travel. For the Institute to obtain a small flow of foreign currency it operates a small business of raising specific pathogen free rabbits. These are mainly exported to Japan. Current policy is that institutes of this type should strive toward being self supporting; the Institute gains one quarter of its total annual budget of about 4 million yuan ($1 million) from these enterprises.

The small support provided to CUTI in dollars from the NOAA grant for this collaborative project was helpful, even though the same nominal amount or perhaps a bit more was expended in housing and feeding the visiting American investigators. However, even when the Institute accumulates foreign currency it is still necessary to apply to higher authority in order to be able to spend it. For income in local currency CUTI operates a domestic manufacturing business, producing underwater mechanical equipment.

One special collaboration is with Wuxi Ocean Engineering Company, which conducts diving and underwater engineering operations in the Yangtze River and nearby offshore areas, but has wider ambitions. CUTI loans decompression chambers and other equipment to Wuxi, and provides advice in special techniques which generates a small amount of income. RWH and WS were able to visit a dive site of Wuxi Ocean Engineering at Jiangyin City.

d. Communications

One place where there seems to be room for improvement at CUTI is in the general area of communications. Part of this is due of course to the Chinese language, which is difficult for westerners to learn and not as adaptable as some to new words and concepts. It seriously limits the usefulness of alphabet oriented devices like typewriters and telex machines which westerners take for granted, and tends to discourage the use of computers. One new device which is catching on in the Orient is the fax machine, which transmits handwritten characters and does not have to rely on using roman characters to communicate; CUTI did not yet have a fax at the time of Chisat 1.

Library facilities are also limited, with only a few of the standard textbooks on diving technology available at the Institute, though most may be found somewhere in Shanghai. This is being compensated in some ways by translation of some more widely used books such as the U.S.

Navy Diving Manual and the NOAA Diving Manual into Chinese (unfortunately only one copy of the NOAA manual was available to us; if it could be found in a bookstore the price would be about $3). A Chinese diving manual includes USN and NOAA saturation-excursion decompression tables, and also includes a set of Russian air decompression tables which are the standard for commercial diving in China. These by examination look rather conservative, but the divers like them (there is not quite the same economic incentive to shorten decompression time as there is in the West.

Another minor limit to communication in the diving world in China is the fact that sport diving is virtually unknown. Thus there is no cadre of eager young scientists and engineers who already know the basics of diving and are dedicated to it. Also, as far as we can tell, there is practically no diving done for scientific purposes in China.

e. *Previous CUTI dives*

There may be limitations to the facilities, but the record established by CUTI is impressive, especially in nitrox saturation-excursion diving of the type developed and practiced by NOAA. This interest is for two reasons, first the obvious one of the high foreign exchange price of helium in China, but also because a large part of the diving work that is needed is in water in the depth range accessible with that technique. A list of the dives done by this laboratory and its predecessor groups at Academia Sinica are given in Table I. At the time the first dives were done national policy was against dissemination of technological information, and little attempt was made to publish the results in Western literature or until relatively recently. Some relevant publications reporting on these dives are Chen, 1985; Jing et al, 1979; Mo and Chen, 1987; Shi and Chen, 1987; Zhang and Wang, 1982; Zheng et al, 1988; Zhao et al, 1982.

2. Facilities

a. *Campus and labs*

The main campus of the Institute is located on Long Wu road, in the southwest environs of Shanghai, in an industrial area just off the Huangpu River (but CUTI has no river frontage in this location). The 8-story main office and laboratory building was built in 1978, and the chamber facility and the building housing it were added in 1985. There is also a gas storage building and two small apartment buildings plus a few older structures; a new building to house the kitchen and cafeteria is under construction. Part of one building is rented to an auto repair shop, and some apartments are available as housing for single Institute workers or for use by the staff during around the clock operations.

The Institute's labs are rather spartan by modern Western standards, but the key instruments seemed to be there, and in some cases are relatively modern. At least two IBM PC "clones" are in use, and although computers are not readily available to the ordinary scientist for day to day routine use, it does seem that such equipment is available for cases where it is really needed. They are not able to take full advantage of the plethora of off-the-shelf software currently available; they write most of what they need. A few small pressure chambers of various sizes are available and fully functional, and seem well equipped. One thing that made an impression on the American visitors was their special coaxial ceramic electrical feed-throughs for pressure chambers,

Table I. Diving/decompression work at Academia Sinica and CUTI.

Expt no.	Date	Satn depth, msw	Breathing gas	Excn depth,	Chamber time, days	No. Subj.	No. DCS	Comments
1	77Nov23-Dec04	20	N_2-O_2	-	12	6	0	No excursions
2	77Dec19-Dec29	30.5	N_2-O_2	-	10	6	0	No excursions
3	78May02-May13	30.5	N_2-O_2	50-70	11	7	0	44 excursions
4	78Jun01-Jun12	30.5	N_2-O_2	50-65	12	7	0	66 excursions
5	78Jul13-Jul23	30.5	N_2-O_2	60,65	10	3	0	24 helmet dives
6	78Aug05-Aug18	36.5	N_2-O_2	60-70	13	7	0	54 excursions
7	79May17-Jun16	36.5	N_2-O_2	60-75	30	7	0	60 excursions
8	79Jun30-Jul11	50	N_2-O_2	-	12	6	1	No excursions
9	79Dec03-Dec13	36.5	N_2-O_2	64,75	11	5	0	17 open sea bell dives
10	79Dec19-Dec26	120	HeO_2	165	7	3	0	3 excursions
11	79Nov28-Dec01	10	Air	30	3	3	0	3 excursions
12	81Apr24-Apr26	10	Air	30	3	3	0	3 excursions
13	81May09-May22	302	HeO_2	-	13	3	0	No excursions
14	83Sep10-Sep16	5000m asl	Air	30-50	7	5	0	15 altitude dives
15	83Sep23-Oct01	4500m asl	Air	30-50	9	5	0	30 altitude dives
16	83Oct06-Oct12	4500m asl	Air	30	7	5	1	35 altitude dives
17	85Jul26-Aug09	4442m asl	Air	18-30	-	6	0	80 helmet dives/Tibet
18	85Jan08-Jan21	3600m asl	Air	-	14	8		Altitude exposure
19	85Jan25-Feb07	4500m asl	Air	-	14	8		Altitude exposure
20	86Nov25-Nov28	18	N_2-O_2	30	3	4	0	8 wet chamber dives
21	87May07-May09	10	Air	30	3	4	0	8 wet chamber dives
22	87May23-Jun12	300	HeN_2O_2	303	20	4	0	16 wet chamber dives

leak free and insulated for at least 20,000 volts: *Ordinary spark plugs* do this job quite well. Another similar innovation is the investigator intercom system used for the main manned chamber; it consists of a small portable radio rewired to use a talkback speaker; it is connected to the speaker inside the chamber through EEG leads.

About 15 beds can be placed in the chamber building during an overnight operation such as this. The Institute head and many of the staff sleep at the lab over most nights (or days) during saturation.

b. Chamber system

During the first few years of existence the Institute used chambers at a Navy facility, and carried out operations in a deep diving system designed for offshore use. This system at first was used on board the *Borgny Dolphin*, now called the *Naihai No. 2*, which is a semisubmersible drilling rig made in Norway (There are several *Naihai's*; No. 1 is a ship-shape drilling vessel, and No. 5 is a modern semisubmersible). The system was later removed from the vessel and moved to the Institute. The chambers and control house are presently rusting in the yard at CUTI. The system was built by Drass in Italy, and instrumentation was provided by Tarrytown Labs (NY); the system was an old friend to one of us (RWH), since we had furnished some of the instrumentation and had conducted training dives in the system in Stavanger in 1976. The Drass system was used as an engineering model for many aspects of the current CUTI chamber complex.

The present diving simulator system was built in 1978 (Shi and Chen, 1987). Its plan is shown in the frontispiece, and as prepared by Chen Baosong in Figure 1. The system has all the expected functions of such a facility, and some special innovations of its own. There are two horizontal living chambers and a vertical "wet pot." The living chambers are good to 300 msw pressure, and the wet chamber to 400 msw. Chamber 1 has a bunk room with four beds; it is 3500 mm long and 2100 mm in diameter, and there is a toilet lock 2000 mm long attached to it that connects to the dry "igloo" portion of the wet chamber. The bunk space is divided by a bulkhead from a small area where the spirometer and other apparatus was used, and which contains the pass through "lunch" lock. The wet chamber is 5500 mm tall and 2950 mm in diameter. It does not have a lunch lock. A second chamber (#2) the size of the living chamber is also attached to the wet chamber; this one was not used in Chisat, but was kept available in case a treatment case came in.

Similar to the engineering style of Drass and Comex, the chamber system uses duplicate external scrubber systems with circulation provided by Rootes-type blowers in pressure housings. The gas stream passes through canisters containing indicating soda lime, the blower, a water trap, cold water (refrigerated) which serves as a dehumidifier, a deodorizing canister containing charcoal and an additional absorbent which seems to be activated alumina pellets, and a heater to adjust the temperature to the desired level. The system is able to maintain ideal living conditions with ease. The machinery is located in the lower floor beneath the chambers, where there is also a diesel powered emergency generator and a treatment gas cylinder manifold.

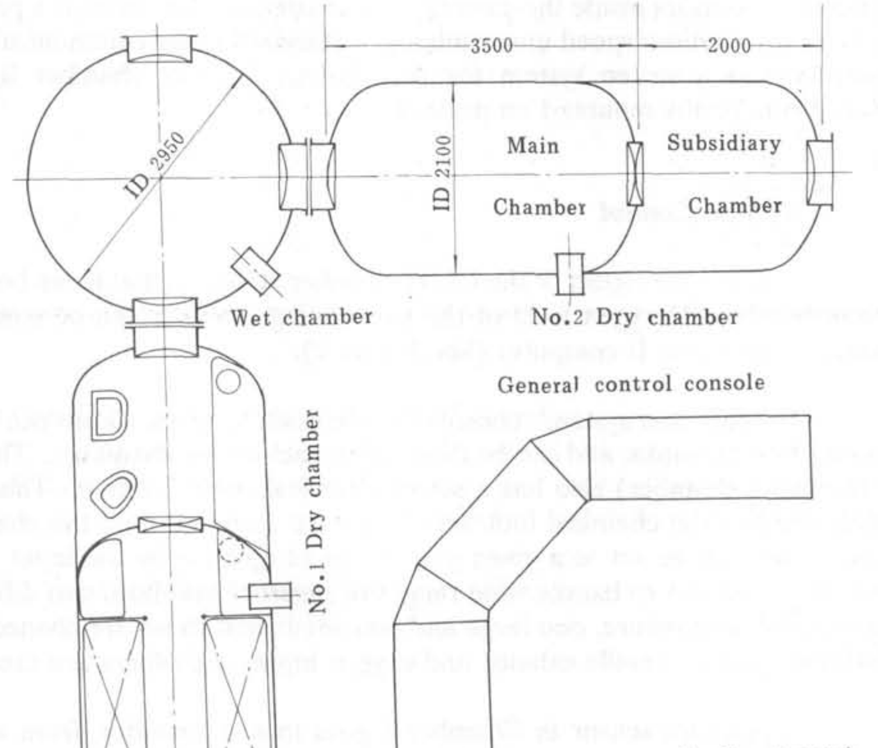


Figure 1. CUTI chamber system. The living chamber used in Chisat, #1, is on the lower left and is attached to a vertical wet chamber; this also joins with another similar living chamber which was not used in this dive. The control panel is in a separate windowed room.

The main gas stores are in a nearby building, where there are adequate storage facilities for helium, nitrogen, and air, and duplicate sets of both high and low pressure, high capacity compressors. A pressure swing helium reclaim system is located there also. Nitrogen for this project was supplied from cylinders.

The chamber system was designed to be compressed at a rate of 20 msw/min, but with the air bank full it can go as fast as 37 msw/min.

Instrumentation consists of precision pressure gauges on the control console, with the usual environmental displays; gauges cover the 0-100 and 0-400 msw ranges. A nearby monitoring rack holds gas analyzers and provides gas selection from the various chambers. Oxygen is read on a gas sample stream from the selected chamber by means of a commercial (Chinese) paramagnetic analyzer. CO_2 is read on a Maihak AG (FRG) non-dispersive infrared analyzer with a 500 ppm most sensitive scale. Relative humidity and temperature are digital displays on the Auto Control panel, from sensors inside the chambers. The console also contains a pair of Helle communications systems with helium speed unscrambling, a standard Helle communications unit, light and heating controls, and a stereo system for the divers. Interior chamber lighting is by special "cold" (fluorescent) units mounted on portholes.

c. Auto Control

One unique aspect of the CUTI chamber system is that it can be computer controlled. Both the pressure and oxygen level of the main living chamber can be controlled by a control system based on an Apple II computer (See Figure 2).

The chamber system's console has the usual controls. Gases can be selected (normally) from several storage banks, and can be directed to each of the chambers. The main chamber (Chamber 1, the living chamber) also has a set of electrical control valves. These are off-the-shelf process valves used in the chemical industry. They are mounted near the chamber, and require a 5 volt signal; each can be set to a given percentage of opening by the input signal. Each has a manual override. In order to handle wide ranges of pressure and flow, two different input valves are used for controlling pressure, one large and one small, and these are connected to the nitrogen supply. Additional valves handle exhaust and oxygen input, and others are used for helium.

A pressure sensor in Chamber 1 goes to a transmitter, from which a signal is sent to an analog-to-digital converter and digital display, and to a strip chart recorder. A polarographic oxygen sensor mounted inside the chamber also sends a signal to a millivoltmeter type digital display instrument that acts as an A-to-D (analog-to-digital) converter. Both of the displays send a signal to a standard Apple II computer which is programmed to act as a controller.

The Apple II program (which is written in BASIC) is given a set point by the operator. The computer compares the input pressure or oxygen signal with the set point and provides a proportional correction. This signal goes to an D-to-A converter, which then sends a voltage signal to a channel selector (which is thus controlled by the computer) and it goes then to an amplifier which converts it to a 0 to 5 volt signal for the control valve handled by that channel; each channel controls a separate valve. If pressure is off by a large amount, as it might be when the set point has just been adjusted, the large pressurization valve (D3) is used. If a smaller correction is needed the smaller valve is used and if pressure is high the exhaust valve (D5) is used. The degree of correction and hence the value used is calculated to be proportional to the change needed. Oxygen corrections work the same way. The set point for this program was set at 25.0 msw, with a dead band of ±0.1 msw.

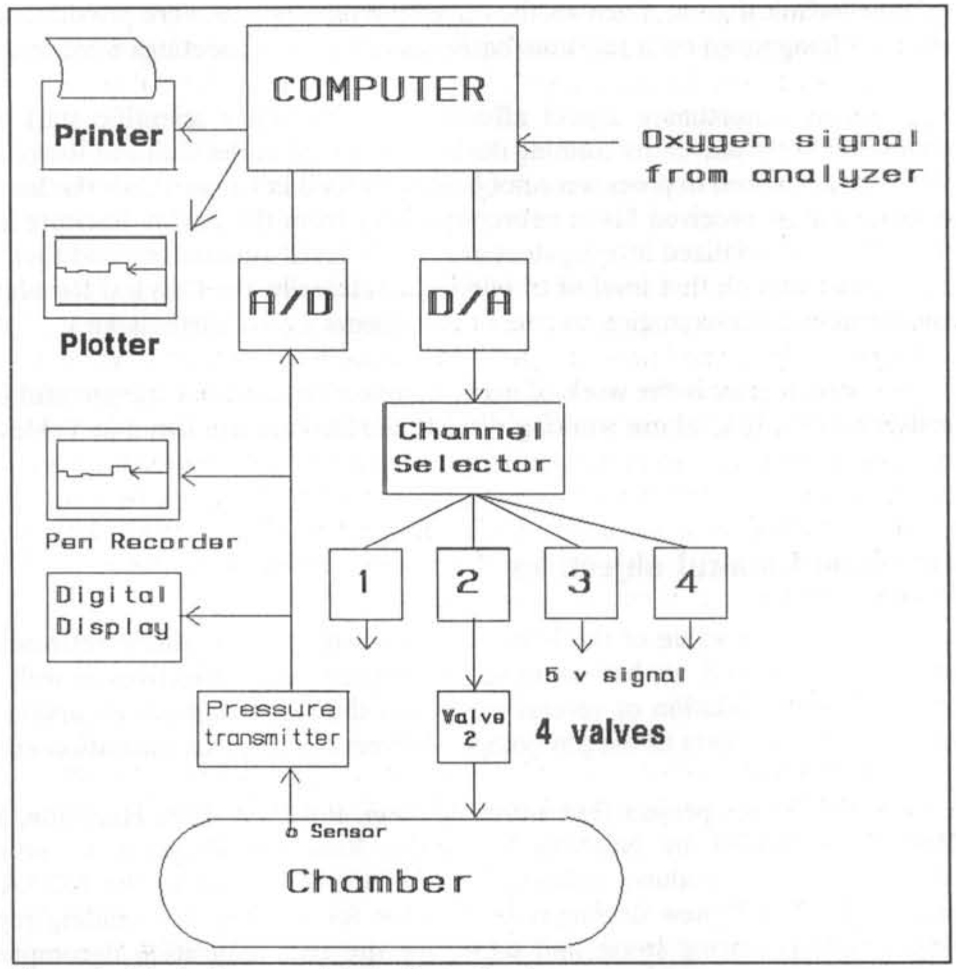


Figure 2. Block diagram of Auto Control system.

During control the parameters are written out to an Okidata Micro 92 printer every minute. At this time a continuous line on a graphics pen plotter is also updated, and the data are stored on disk. Thus there is a plotted line chart, a text printout, and disk storage of the chamber oxygen and pressure throughout the dive. Relative humidity and chamber temperature are also stored on the printed and disk printouts, but are not controlled automatically. An additional 4-pen recorder monitors these 4 parameters and acts as a backup independent of the computer. An independent single channel plotter tracks CO_2.

In practice, when the system is being autocontrolled the operator occasionally would make corrections in a semi-manual way in order to save nitrogen. For example, after an excursion when an excess of oxygen from the working chamber got in the living chamber, the operator would decompress slightly, then allow the auto control to restore to the correct pressure level by adding nitrogen. This had been determined to use less nitrogen as well as being quicker than if the Auto Control had to make the whole correction. One limitation during Chisat was that the control valves had been selected to control the chamber when used with helium, so were smaller than ideal when used with nitrogen.

3. Organization and staff

The scientific staff participating in Chisat was a group of competent, highly motivated, and well trained scientists. Several speak English well. All are able to read English and most can write it--occasionally with justifiable difficulties with grammar--and most can understand it when spoken in their technical area. Even so, the American participants were provided with a skilled interpreter (Geng Zhongming) on a full-time basis, and all formal meetings were interpreted.

One unfortunate aspect affecting this institute's scientific staff was that most of them completed their university training during the period of the Cultural Revolution (in full swing 1966-76) when advanced degrees were not being awarded in China. Only the leader, Dr. Shi, has a Ph.D. degree, and he received his in neurophysiology from the Pavlov Institute in Leningrad. However, most of the specialized investigators are "Ph.D. level" researchers and their work and performance are consistent with that level of training. (Incidentally, the Cultural Revolution is discussed openly and without obvious malice, as one might discuss a past earthquake.)

This report is the work of many people. The authors are grateful to be able to report this collaborative work. Those working directly on Chisat 1 are listed in Table II.

D. Experimental objectives

While the value of the international scientific cooperation reflected in this project cannot easily be overstated, we had some serious experimental objectives as well. These were to secure an additional validation of several aspects of the Repex habitat excursion diving method, and to obtain additional data of the physiology of divers in the nitrox saturation-excursion diving situation.

The Repex project (Hamilton, Kenyon, Peterson 1988; Hamilton, Kenyon, Peterson et al 1988) was funded by NOAA's Undersea Research Program to improve and extend the decompression procedures published in the second edition of the NOAA Diving Manual. The project resulted in new decompression tables for excursions, including repetitive excursions and longer ones requiring stops, and tables for the final saturation decompression which include a method for dealing with recent excursions. Further, a simple but effective algorithm for managing exposure to elevated levels of oxygen over multiday exposures was produced. These procedures were subjected to limited validation testing as part of Repex (Hamilton, 1989), and though the results were successful, additional data points would of course be desirable.

Validation of the Repex pattern by another laboratory would alone be a sufficient goal to justify the experiment. We wanted, however, to extend the validation to a point not covered by the Repex validation. This was to evaluate the **algorithm** used for computing the Repex tables rather than just the tables themselves. The tables, especially those used for repetitive excursions, tend to "group" the exposures, and only an occasional dive is near the limit of the algorithm. Further, the longer excursions with stops are rather limited due to the requirement to fit them into table format. Even though in the Repex tests the excursions were as close together as allowed by the tables, in many cases they were not as stressful from a decompression point of view as they would have been if calculated specifically on the basis of the current gas loading. Our objective in Chisat was to perform a week (5 days) of saturation-excursion diving with **every** excursion calculated to the limit of the algorithm. The beneficial result of this, to the extent that the limited tests were to represent the true behavior of the algorithm, would be that future dives could then be calculated with the algorithm specifically for a given operational situation, with some confidence.

To get a good test of excursions we selected a storage depth of 25 msw. This was shallow enough to allow extensive deeper excursions, and would mean that some of them would require

Table II. List of participants in Chisat I.

Principal Investigators:
Shi Zhongyuan, Professor, President of CUTI
R.W. Hamilton, Ph.D., Hamilton Research, Ltd., Tarrytown, NY USA

Supervisors:
Chen Baosong, Vice-Professor, Vice-director of Physiology & Medicine Dept.
Fan Zhenghuan, Associate Professor, Director of Hyperbaric Laboratory
Gu Zhengzhong, Associate Professor, Vice-director of Physiol. & Medicine
Zhang Longbao, Assistant Professor, Vice-director of Hyperbaric Laboratory

Divers:
Guo Chenrong (Diver #1)
Liang Hongkun (Diver #2)
Chen Zhongtao (Diver #3)
Wang Baojian (Diver #4)

Medical support (also Fan ZH, Zhang LB):
William Schane, MD, Diving Medical Officer, NOAA URC, Virgin Islands, USA
Zhou Xuerao, Research Assistant
Yuan Hongchan, Assistant Professor

Chamber operation (also Zhou XR, Zhang LB):
Xiu Lijiun, Engineer
Zhuang Qinhon, Engineer

Chamber auto-control:
Chen Huiping, Engineer, designer
Li Hongming, Assistant Engineer
Yu Weining, Assistant Engineer

Physiological research (Also includes Shi ZY, Gu ZZ; W. Schane (Doppler)
Zhao Deming, Associate Professor (EEG, reaction time)
Moa Lofei, Research Assistant (EEG power spectra)
Cui Renjing, Associate Professor (Pulmonary blood flow, heart studies)
Zheng Jichang, Assistant Professor (Pulmonary function)
Qu Qinling, Research Assistant (Doppler)
Ding Yuxian, Research Assistant (Gas analysis)
Deng Xuegeng, Assistant Professor (Nutrition)
Lee Yuanchen, Assistant Professor (Decompression computations)

Machine room:
Zhang ZX (also Gas supply)
Chen ZH
Huang AZ
Chen ZN
Wang WJ
Hu JL
Xu J

Administration:
Wang Deyuan, Vice-president of Institute
Zao Shijiang, Vice-president of Institute
Geng Zhongming, Interpreter
Tang Xiewei, Secretary
Xu Jiangfen, Supplies
Yu Yishen, photographer
You Shengdi, driver
Jian Zhenglong, driver

stops. A deeper storage depth would make the excursions so long that only a few could be performed.

The method used in Repex to account for excursions before the saturation decompression is to begin the final decompression on the return from the last excursion. This may require a brief return to storage pressure to "pick up" any divers not on the last excursion. This short return to surface pressure was not tested in the Repex trials, and we hoped to try it in Chisat.

To have a better idea of the results of the decompressions we planned to monitor the divers with doppler bubble detection after each excursion and during the saturation decompression.

As is pointed out in the Repex report, one of its most important findings is the algorithm for managing multiday oxygen exposure. We therefore planned to use the Chisat experiment to get another set of data points that would help to define the limits, in this case for a 6-day exposure to daily levels slightly above the Repex limits.

Another objective was to study divers' physiology both during excursions and saturation storage. A comprehensive monitoring package was performed by a team of investigators covering several specialty areas, including pulmonary function, nutrition, psychomotor performance, neurophysiology, and cardiopulmonary physiology. Both the methods and the specific experimental objectives are known best to the investigators, and we do not have full details on many of them. The differences in level of coverage of the different studies in this report are perhaps due more to differences in our understanding of the various investigations than to thoroughness of the investigator's study. Some of these measurements seem more to be a general phenomenological investigation of the nitrox saturation-excursion diving environment than to address a specific hypothesis. Two areas we had hoped would be looked at were the effect of the oxygen exposure on vital capacity, a commonly used indicator of pulmonary oxygen toxicity (Harabin, et al, 1987), and the accommodation of the divers to nitrogen narcosis over several days.

Somewhat as a curiosity unrelated to the main project we wanted to test the "logging" function of a Suunto SME-ML dive computer in the "excursion" situation. This is covered in Appendix C.

III. METHODS

The experiment consisted of 5 days of saturation of four experienced divers at 25 msw pressure in a diving simulator at a "near-normoxic" PO_2 level of 0.32 bar, with several daily excursions to higher pressure ("descending" excursions); this was followed by saturation decompression. The pressure phase was preceded and followed by 3-day predive and postdive periods during which control studies and medical examinations were performed.

A. Divers

The four professional divers were all experienced, and ranged in age from 27 to 36. All were fit and performed some regular daily exercise. Weights ranged from 57 to 77 kg. Some had been on numerous dives at CUTI, and all had had the experience of multi-day saturation exposures in this chamber complex at least once. None of the four had experienced decompression sickness (DCS), and none had been treated for it. The lead diver (#1) speaks English, and the others were able to understand expected statements. A summary description of the divers is given in Table III.

Table III. Chisat I diver descriptions.

Diver number	No. 1	No. 2	No. 3	No. 4
Name	Guo Chenrong	Liang Hongkun	Chen Zhongtao	Wang Baojian
Initials	CRG	HKL	ZTC	BJW
Age, Year	36	28	28	27
Weight (kg)	76	67.5	57.5	77
Height (cm)	176	173	167	170
Fitness level	Very good	Good	Fair	Good
Daily exercise	2 hrs	2 hrs	1 hr	1 hr
Smoke?	Yes	No	Yes	Yes
Diving school?	Yes	Yes	Yes	Yes
Professional diving, yr	18	10	11	10
Approx number of dives	420	200	220	150
Previous DCS	No	No	No	No
Previous skin bends	No	No	No	No

B. Topside and investigators

The "Topside" crew was well staffed for an around-the-clock operation. In addition to the three primary investigators SZY, RWH, and WS (Shi, Hamilton, and Schane) there were 8 others whose job was mainly to do physiological investigations, plus 4 shift supervisors, 2 additional doctors, 2 chief operators of the chamber system, 3 auto control engineers, 7 machine room and gas technicians, and numerous support and administrative personnel. The names and functions of the principals are given above in Table II, section II.C.3.

C. Schedule

In preparation for the dive we first prepared a profile showing the planned excursions (shown graphically in a later section). To this profile were added the daily routine (meals, etc.) and scheduled events, most of which were test periods for various studies. This became a detailed schedule for the entire dive period. This is included as Appendix A; a summary of the excursions performed is shown as Table IV. A copy of the daily schedule which also included modifications and events not shown on the master schedule was posted in English on a blackboard in the lab.

The normal dive day began with the divers being awakened at 0600, after which they ate breakfast and prepared for the first excursion at 0800. On normal days excursions were over around 1700, but sometimes doppler readings lasted for another hour or two, and we intentionally continued diving until midnight on the second day. Bedtime was normally around 2130.

Table IV. Chisat I excursion summary.

No	Excu. No	Date	Dive Day	Excu. Depth (m)	Excu. Time (min)	First Stop (m)	Interval After (min)	Excu. OTU	OTU /Day	Total OTU
1	1-1	88Oct22	1	60	40	-	164	77		
2	1-2	"	"	60	240	37	870	501	578	578
3	2-1	88Oct23	2	70	30	28	108	74		
4	2-2	"	"	50	240	28	233	361		
5	2-3	"	"	65	30	-	142	66		
6	2-4	"	"	60	60	28	526	115	616	1194
7	3-1	88Oct24	3	50	240	28	95	353		
8	3-2	"	"	60	40	-	104	77		
9	3-3	"	"	60	40	-	883	77	507	1701
10	4-1	88Oct25	4	75	16	-	154	49		
11	4-2	"	"	50	128	-	167	184		
12	4-3	"	"	75	20	-	929	58	291	1992
13	5-1	88Oct26	5	50	130	-	374	187		
14	5-1	"	"	75	15	-	246	46		
15	5-3	"	"	50	60	(40)	-	90	(450)	2442

D. Operational support

Topside management of this dive was according to traditional methods. Facilities at the Institute were available for most functions. The Institute seemed to take the around-the-clock operation in stride; the practice in China is to work a 6-day week with Sunday off, so only essential personnel were present on the Sunday of the dive period.

1. Dive control personnel

The chamber operational crew worked in 3 normal shifts. An experienced supervisor was in charge of each shift, and in addition to the main operator there was also a person for gas analysis, the machine room, and one to manage the auto control. There were two diving doctors on each shift, but one pair of these covered two shifts. Dr. Schane did not work as a duty doctor. Prof. Shi, Head of CUTI, remained on site during the entire dive, staying in one of the Institute's apartments.

2. Chamber use

Chamber No. 1 was used for the living space in Chisat. All four divers lived in it, and Chamber No. 2 was kept in readiness for treatment of decompression sickness.

The "igloo", the dry area at the top of the wet chamber, was used for the excursions. It contained an ergometer, spirometer, seats, and smaller apparatus used for tests during excursions. Wet diving was not done, although it had been considered (we were never quite clear why it was not done). One reason for not doing wet excursions might have been that it would have made it more difficult to maintain a uniform excursion pattern over such a wide difference in excursion times. It was a significant effort and expense just to do the dives dry, and wet excursions would have added significantly to the complexity and cost.

When an excursion was made the divers locked into the excursion chamber a few minutes ahead of time and the hatch was sealed by a slight overpressure (1 or 2 msw) and held until it was time to pressurize. This made it relatively easy to start each excursion at the scheduled time, and had a negligible effect on the profile.

During decompression from excursions when the pressure reduction caused adiabatic cooling the divers wore heavy quilted "siberian" coats until the temperature began to return to a comfortable level.

The dive was controlled by a combination of manual and automatic methods. The living chamber was taken to 25 msw a few hours before initial compression and held with auto control. The divers were then compressed in the igloo and they transferred to the main chamber which continued on auto control during the night. Excursions were manually controlled because the "wet" chamber did not have auto control.

Whenever a transfer to or from the igloo took place a bolus of air entered the main chamber, raising the oxygen levels slightly. When this happened at the end of the day it was normally allowed to drift down by metabolic consumption, but if it was too far out of line a correction was make by adding nitrogen. In order to save nitrogen the auto control for O_2 was not used most of the time, but rather was just turned on momentarily when an adjustment was needed.

3. Meals

a. Divers

Meals for the divers were prepared by the Institute's kitchen under supervision of an investigator trained in nutrition; he served as the dive's dietician and at the same time performed the nutrition study. He weighed and locked all meals into the chamber at the scheduled time, and took the remainder for reweighing and analysis. Prior to the dive the divers had been queried as to their tastes, and a suitable diet was selected.

b. Topside

The topside crew were able to get regular meals from the kitchen, and they usually returned to their work stations to eat. A "midnight" meal was available each night during the dive. The visiting investigators were provided a formal multi-course sit-down lunch each day prepared by the kitchen.

E. Excursions: Decompression and oxygen dose

This section covers the things that had to be considered in developing the Chisat profile, which is necessarily a function of both decompression and oxygen exposure.

1. Excursion profile for the complete dive

The excursions were calculated to stress the limits of the Repex algorithm by computing the entire dive as a single profile. That is, the decompression from each excursion was based on the gas loading present at the time. The Repex approach to computing repetitive dives considers that gas loading is the controlling factor in determining a repetitive decompression. While this is clearly a point for continuing study, it is a good working approach.

The calculations were made with DCAP, Hamilton Research's Decompression Computation and Analysis Program, Version 5.506, using the Haldane-Workman-Schreiner computational model designated "Tonawanda II" and the constraint matrix MM0805 worked out for Repex and converted to metres. The calculations were done with a Basecase for Chisat designated D87AN0.Y00. The calculated profile (the "Table" file in DCAP terminology) and the Basecase used to generate it are included as Appendix B. The profile itself is shown in Figure 3, and a summary of the excursions done is shown above in Table IV.

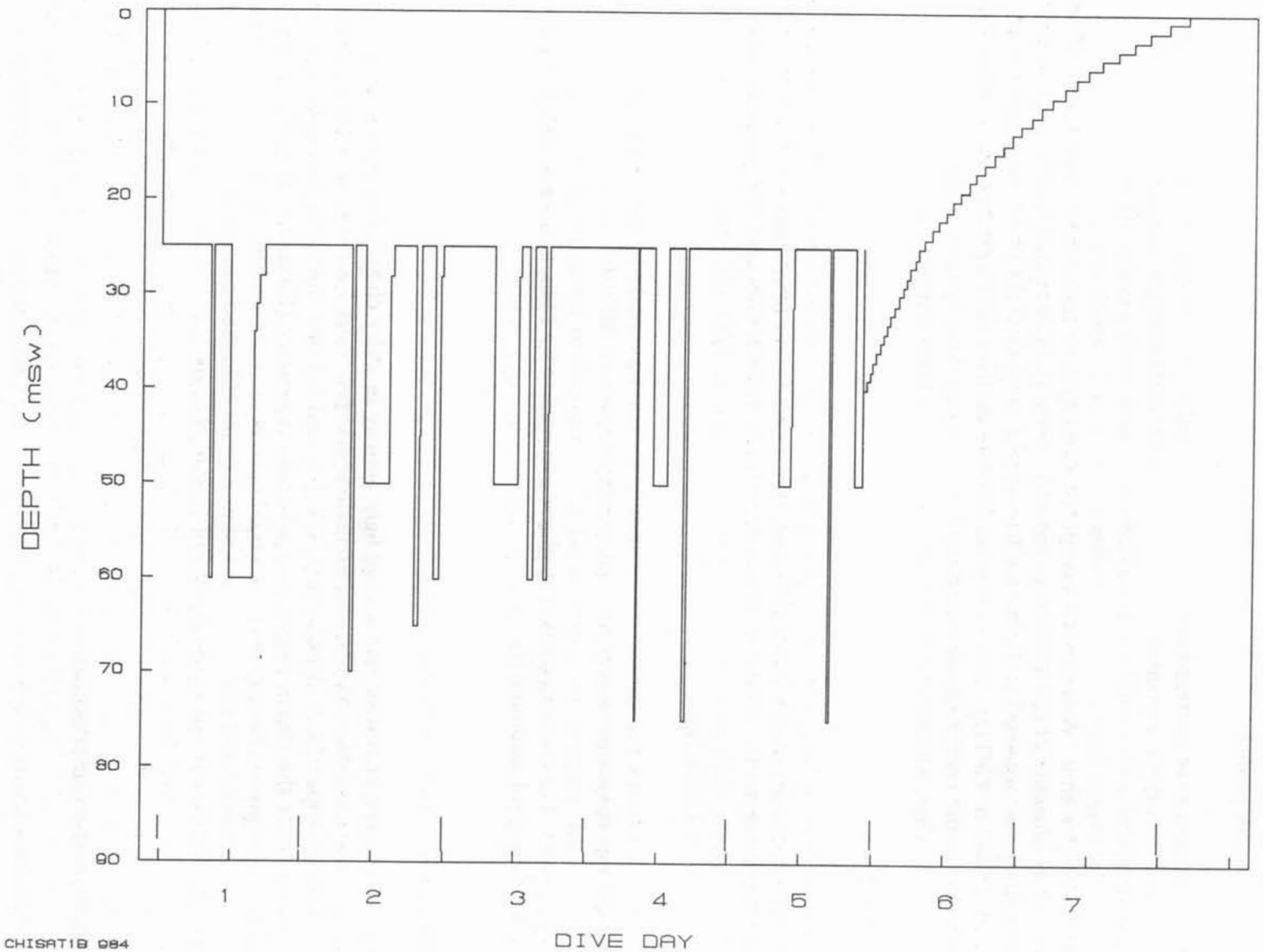


Figure 3. Profile of Chisat I. Pressurization started at midnight 88Oct21, and the first excursion began at 0800 88Oct22. The last excursion was over at 2207 on 88Oct26 and the "precursory" leg of the saturation decompression began after a 2 min excursion to 25 msw. The divers reached surface pressure at 0359 88Oct29.

We wanted a maximal or "worse case" saturation-excursion dive. To do this it is not sufficient just to select a set of no-stop excursions, unless each of them is itself the longest excursion that can be done for the selected depth at that moment. Only one no-stop excursion time, the one allowing the maximum time, would be maximal for each situation. We therefore made all no-stop excursions extend to within a minute or so of the maximum one that would be allowed at that moment in the overall profile.

The excursions were scattered around the daily schedule so as to balance the decompression requirements and the oxygen exposure. We were in fact limited by oxygen exposure in the number and duration of excursions we could do. It was necessary to do some manipulations of the schedule in order to get the oxygen level to the point where we wanted it, which was several hundred units higher than the Repex limit. We intended that the oxygen exposure tested would be enough above the Repex limit to allow for a USN Table 6 treatment with acceptable response to the oxygen. That is, for the peak of the exposure at 7 days we had a total of 3013 OTU (Oxygen Toxicity Units, equivalent to UPTD or CPTD). To avoid exceeding the desired level we had to hold down the oxygen dose toward the end of the excursion period. This was done by making deeper excursions during the last two days, which were shorter and thus gave a lower oxygen dose.

2. Pressure units

The pressure units used for the table and dives were **metres of sea water**, msw. The msw is defined as 0.1 bar or 10^4 Pa. For comparison with Repex, NOAA OPS, and other Imperial units we used the common definition of the foot of sea water as **1/33 std atm**, which makes the conversion 1 msw $\equiv$ 3.2568 fsw.

For the excursions the conversion to msw from fsw was made in the constraint matrix MM0805, which was converted to msw from the original fsw matrix MF0805. Once that conversion was made the DCAP program took care of all other conversions by doing all the calculations directly in msw units. For convenience sea level was assumed to be 1 bar, and we assumed that we were at sea level (a good assumption).

3. Exercise

The divers were at rest or performing light activity in a dry chamber during most of the excursions. Exercise was done only on those excursions in which "work load" was an activity (shown on the schedule in Appendix A, 3 excursions 1-2, 3-1, and 5-1 and discussed as "work load" in III.J.1), in which cases the divers pedaled on a bicycle ergometer (Electronic Ergometer TF-1, Beijing Medical Equipment Factory #4). It would have been more realistic to do some planned exercise on each excursion, but this point was lost as a result of limited communications during the planning, and by the time it was noted it was not easy to change.

F. Saturation decompression

Although the excursions were calculated specifically for Chisat, the saturation decompression was taken from the Repex procedures (Hamilton, Kenyon, Peterson, 1988). The decompression from saturation used in Repex was calculated using both gas loadings and an integral of supersaturation over time, called "t-delta-P" (Peterson and Hamilton, 1987), and it is not directly calculable with the version of DCAP (5.506) used for Chisat. In this case another check of the Repex saturation decompression **table** seemed more valuable than testing a new calculation.

1. Choosing the decompression

For the saturation decompression we followed the appropriate Repex table, the one for 80-84 fsw (25 msw = 81.42 fsw), using the "precursory" table required when descending excursions have been made. The precursory table is a method of compensating for the excursions prior to starting saturation decompression; it involves starting the final saturation decompression from a point on return from the last excursion that is a function of the deepest recent excursion. The precursory table was started at 40 msw (130.2 fsw) to match the Repex precursory starting depth of 130 fsw.

The total decompression time used from 40 msw was 3235 min. For comparison, the Repex time for the full decompression from 130 fsw (39.9 msw) is 3225 min; this inconsequential difference is due to the unit conversion.

2. Handling the precursory ascent

The Repex method of dealing with saturation decompression of divers who have recently been on a descending excursion is to begin the final saturation decompression at a (specified) point between the excursion and saturation depths, at a specified rate. The period of time spent deeper than saturation depth is called the "precursory" ascent.

Ideally the precursory table has the divers ascend at the normal inwater ascent rate from the last excursion to an intermediate "starting depth," and there begin the slower precursory rate. However, in order to decompress in the habitat it is necessary to return momentarily to habitat depth (here 25 msw) to lock in and be recompressed to the starting depth. To simulate this the Chisat profile included 5 min to return to habitat depth for a 2 min. stop and be compressed back to the precursory starting depth of 40 msw.

G. Decompression assessment

One Chisat objective was to evaluate the Repex algorithm as represented by the excursions used here with regard to their decompression reliability. This was done by monitoring for decompression sickness and for bubbles using a doppler bubble detector.

1. Decompression sickness

As is the practice in most experimental diving, symptoms of decompression sickness were used as the final end point in evaluating the tables. The divers were briefed to report any symptoms of DCS, and they were queried each evening as to their condition. We also watched them for signs of unusual fatigue.

2. Doppler bubble detection

Although bubbles that can be detected with doppler ultrasonic devices are not strictly correlated with DCS, bubbles are without doubt involved. Decompression exposures that are low in doppler bubbles are generally low in DCS, and vice versa. Accordingly, and in keeping with current practice, we monitored for bubbles after each excursion and during the final decompression.

To enable us to monitor for doppler-detectable bubbles we prepared a monitoring system to be taken from the US. The doppler recording equipment was well packed in two aluminum "Pelican" cases, and included adequate spares and expendables. When the experiment was over this equipment was returned to the US on a courier aircraft by courtesy of the US Consulate in Shanghai.

Bubble detection was with a Techno-Scientific Inc. (Woodbridge, ON, Canada) 2.5 Mhz doppler ultrasonic monitor Model DBM-8703. This was recorded on a Marantz Model PMD 430 portable cassette tape recorder/player using the "DBX" mode (a special noise-canceling method). Precordial measurements were taken 45, 90, and 135 minutes after return to habitat pressure from each excursion where this was possible; on Day 2 the second and third readings which would have been after midnight were skipped. The diver listened to the sounds and placed the probe according to his own assessment and that of the investigator, which was relayed to the diver via a talk-back speaker. All the doppler readings and assessments were done by WS.

For each reading a measurement was taken with the diver standing and again after a deep knee bend. Scoring was with a hybrid of Spencer and Kisman-Masurel (which give essentially the same score if done properly). Resting scores were straight Spencer, but after the flexion the heartbeats with bubbles were counted (the Spencer code does not address this specifically). Most of the time the signal was not good enough for K-M to be used. A diver with bubbles in the range from one-half to all the heartbeats would be Grade III (this range is not covered in the Spencer method).

We had significant difficulties with the doppler. It was planned for both the probe and amplifier of the doppler unit to be inside the chamber with the diver, so only the audio signal had to be transmitted outside. When the doppler unit (the small metal box with the signal generator, detector, and amplifier) was taken to pressures greater than about 20 msw, however, it stopped working. Repeated tests in small animal chambers and twice in the "igloo," along with telephone discussions with Techno-Scientific, failed to resolve the problem, and it was necessary to place the doppler amplifier on the outside and to try to pass the high frequency signal in to the probe and back out to the amplifier. There were no leads available with adequate shielding for this, and though many variations were tried we never got much better than a barely "satisfactory" audio signal. At one time we were even getting music on the amplifier, from a radio source judged by one listener to be coming from outside China. However, for the times where data is listed the signals were good enough to assess, and we regard the doppler monitoring as being acceptable and effective.

Because bubbles were still present at the end of the first postdive day additional readings were taken through the second postdive day some 30 hours after the divers reached surface pressure.

H. Treatment of decompression sickness

Prior to starting the dive we had a meeting of the medical staff and principal investigators and agreed on the plan to be used should there be a case of DCS. For most cases we agreed to use the procedures developed for Repex. One minor difference would be, depending on the judgement of the doctors, in a case that looked difficult we reserved the option to compress an additional bar after relief for the oxygen breathing, and would continue the treatment as if that were the depth of relief.

In addition to the medical staff at CUTI we had the support of the First Medical University, including in particular Dr. Jing Yanling, who is experienced in nitrox saturation diving (1979).

I. Oxygen tolerance

Air excursions from nitrox saturation allow such long exposure times that the toxicity of the oxygen in the air breathed during the excursions becomes a consideration. This can be true for both of the "classical" forms of oxygen toxicity, the short-acting CNS toxicity which may lead to a convulsion, and the longer acting lung and whole-body effects. For dealing with oxygen Chisat used the Repex plan (Hamilton, Kenyon, Peterson et al, 1988; Hamilton, 1989), which deals with both of these.

1. Background: The Repex algorithm

For preventing CNS toxicity Repex sets an arbitrary depth limit of 60 msw (200 fsw) for decompression-limited air excursions, allowing only short oxygen-limited excursions beyond this depth. More specifically Repex limits the duration of exposures to PO_2's of greater than 1.5 bars. This is a conservative approach, and could easily be varied according to reliable experience in avoiding CNS toxicity. Chisat used specifically calculated excursions, and these were planned to exceed the Repex limits slightly.

The other classical toxicity is pulmonary, oxygen's effect on the lung. This takes hours or longer to develop from exposure levels that may be below those that cause CNS symptoms; it is seen as chest pain, coughing, and a reduction in vital capacity.

Another "category" of toxicity that develops after hours to days of exposure is the "whole-body" or "somatic" oxygen toxicity. This has been widely observed but is not prominently mentioned as a separate type of toxicity in the classical literature. Its effects are a collection of symptoms that include paresthesias (especially numbness in fingertips and toes), headache, dizziness, nausea, and reduction of aerobic capacity. This has been described in detail by Sterk (1986).

For dealing with the longer duration toxicities Repex draws on experience with the empirical oxygen "dose" developed some years ago at the University of Pennsylvania. Called the Unit Pulmonary Toxicity Dose (UPTD; when "Cumulative" it is called CPTD). A "unit" dose is 1 min of exposure at 1 bar PO_2; doses above and below this are calculated by a formula that gives extra weight to higher PO_2's and vice versa (Wright, 1972; Shilling, Werts, and Schandlemeier, 1976). One problem with using these units has been the lack of precise exposure limits.

The "Repex" algorithm limits exposures below the CNS limit by "whole body" criteria (which also takes care of pulmonary problems). It sets a daily limit as a function of the total number of days of exposure, the "mission duration." For a single day of exposure the dose can be much higher than if the exposure goes on for many days. The method accounts for "recovery," because for most exposure levels the daily oxygen dose is built up in less than 24 hr, and thus there is some time for recovery. The Repex dose is measured in OTU, Oxygen Tolerance Units, which are calculated by the same equation used for UPTD. A set of empirical daily dose limits based on the number of days of exposure defines a curve or limit line, and all that is necessary to stay within this particular set of limits is to stay below this curve. The curve is still in the process of being defined, and in fact eventually may become a family of curves in order to deal with operational experience or desired conservatism.

2. Managing oxygen in Chisat

Since additional validation of the Repex limits was a Chisat objective, we used exposures slightly greater than allowed by Repex for both CNS and whole body limits.

a. CNS limit

Chisat used specifically calculated excursions (rather than the Repex tables). Those that slightly exceeded the Repex CNS tolerance limits are shown in the following table.

Repex limits				Chisat excursions		
fsw	msw	PO2	time	msw	PO2	time
220	67.6	1.61	29	65	1.58	30
240	73.7	1.74	16	70	1.68	30
				75	1.79	20

b. Whole body limit

In designing the Chisat excursion plan the oxygen exposure was considered on a daily basis. The table shown in Appendix B includes the total OTU's for the day at the end of each stop (column at far right). How the Chisat exposure fits in with the Repex limit is shown in Figure 4.

3. Monitoring for oxygen toxicity

No specific physiological monitoring for signs of oxygen toxicity were performed. The pulmonary function studies included a forced vital capacity maneuver each time, but this was not intended as a precise vital capacity of the type needed to monitor the development of pulmonary oxygen toxicity. Daily questioning of the divers by the topside investigators included specific questions about substernal pain, coughing, and the various manifestations of whole body toxicity.

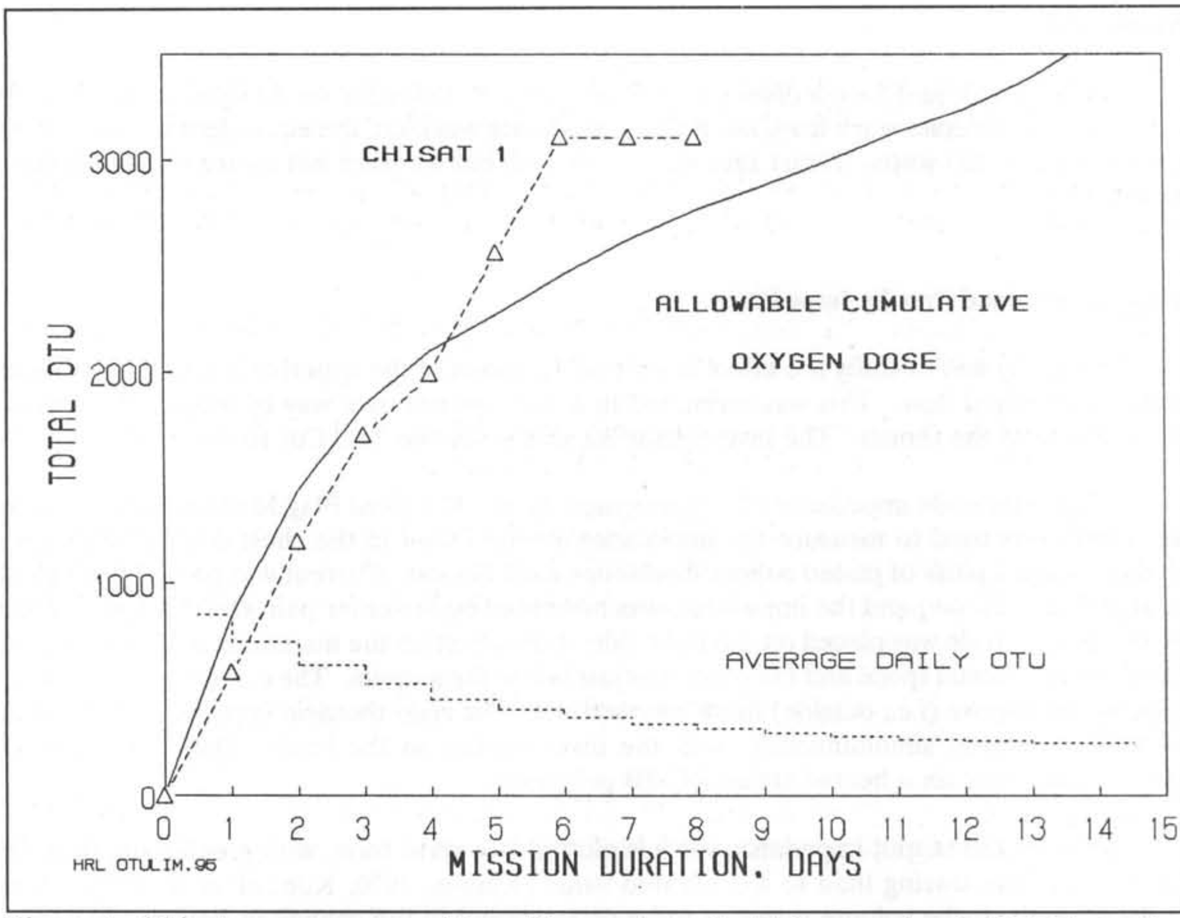


Figure 4. Chisat oxygen exposure. The solid curve shows the total oxygen dose in OTU that a diver should have on a given day. The dotted line with triangles shows the exposure during Chisat 1.

J. Physiological studies

The CUTI investigators performed familiar physiological measurements using methods that had, for the most part, been developed and used for previous CUTI dives.

1. Pulmonary function

Pulmonary function was measured both in the habitat and in the igloo by Mr. Zheng Jichang (Zheng et al, 1988). In each case this was done on one of two similar standard clinical water-filled "vitalometers," 7 liter Tissot spirometers with pen writers. From forced vital capacity maneuvers various parameters were determined. A predive control was done in each location. Measurements were taken in the living chamber at 25 msw on days 1-5, and again on day 6 as the chamber passed through 25 msw during decompression; decompression values were taken at 15 and 8 msw (Days 6 and 7). Vital capacity was also measured during excursions at 50, 60, 70, and 75 msw.

2. Work load

On Days 1, 3, and 5 each diver performed a period of exercise on a bicycle ergometer. We failed to record the exact work load, but it was a moderate workout, the equivalent to about 10 min at a work load of 150 watts. Heart rate was monitored, but we were not aware of any additional measurements.

3. Pulmonary blood flow by impedance

This study was to study the effect of various elements of the hyperbaric nitrox environment on pulmonary blood flow. This was estimated in a semi-quantitative way by means of changes in the impedance of the thorax. The investigator for this study was Mr. Cui Renjing.

A four-electrode impedance plethysmograph Type ZK-3 (Red Flag Medical Instrument and Meter Plant) was used to measure the impedance changes seen in the chest during heart action. Each diver wore 2 pairs of plated copper electrodes each 2x3 cm. Current was passed through one pair (at 100 or 1000 mv) and the impedance was measured by the other pair as a change in voltage. One voltage electrode was placed on the right side of the chest on the mammilaris line between the 2nd and 3rd intercostal space and the other was just below the scapula. The current electrodes were 2 cm below and above (i.e., outside) these, respectively. The right thoracic impedance changes and EKG were measured simultaneously, with the diver supine on the bunk. Data were recorded outside the chamber on a heated stylus RG-2B polygraph.

Normally the output impedance valve is plotted as a wave form, with greater attention paid to the shape of the tracing than to a calibrated value (Kinnen, 1970; Kubicek et al, 1970; Kinnen et al, 1964), with stroke volume assumed to be proportional to the change in impedance during a heart ejection period.

The 11 numbered measurement periods were scheduled so as to sample various aspects of the dive environment, including (1) a predive control measurement. Measurements were taken (2) 4 hr following Excursion 1-2, (3) during Excursion 3-1 at 50 msw, (4) 20 min after Excursion 3-2, (5) 1.1 hr after 5-1, (6) 2.5 hr after 5-2, (7-9) during decompression at 24, 18, and 4 msw, and (10-11) 6 and 30 hr after the divers reached surface pressure. The measurement times are shown in Appendix A, as scheduled and done in the "experiment" column, and according to a modified schedule in the "comment" column. After early measurements following excursions showed a possible effect of bubbles, later readings were moved to times following excursions when bubble effects would be more likely to be seen.

4. EEG

Like the pulmonary function, electroencephalograms were recorded at various times during the dive in order to sample during the different exposure conditions; these were recorded by Mr. Zhao Deming. These were done twice each at 60 and 50 msw, twice at 25 msw, and pre and postdive (see Appendix A). Six leads were used, 2 above the eyes, 2 central, and 2 occipital. Signals were fed outside and recorded on a Nihon Kohen clinical EEG unit, estimated vintage pre-

1980. Power spectrum analysis was to be performed on a Great Wall 0520CH computer (IBM PC clone), but the full analysis was to be performed later.

5. Reaction time and short-term memory

A standard Chinese psychological testing device (specific name not available) was used by Zhao Deming to test pattern memory and reaction time. This unit displays a 6x6 pattern of squares, with 4 of the squares illuminated at a time. A series of patterns can be displayed in a programmed sequence. It was placed in front of a viewport. For the memory test the diver had to memorize the sequence from a series of 4 patterns displayed for a short time (5 sec). Using a 4-key switch box the diver had to reconstruct the sequence and the time to do this was recorded on a timer. A low score is better.

The reaction time test used the same display, but here a set of 4 familiar patterns were displayed and the diver had to press one of the 4 buttons as quickly as he could indicating which pattern it was. A test consisted of 20 trials, and the total time was summed to get the score. The number of errors was also recorded. Again, a low score indicates better performance.

The tests were given at each of the excursion depths, once at all depths except 50 msw, where more time was available; it was done there 4 times. It was given only once at 25 msw during storage. Four patterns were used, thus they were repeated every 4th day. No comparisons are available to us with equivalent dives done directly from the surface (for evaluating acclimation). Pre-dive measurements were done for record only once, the day just before the dive began.

6. Nutrition

A moderate nutrition study was performed by Deng Xuegeng on these active individuals who perform regular but not regimented exercise. Two weeks before the dive the divers selected a set of standard meals and their caloric intake was determined to be about 3500 to 4000 kcal/day. During the dive meals were weighed before being locked in and the uneaten remains were again weighed after the trays were taken out.

7. Transcutaneous O_2

It was planned to measure capillary PO_2 with a transcutaneous oxygen probe several times during the exposure using a Chinese clinical unit. The probe failed under pressure and this effort was canceled.

IV. RESULTS

The experiment was carried out according to plan, with only minor deviations. The schedule was followed quite well. Most planned measurements were made either at the time they were scheduled or at a more appropriate time. Some instrumentation failures prevented all desired measurements from being taken; the transcutaneous oxygen sensor produced no data, and the doppler bubble detection was incomplete during the first two days.

It should be mentioned again that the results of data collected by the CUTI investigators and reported here are preliminary and in some cases incomplete. With the gracious permission of these investigators we include here all the data that we were able to get; it is included here not so much to be a formal reporting of this work but rather to describe the experiment better. Lack of postdive data does not necessarily mean that studies were not done, but more likely that we for some reason did not get the results.

A. Schedule and profile

The schedule was followed within one or two minutes, and all planned events were performed except the few related in the text or on the timetable.

1. Timetable and log

A detailed timetable of the dive as it was planned is contained in Appendix A. This shows the schedule as it was prepared (in normal type) and the actual times things were done, plus comments (in italics).

As far as our notes are concerned this was the main log; actual activity times such as arrival and departure from depths, etc., were (usually) written by hand on the schedule, with occasional comments. Some times and comments noted on the Auto Control printout or experiment logs were transferred to the main log. Most notations were in English, and those that were made in Chinese were later translated for us. We believe that another "life support" log which we did not use was kept in Chinese. No other minute-by-minute log of the dive was available to us. Because the schedule was followed closely the annotated schedule serves adequately as a log of the experiment.

2. Profile

As stated above, the pressure profile was followed quite precisely. Compression to depth was done with the Auto Control prior to the divers' locking in. All excursions and the decompression were carried out as planned, with occasional deviations of one or two (and in one case, 6) minutes; on Excursion 2-1 there was a 6 min delay getting to pressure due to an ear block.

All gas changes were as planned. None of the deviations are regarded as significant. The actual profile is well represented in Figure 3, section III.E.1.

It was necessary to seal the hatch a few minutes before going to pressure on excursions, so the divers transferred into air in the igloo some 5 min before each excursion. After each excursion some air from the work chamber mixed into the living chamber, so there was a slight increase in oxygen in the living chamber for a few minutes. This is addressed below under Oxygen Tolerance.

3. Press conference and postdive debriefing

Press conferences were held before and right after the dive, and both were well attended. Dr. Shi and RWH were pictured on the front page of a major Chinese-language Shanghai newspaper. We were not aware if a story appeared in the Beijing English-language *China Daily* although we talked at length to the reporter. Some clippings that did appear are in Appendix E.

A meeting of the entire dive and investigative team plus some visiting scientists was held on October 29, just a few hours after the chamber reached surface pressure. Investigators reported their findings, and most provided preliminary data in written form; this was the source of much of the data in this report. In most cases it did not include postdive determinations so we did not get some of these.

B. Environment

1. Auto Control of living chamber pressure and oxygen

The Auto Control system was used to control the living chamber throughout the bottom time and decompression. It was used to make the initial compression of the living chamber, and the divers locked in at the starting time. The Auto Control was off for a few minutes during paper changes (approximately once per day) and for three hours on Day 3. The pressure in the living chamber was maintained within about 0.2 msw of the target 25 msw throughout the dive, except for momentary changes such as lock transfers and adjustment of the oxygen level.

As mentioned, there were increases in oxygen after each excursion due to mixing in of some air from the working chamber. When these were large the operators would lower the pressure a msw or so, then would let the chamber refill with nitrogen by the Auto Control. This used less nitrogen and was much faster than if the control system had been allowed to do the adjustment. Oxygen levels are discussed in section IV.C, below.

The decompression was staged in 1 msw steps. The operators would lower the set point by one msw at the scheduled time, and the Auto Control would adjust and hold at the next depth.

2. Carbon dioxide

The CO_2 partial pressure in the living chamber was kept below 0.5 kPa throughout the exposure.

3. Temperature

The temperature was comfortable in the living chamber at all times except briefly during decompressions. The mean was 25.8C ±0.46. On decompression from excursions the work chamber cooled down as expected. During these periods the divers wore heavy jackets.

4. Relative humidity

The relative humidity was comfortable, with a mean of 55% ±8.3%. It rose for a period after the divers took showers.

C. Decompression

All decompressions were carried out as planned, and there were no reported symptoms of DCS (decompression sickness). The total time for decompression was 53 hr 50 min, of which 9:59 were in the precursory decompression and 43:51 in the pull from 25 msw. The doppler scores showed a few Grade III bubble scores after excursions, and also some during and just after saturation decompression.

1. Symptoms

As far as the topside observers could tell there were no overt symptoms of DCS during any part of the exposure. The divers were examined by three diving medical officers at the end of Day 4, and at the end of the decompression, yet no symptoms were reported. Despite the use of air and nitrogen mixtures in the chamber, little or no itching was felt, and none was reported. The divers admitted to being fatigued sometimes after the excursions, but no one regarded this as "inappropriate" fatigue which could not be accounted for by activity and stress.

No symptoms that could reasonably be called DCS were reported as a result of the saturation decompression. Diver 2 was "tired" after the end of the decompression on Day 8, at about 1300.

2. Doppler ultrasonic bubble detection

The doppler unit failure prevented our getting doppler readings during the first 2 dive days, but readings were acceptable and completed on schedule thereafter. The results of the doppler monitoring are shown in Figure 5 for Divers 1 and 2 and Figure 6 for Divers 3 and 4. These figures

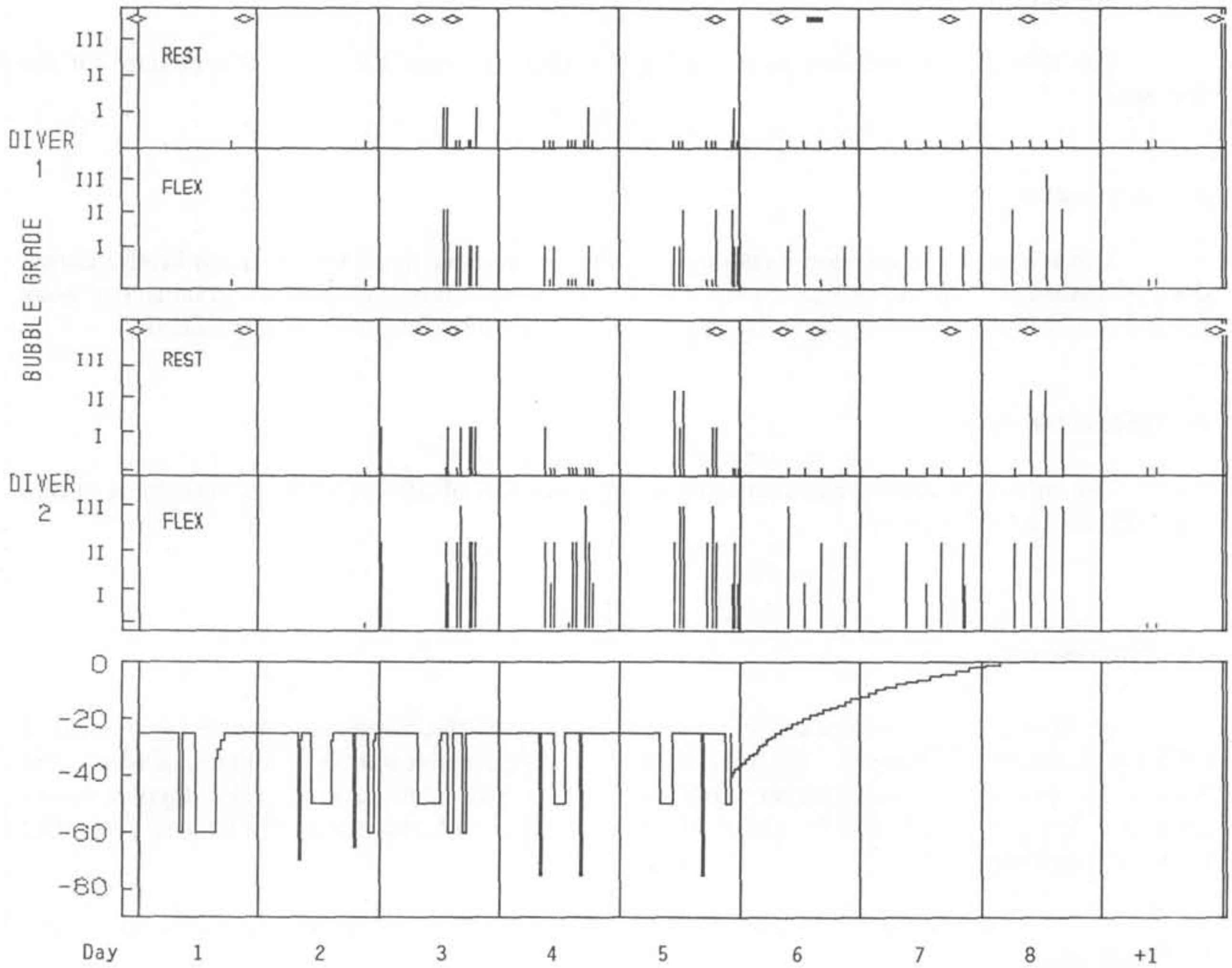


Figure 5. Doppler results for Divers 1 and 2. Bar height shows doppler grades 0-IV; upper panel for each diver taken with diver at rest, lower panel after a knee bend flex. The diamonds and bars show where pulmonary blood flow was done; bars indicate flat tops.

show vertical bars of 5 heights, 0, 1, 2, 3 and 4, for bubble grades 0, I, II, III, and IV. At the top of the figure for each diver are the scores at rest, and below these are the scores after a single "flex," a deep knee bend. The zero readings are included to show each time a reading was taken. In all some 41 readings were taken on the group of 4 divers, with a few isolated additional or missed points.

The readings are distributed among the 4 divers in a predictable way, with Divers 1 and 4 having all zeroes with just a few Grade I scores at rest, while the other two divers had more I's and II's; this type of distribution is expected.

Diver 1 showed only 5 Grade 1 readings at rest, and no bubbles at all in the resting readings during and after saturation decompression. More than half the readings showed at least Grade I

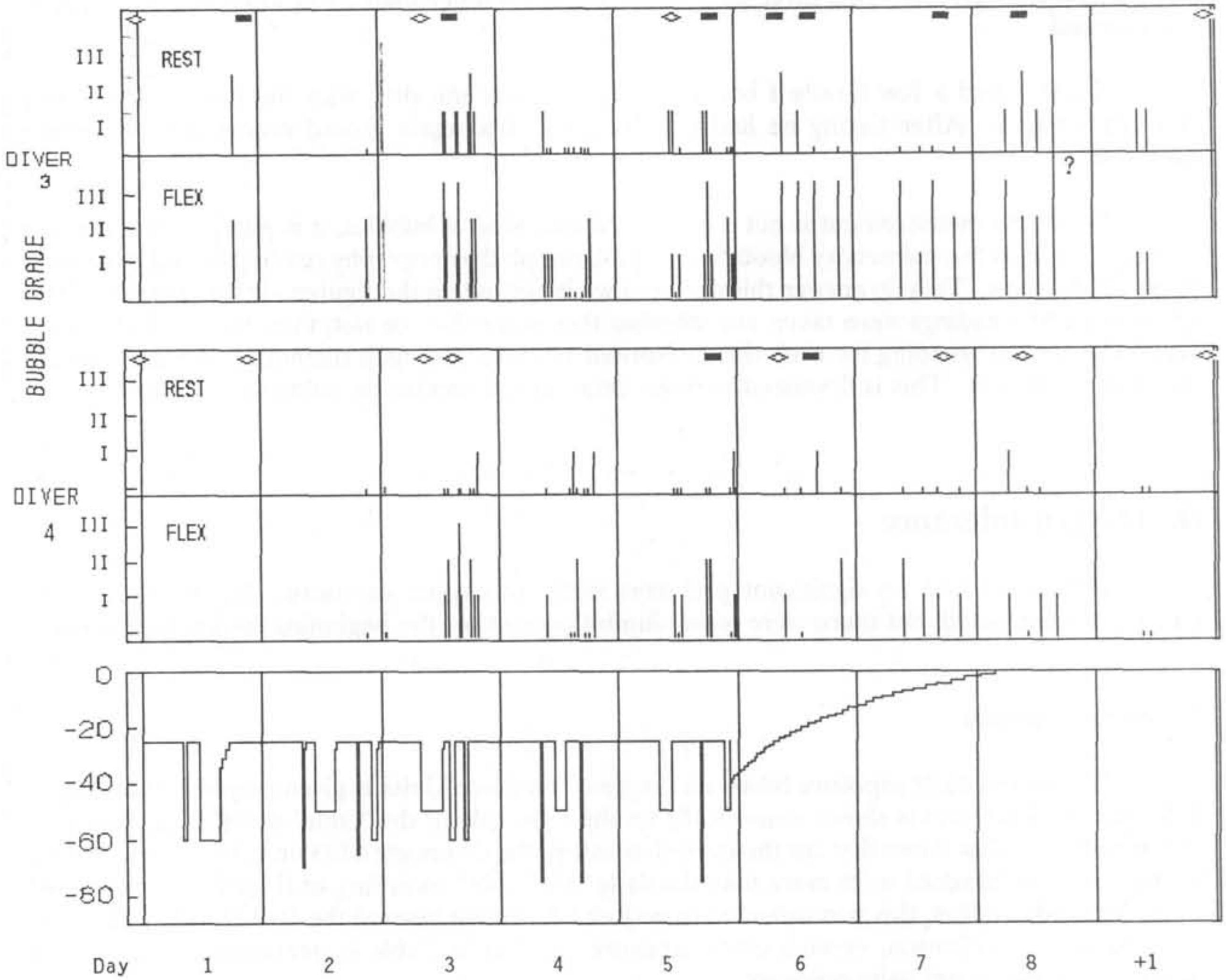


Figure 6. Doppler results for Divers 3 and 4. Bar height shows doppler grades 0-IV; upper panel taken with diver at rest, lower panel after a knee bend flex. The diamonds and bars show where pulmonary blood flow was done; bars indicate flat tops.

after flexing, a few Grade II's after flexing were scattered over the dive, and one Grade III was heard after the end of decompression.

Diver 2 showed some Grade I and II bubbles at rest (4 II's); the II's were on the last day of excursions and after the end of decompression. Some (8) Grade III's were detected after flexing, at least one on Days 3, 4, 5, 6, and 8. This diver had no bubbles at rest during the saturation decompression.

Diver 3 had mostly 0's and I's at rest, but had 4 II's and 2 III's. After flexing 3 Grade III's were heard after excursions and several each day during decompression. After the end of decompression one reading was judged a Grade IV, after flexing (after a III at rest) but there was disagreement about this score. Since other scores were not vetted the dispute about this one should probably be disregarded. This diver had Grade I bubbles more than 24 hr after surface pressure was reached.

Diver 4 had a few Grade I bubbles scattered over the dive with the rest of the resting readings being 0. After flexing he had one III and 7 II's, again spread evenly over the whole exposure.

While the measurement is not a confirmed indicator of bubbles, it is possible that unusual "flat tops" seen in the pulmonary blood flow impedance plethysmography readings could have been caused by bubbles. To help answer this question we indicated on the figures for the doppler scores where the PBF readings were taken and whether they were "flat" or not; these symbols are at the top of the "at rest" reading for each diver. Normal readings are open diamonds, the flat tops are shown as solid bars. This is discussed in more detail in the section on pulmonary blood flow.

D. Oxygen tolerance

The divers had no significant problems with the oxygen exposure. No definitive lung symptoms were noted, but there were some numb fingertips at the beginning of decompression.

1. Oxygen exposure

The overall daily exposure based on Oxygen Tolerance Units is given graphically in Figure 4 (Section III.I.2.b) and is shown numerically on the right side of the "table" which is the first part of Appendix B. This shows that for the overall exposure the divers got 3103 units by the end of Day 6, which is a few hundred units more than the daily "allowable" according to Repex. As mentioned in the Methods section, this was intended to go just far enough beyond the Repex limit to provide a "worst case" verification, enough extra exposure simulate a Table 6 treatment carried out in addition to a maximum daily exposure.

The overall exposure to oxygen as recorded by the Auto Control is plotted in Figure 7. This shows the oxygen partial pressure that was in the living chambers when the divers were there, plus the oxygen encountered during excursions; the latter was calculated from the pressure and FO_2 of air. Because the return of the oxygen to control level was delayed a little after each excursion, and because the divers moved into air 5 min before each excursion, the actual oxygen exposure was slightly greater than that indicated in Appendix B and Figure 4. There was a definite increase in "background" oxygen exposure at the beginning of decompression when the composition of the living chamber atmosphere was switched to air. This increase in oxygen is seen clearly in the top curve of Figure 7, after the last excursion. This was below 0.5 bar by the end of Day 6, so according to the formula no further OTU's were recorded after that.

2. Effects of the oxygen exposure

The oxygen exposure was well tolerated. Three out of 4 divers mentioned mild numbness in the fingertips on Day 5, shortly after the switch to air in the living chamber for the

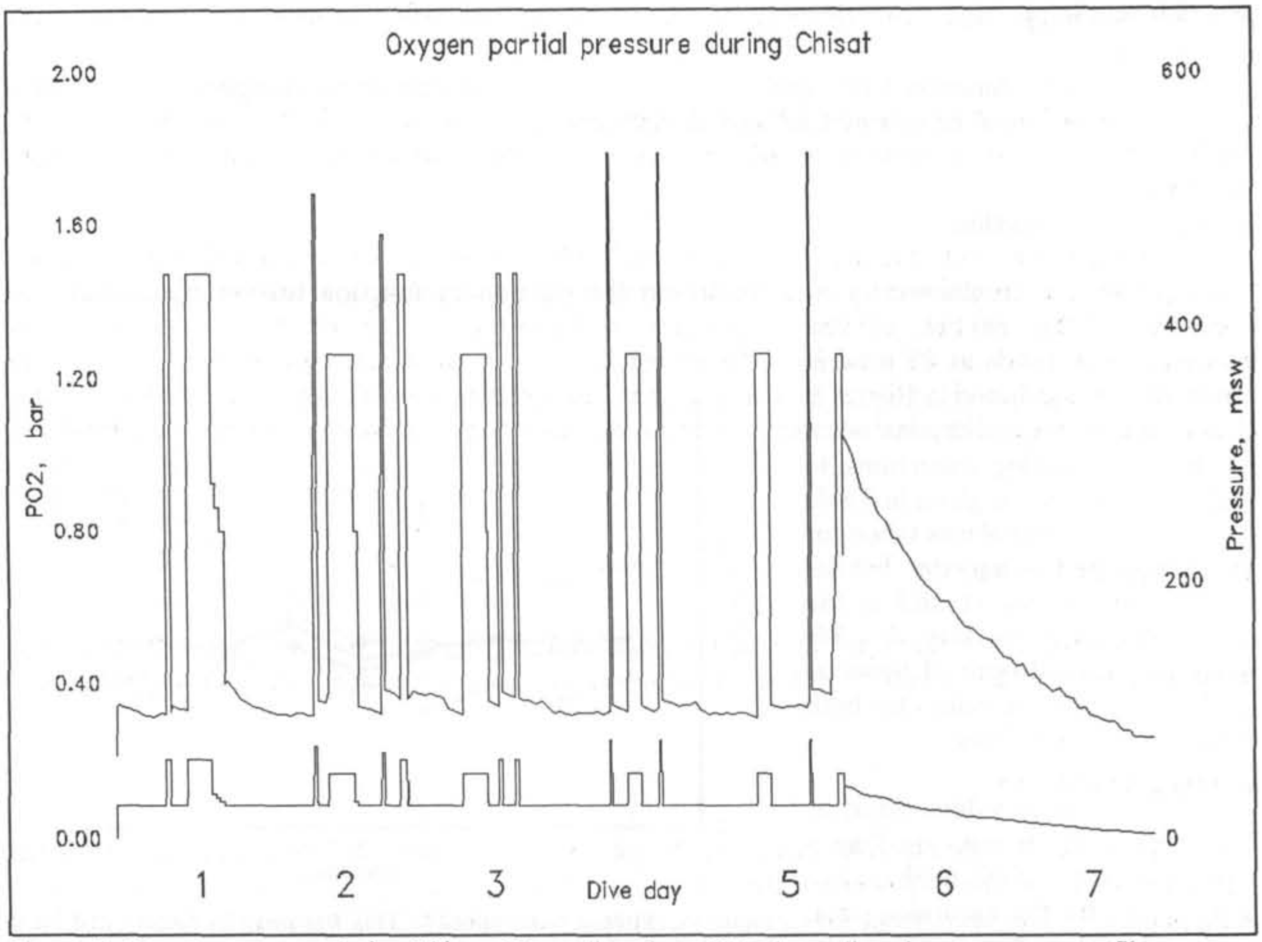


Figure 7. Oxygen exposure during Chisat. Upper line shows PO_2, lower line shows pressure profile.

decompression. Diver 1's finger numbness was first noticed after the switch to air; this diminished during decompression and was barely noticeable after surfacing. Diver 2 noted "a little chest tightness," and had the same finger symptoms. Diver 3 did not have the finger numbness. Diver 4 reported much the same finger symptoms as divers 1 and 2, but did not mention any other symptoms.

Another traditional measure of tolerance of continuous exposure to hyperoxia is vital capacity. Unfortunately this could not be included in Chisat as a monitoring method; we were not able to do unhurried vital capacity measurements repeated until a consistent value was reproduced. However, as part of the pulmonary function studies forced vital capacity was taken daily both in the living chamber and during one of the excursions, and showed some day-to-day variation but no clear trends. These results are covered in the section on pulmonary function, IV.E.1.

No other lung or whole-body symptoms were reported. The divers denied coughing when performing the pulmonary function; this is a fair indication that there was no significant lung or bronchial irritation.

E. Physiology

Pulmonary function, EEG, and performance test results were about as expected. An unusual finding was "flat tops" on some chest impedance waves.

1. Pulmonary function

The only results we have to report on the pulmonary function testing are forced vital capacity. The results of the measurements taken at 25 msw in the habitat are graphed in Figure 8. The results of measurements taken in the igloo during excursions to higher pressures are given in Table V. A predive control was taken for each of these, using the habitat spirometer on Day -1 and in the igloo spirometer on Day -2. We choose to regard both of these as appropriate predive values for both measurement locations.

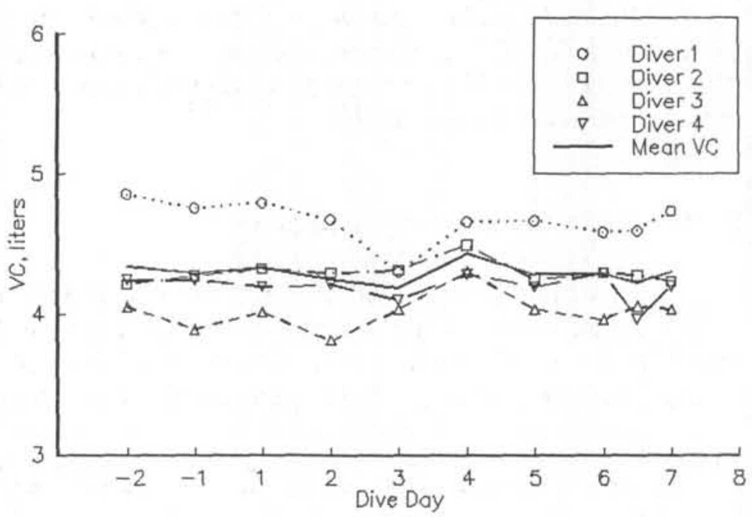


Figure 8. Forced vital capacity. This was measured daily at 25 msw during the pulmonary function studies. No trend is seen over the dive period. Postdive readings were not available.

One set of values listed as being taken at 50 msw on Day 5 was reported with the habitat data instead of with the excursion data. The values for this reading are given in Table V with the other excursion measurements, with the depth marked with a question mark. This may have been taken during the "precursory" decompression after the last excursion (but it could not have been at 50 msw; this reading was not included with the other 25 msw readings in Figure 8). The final 25 msw reading on Day 6 was taken as that depth was passed through on decompression.

Table V. Forced vital capacity during excursions. Values taken at depths and days shown. No clear effect of depth is evident.

Day	-2	-1	1	2	2	3	3	4	4	5	5
Depth	0	0	60	70	50	50	60	75	75	75	50(?)
Diver 1	4.85	4.75	4.28	4.85	4.39	4.61	4.77	4.76	4.73	4.93	4.58
Diver 2	4.21	4.27	4.02	4.30	4.13	4.25	4.31	4.37	4.21	4.38	4.32
Diver 3	4.05	3.89	3.88	3.97	3.49	3.73	4.06	3.76	3.96	4.13	3.95
Diver 4	4.24	4.24	3.90	4.09	4.22	4.22	4.20	4.01	3.96	4.29	3.86
Mean ±S.D.	4.34 ±0.35	4.29 ±0.35	4.02 ±0.18	4.30 ±0.39	4.06 ±0.39	4.20 ±0.36	4.34 ±0.35	4.23 ±0.44	4.22 ±0.36	4.43 ±0.35	4.43 ±0.35

Since the FVC was taken daily on the same days when there was an exposure to hyperoxia during excursions, we felt this parameter might reflect a change in vital capacity if such a change were to have happened. The data in Figure 8 show rather large day to day variability of FVC, of about the magnitude one might be looking for as an oxygen-related decrement. It might therefore be difficult to see a small drop in VC (say 5%) if it were present. In any case there seems to be no strong trend with time in any of the divers, and the mean of all four divers is quite flat over the entire dive. We feel safe in concluding that there was no large change in VC.

2. Work load

The work load periods were routine, and no symptoms or special findings were mentioned. Heart rate increased as expected during the exercise, and recovery was normal. Subjectively the divers were quite aware of the increased gas density. Pressure bradycardia was seen consistently, both at rest and during exercise.

3. Pulmonary blood flow by impedance

Impedance plethysmograms to measure pulmonary blood flow were recorded from the divers once before the dive, 4 times at the storage pressure of 25 msw following excursions, once at 50 msw (Excursion 3-1), 3 times during decompression at 24, 18, and 4 msw, and at 6 and 30 hr after reaching surface pressure. The impedance readings are summarized in Table VI.

Table VI. Summary, "Flat tops" on impedance plethysmograms of pulmonary blood flow.

#	Day	Time	Condition; t since last excn	Diver 1	Diver 2	Diver 3	Diver 4
1	-1	1100-1145	Surface, predive	Normal	Normal	Normal	Normal
2	1	2100-2200	25 msw; 1-2 (60/244)+4 hr	Normal	Normal	Flat top	Normal
3	3	0900-0950	Excursion, at 50 msw	Normal	Normal	Normal	Normal
4	3	1508-1530	25 msw; 3-2 (60/44) +20 min	Normal	Normal	Flat top	Normal
5	5	1125-1145	25 msw; 5-1 (50/133) +1.1 hr	-	-	Normal	-
6	5	1930-2000	25 msw; 5-2 (75/20) +2.5 hr	Normal	Normal	Flat top	Flat top
7	6	0830-0915	Decomp; at 24 msw	Normal	Normal	Flat top	Normal
8	6	1500-1545	Decomp, at 18 msw	Flat top	Normal	Flat top	Flat top
9	7	1815-1830	Decomp, at 4 msw	Normal	Normal	Flat top	Normal
10	8	0950-1030	Surface, post dive, 6 hr after reaching surface	Normal	Normal	Flat top	Normal
11	+1	0945-1015	Surface, post dive, 30 hr after reaching surface	Normal	Normal	Normal	Normal

An unusual and unexpected finding showed up on these recordings. The tops of some of the impedance curves are "flattened." These "flat tops" were seen most often in Diver 3, but were seen twice in Diver 4 and once in Diver 1. Representative recordings from each of the measurement periods are shown in Figures 9 through 12 (Diver 3 spills over into Figure 11a).

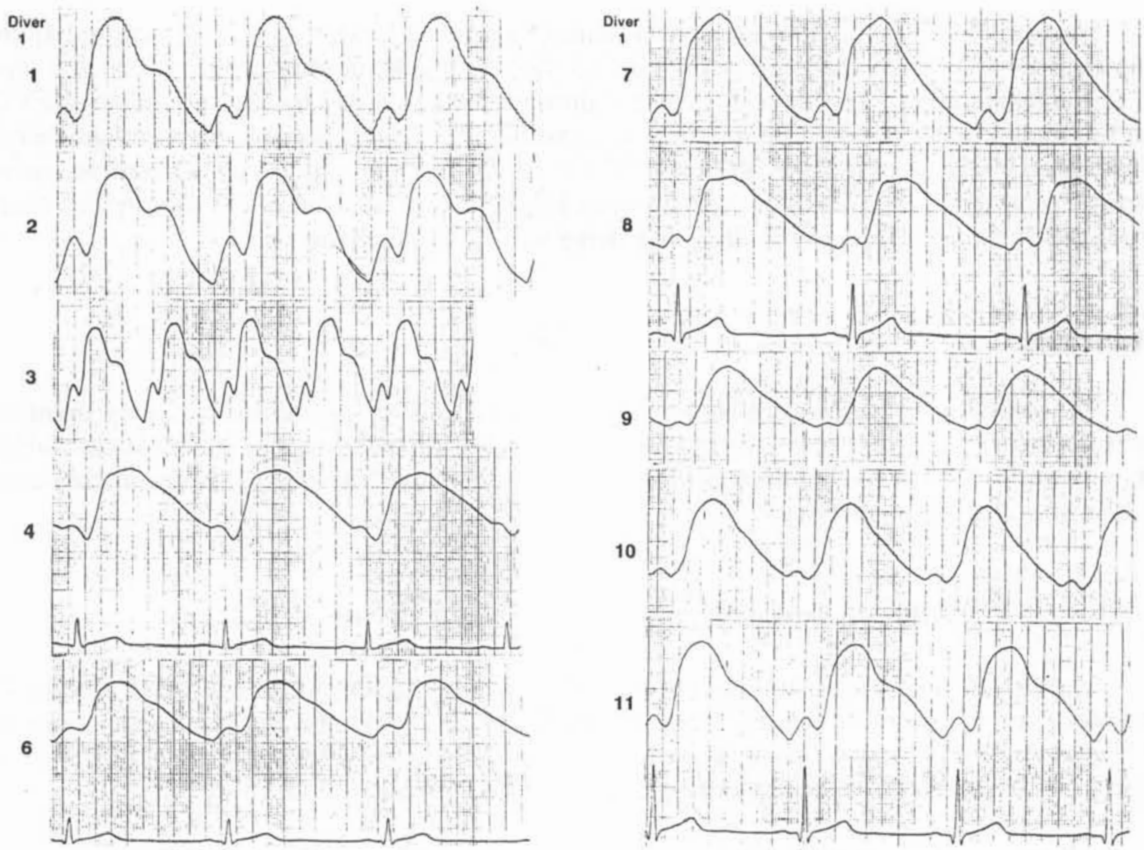


Figure 9. Diver 1 impedance plethysmograms for pulmonary blood flow. Record #3 was recorded at reduced speed, 25 mm/sec instead of 50. Note "flat top" on #8.

These show the impedance waveform at a recording speed of 50mm/sec, all at the same amplitude (except as noted). The upper part of the curve is toward reduced impedance. The predive and most other runs are normal, 3-peak waves clearly showing the A, S, and D peaks. Amplitude of impedance plethysmograms is usually not given, since the stroke volume can be determined by the slope of the main peak of the wave and the timing of the heartbeat.

The actual pulmonary blood flow calculations were not available to us, largely because the attention of the investigators was on the flat tops of the wave shapes rather than the flows.

To try to relate these readings to bubbles we have also plotted their occurrence as symbols on the charts showing the doppler results, Figures 5 and 6. The open diamonds at the top of the "at rest" panel for each diver show when a normal reading was taken, and the solid bars show when the waves had flat tops. Most of the flat tops were seen in Diver III. In plotting the curves on the doppler graph we were looking for a connection between a flat top on the PBF plethysmogram and circulating bubbles as indicated by high doppler scores.

Looking closely at these, Diver 1 has one slightly flattened wave on the second reading on Day 6, at 18 msw during decompression. This is during a period when no bubbles were being detected in this diver at rest, and somewhere between 0 and Grade II were being heard after a flex. Diver 2 showed no flat tops, but had significantly higher bubble scores than Diver 1.

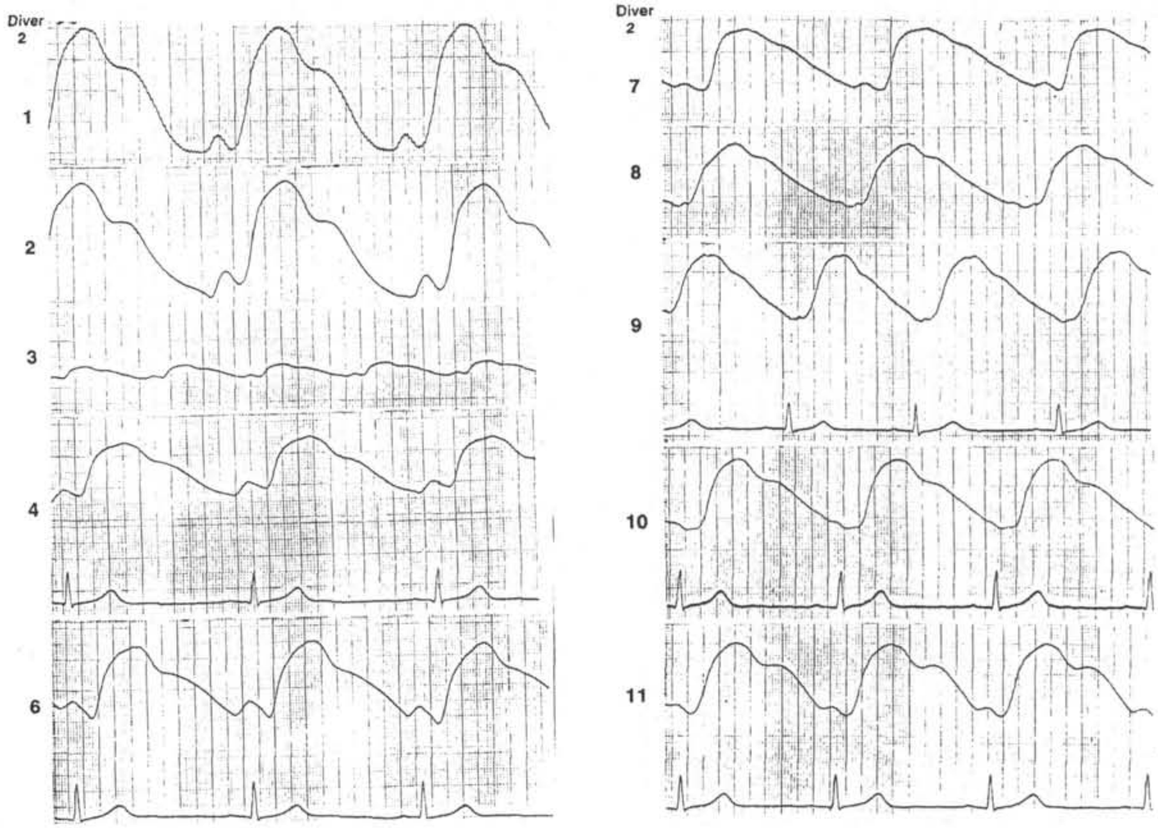


Figure 10. Diver 2 impedance plethysmograms for pulmonary blood flow. Record #3 was recorded at reduced amplitude, 1/10 of normal. No "flat tops" were observed with this diver despite rather high doppler bubble grades.

Diver 3's waveforms are the most interesting. On Day 1 the tracing for Diver 3 had a high frequency signal superimposed on it which was never identified. A half hour later the first recording with a flat top was noted, some 3 hr after a Grade II score at rest. The next was the second reading on Day 3, 20 min after an excursion and during a time when Grade I had been detected at rest and Grade III after flexing. An earlier normal PBF the same day was during an excursion when no bubbles would be expected. During saturation decompression there are no excursions to be concerned about, and the general indication of prevailing bubble grade is more relevant than a particular reading. Although doppler readings were taken only occasionally, it is possible that bubbles were prevalent for a larger portion of the time during saturation decompression than in the periods between the intermittent excursions. Four flat top readings were taken during this decompression period when this diver had Grade I to II readings at rest and I to III after flexing (in one case perhaps even higher). These returned to normal for the last reading 30 hr after the end of decompression, but with some reduction in amplitude.

Diver 4 showed flat tops on Day 5 some 3 hr after Excursion 5-2, along with Grade 0 at rest and Grade II after flexing. Again on Day 6 during decompression and accompanied by no more than Grade I bubbling, there was a flat top.

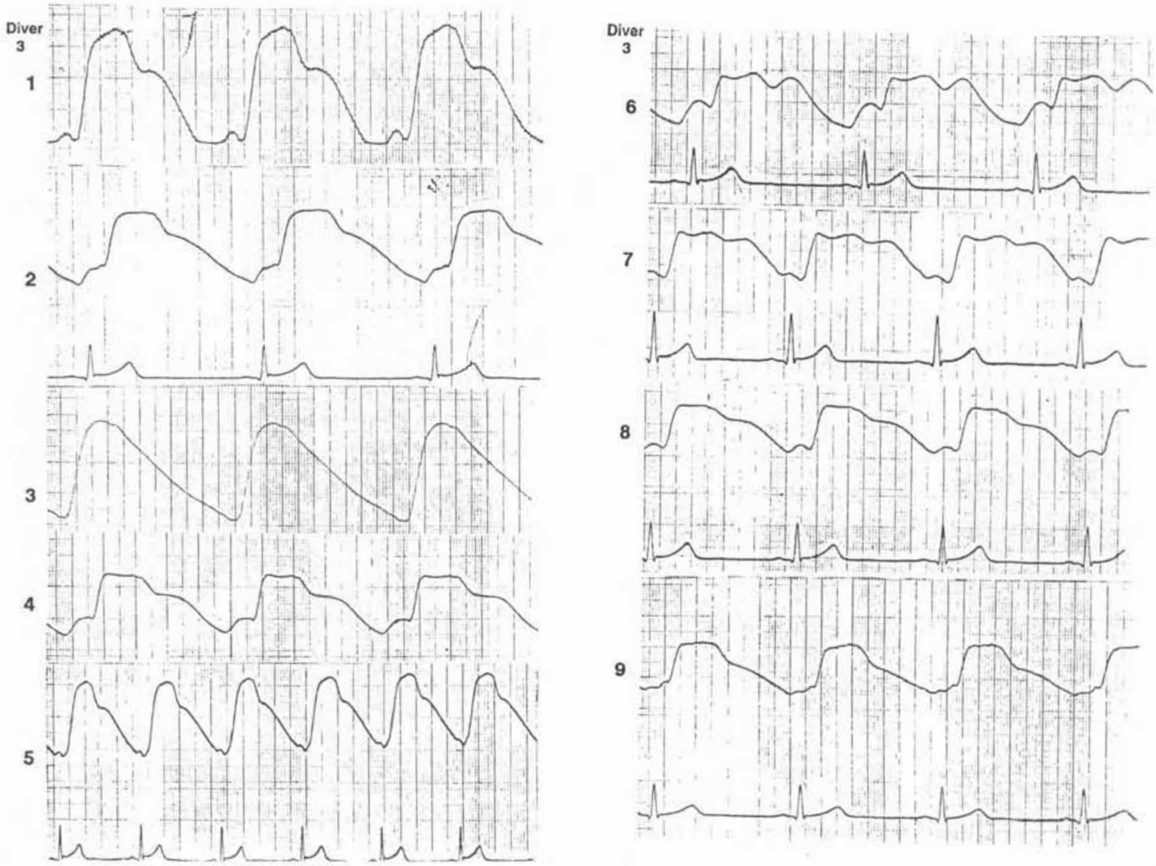


Figure 11. Diver 3 impedance plethysmograms for pulmonary blood flow; f.s. 100 mv, 50 mm/sec. #10 and 11 are in separate Figure 11a. "Flat tops" seen on #'s 2, 4, 6, 8, 9, 10. observed with this diver despite rather high doppler bubble grades.

A perplexing about this are the normal readings in Diver 2 throughout, despite more apparent bubbles than with some of the flat tops, and several readings were taken at times that looked just as stressful as the ones that were associated with the flattened waveforms. While doppler bubbles come and go during a single listening period, the flat tops seemed to be steady and of the same shape throughout a sampling period of 3 or 4 min. Some thoughts on how bubbles might cause these flat waveforms are in the discussion.

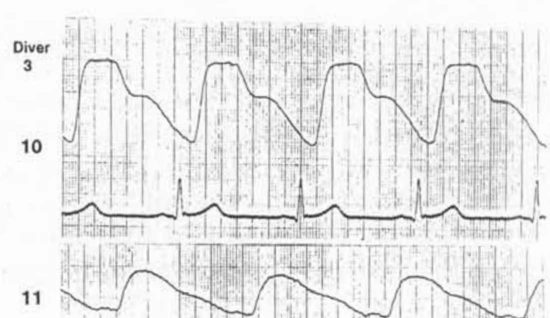


Figure 11a. Diver 3 impedance plethysmograms for pulmonary blood flow, runs #10 and 11. #10 has a "flat top."

4. EEG

The EEG recording regime was carried out as planned, with good quality readings taken. The

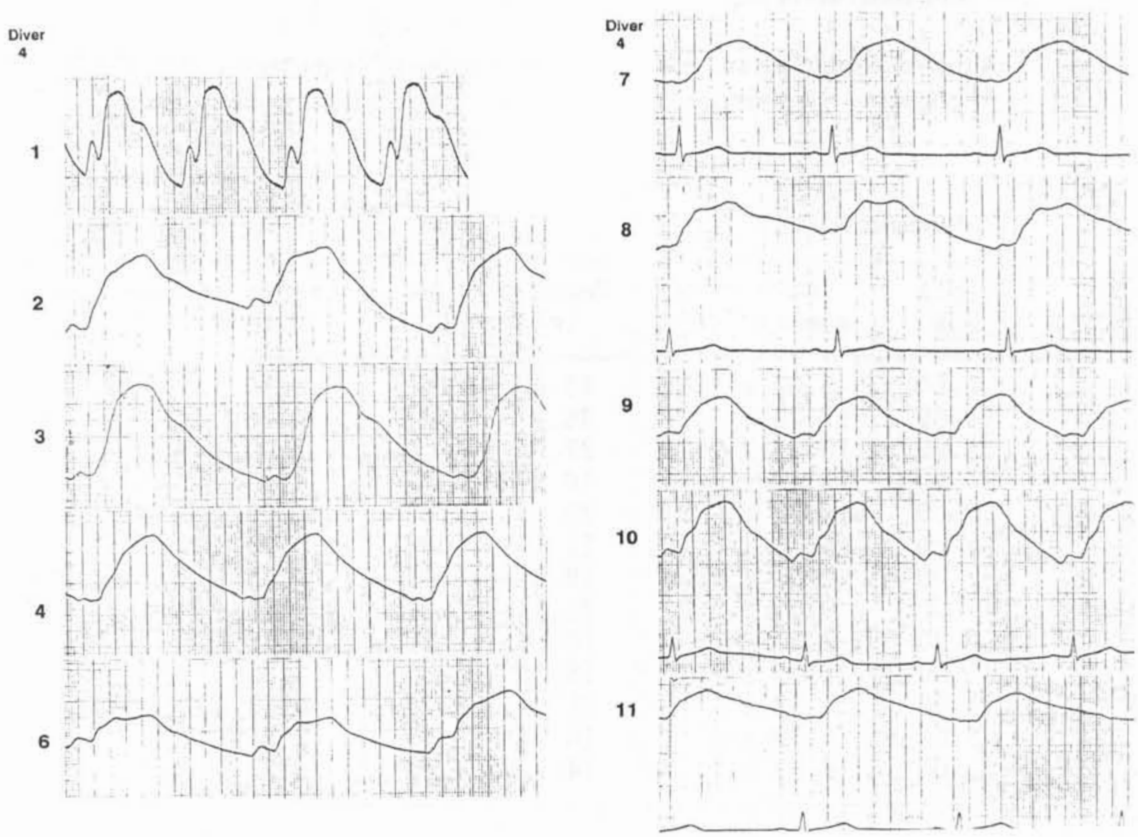


Figure 12. Diver 4 impedance plethysmograms for pulmonary blood flow; f.s. 100mv, 50 mm/sec. "Flat tops" on #6 and #8.

results were unremarkable, or according to Mr. Zhao Deming, there were "no surprises." Power spectral analysis had not been performed as yet.

Online observations indicated that there was an increase of slow waves on arrival at depth as expected, which went back toward normal over several days of exposure. The patterns did not return to normal until decompression was underway, at about 23 msw. There were occasional variations, but in every case the results of different divers went in different directions. That is, any such variations were not seen in all divers together, as would have been expected had the effect been due to the environment. From the central electrodes delta increased on the first and second days and became normal thereafter. Theta increased a bit in the dive and was normal postdive. Alpha (8-12 Hz) was down the first 3 days, then up until the end. Beta 1 and 2 decreased in the dive.

5. Reaction time and short-term memory

Results of the reaction time and memory tests available to us are shown in Table VII. Aside from the expected effects of narcosis there are some points worth noting. First, the first excursion

Table VII. Performance scores.

Dive Day	Depth MSW	Short term memory, sec	Reaction time, total sec	Errors in reaction time test
-1	0.00	6.02 ± 1.20	15.40 ± 2.01	0.50 ± 0.57
1	60.00	17.70 ± 1.35	36.22 ± 8.07	4.25 ± 2.21
1	25.00	10.80 ± 1.17	22.38 ± 4.18	2.00 ± 1.15
2	70.00	10.43 ± 1.51	18.39 ± 3.77	1.25 ± 1.25
2	50.00	10.78 ± 2.51	22.09 ± 3.80	0.00 ± 0.00
2	65.00	15.40 ± 6.80	21.45 ± 2.83	0.00 ± 0.00
3	50.00	7.55 ± 1.83	19.80 ± 4.04	0.75 ± 0.75
4	75.00	8.41 ± 1.22	22.72 ± 4.31	5.75 ± 0.50
4	50.00	7.33 ± 0.50	18.86 ± 3.90	0.75 ± 0.50
5	50.00	7.50 ± 1.06	18.16 ± 3.00	1.00 ± 0.81
5	75.00	7.32 ± 1.12	21.51 ± 5.78	0.75 ± 0.50
6	23.00	6.39 ± 0.42	16.72 ± 3.45	0.25 ± 0.50
8	0.00	4.89 ± 0.59	14.97 ± 4.11	0.33 ± 0.57

to 60 msw showed a substantial effect (higher scores reflecting a greater decrement in performance) in all three categories, memory, reaction time, and errors in the reaction time test.
There does not seem to be a distinct effect of depth; for example, the results at 75 msw toward the end of the exposure are about the same as the first trial at 25 msw.

Unfortunately the testing plan was not designed to evaluate the effect of accommodation to narcosis (for a review of the so-called "adaptation" question see Brauer, 1985). There are, however, 4 tests at 50 msw over a 4-day period, and one at 60 msw which can be used to look at this phenomenon. The Short Term Memory results at 50 msw are plotted in Figure 13, along with the pre and post dive scores and the initial exposure to 60 msw on Day 1 (the latter shows substantial decrement). The points at 50 msw on Days 2-5 line up nicely, showing that the performance improved consistently in speed over this period. The Reaction Time results (not plotted) show exactly the same pattern. The errors, while not significant in magnitude, did not show any important trend; they varied between 0 and 5% over the same period. One test at 70 msw and two at 75 msw on Days 2, 4, and 5 showed a decrease (improvement) in short-term memory scores over time, but no trend was seen in reaction time or errors over this period at this depth, and errors on the 75 msw trial on Day 4 were the highest of the whole experiment.

6. Nutrition

During the dive the divers had high energy requirements, consuming an average of 5000 kcal/day, compared with 3500 to 4000 kcal before the dive. The food they preferred while in the chamber was high energy, high protein, low fat, very tasty, and full of vitamins. Their tastes changed somewhat, leaning towards more fruit as time went on. They were usually hungry after excursions.

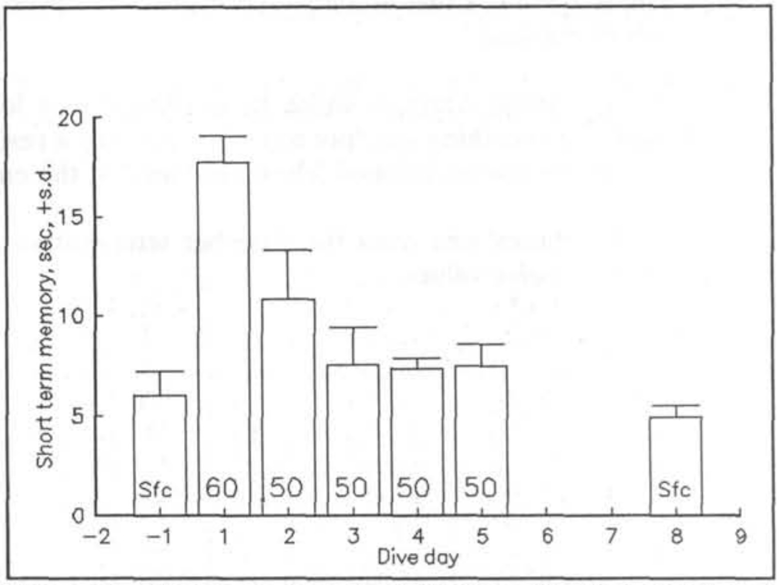


Figure 13. Short term memory at 50 msw. Depth at which tests were run shown inside each bar. A low score represents better performance. Note the high decrement at first (at 60 msw), showing acclimation toward but not quite back to normal.

The food selected by and for the divers was typical of the type usually eaten in Shanghai, but was in larger quantity and of better quality than most people would get. The fare included soft-shelled turtles, yellow croaker, salted vegetables, soup, prawns, sea cucumbers, noodles, rice, sour milk, orange juice, pineapple, apples, bananas, pears, chocolate, and soft drinks. It was taken in 4 or 5 meals per day.

Divers 1 and 2 lost 1 kg, diver 3 lost 1.5, and diver 4 stayed the same weight.

F. General diver condition

The exposure was well tolerated. The divers were in good spirits throughout the experiment, but were especially so during excursions, where when not otherwise occupied they joked and teased and generally enjoyed themselves. Appetite was good, especially after excursions.
There was some loss of sleep the first 2 nights and the divers were sleepy during the day for the first 3 days, but recovered and enjoyed essentially normal rest thereafter. The sleepiness was regarded as being due to nitrogen. Two divers noted skin itching and irritation on the face and neck for 2-3 days; this was attributed to shaving.

The divers were quite aware of the increased gas density during the first 2 or 3 days. One diver attributed ear pain to this, the density making it hard to clear the ear; there were no complications from this. After excursions the divers were tired and hungry; this was more prominent the first 3 days. The divers noted a decrease in subjective narcosis by the 4th and 5th days.

On Day 4 WS and two other doctors locked in, took blood samples, and examined the divers. There were no special findings. The divers all claimed to feel well, and by their demeanor this appeared to be the case.

The bradycardia that accompanies exposure to pressure was seen, both at rest and during the periods of exercise.

Diver 2 noted dizziness which he attributed to a lot of reading. He also noted the gas density, said that breathing was "not so easy." Possibly a result of oxygen exposure and mentioned in that section, he also mentioned "chest tightness" at the end of the dive.

On the divers' exit from the chamber temperature and blood pressure were not greatly changed from predive values.

V. DISCUSSION

This chapter includes first a discussion of the experimental results, then follows with a general commentary and critique on the project.

A. Schedule and profile

As is mentioned several times, the operation was carried out according to the plan, with a few "glitches" in the experiments but no serious concerns for safety or serious loss of data.

The number of excursions and experiments seems to have been well chosen, in that the divers tolerated the exposure well, and neither topside nor divers were exhausted by the program. Sometimes projects of this sort are too ambitious and nothing gets done well. We had originally wanted more excursions, but had to cut back because of excess oxygen exposure as well as to make a more reasonable schedule. Even so, it was a much more varied set of excursions than one would be likely to encounter in a real-world habitat.

B. Environment

1. Auto Control

The Auto Control system worked as promised, controlling the chamber to within its specified limits, except during daily maintenance and once when incorrect instructions were entered. As with any control system, it requires the use of some gas to perform the controlling function, and the system is not yet able to work with minimal gas consumption. This made it advantageous in Chisat to make some adjustments manually to save nitrogen. It should be possible to program some such functions into the system, but a nitrogen addition line under computer control would probably be necessary to do this in an optimal way.

Despite the fantastic improvements in the capability of small computers in recent years and concomitant improvements in reliability and reduction in cost, the use of computers to control hyperbaric chambers is still a relatively rare practice. Thus the CUTI Auto Control is a meaningful progressive step. Even the newest and most sophisticated manned deep ocean simulators are slow to embrace computer control. For example, the GKSS system in Germany, which is probably the most sophisticated deep ocean simulator, is only now adding computer **control** as an option; it had computer monitoring, etc., from its inception but always had a person turning the valve. Several other contemporary systems leave computer control as a "future" addition or do not plan to incorporate it at all. Computer control is being used, however, and is now beginning to be accepted conceptually.

A big advantage of computer control is that the use of remotely controlled valves (electrical or pneumatic) located on the chamber hull makes it possible for only control lines to go to the console and thus minimizes the amount of heavy piping needed. In most installations the saving in piping can offset the cost of the remotely actuated valves. CUTI's system is a "hybrid" in this respect, with the Auto Control acting as a supplementary system. Auto Control also works only on the living chamber and was therefore not utilized for the excursions. However, as a practical device it should work effectively with few modifications for the less demanding control of medical hyperbaric chambers.

Auto Control puts a log onto computer disk, but we did not have access to that and plotted Figure 7 from the pen tracing produced by Auto Control.

Another feature that could facilitate some decompressions would be programming the system to follow a linear decompression (rather than the steps used in Chisat and the Repex plan). This is possible of course, but we did not see it demonstrated and do not know if the system could do it. One advantage of linear decompression could be that virtually all of the pressure control needed could be covered by release of gas; oxygen would have to be added, but the constant corrections needed to hold a pressure would be minimized. Incidentally, the experts do not agree as to whether linear or staged saturation decompression is best physiologically, and in any case the differences are not significant.

2. Environment

The environment was maintained in the planned comfortable range. No problems worthy of mention were reported.

C. Decompression

Chisat I furnished additional validation for the Repex algorithm for making descending excursions from saturation in a nitrogen-based seafloor habitat. The Repex saturation decompression profile was also performed successfully, but with some doppler-detected bubbles, a few more than desired, during and after the decompression.

1. The algorithms

The decompression objective and a main objective of Chisat was to perform a simulated mission in a subsea habitat with repetitive descending vertical excursions, and to do this in such a way as to get another test of the Repex computational algorithm for repetitive excursions. For a test of the algorithm as opposed to decompression tables generated with the algorithm it is more or less necessary to "push" the limits as much as possible throughout the exposure. In order to do this we calculated the entire saturation exposure as a single "dive," continuously updating the gas loadings which act as the basis of the computations.

A problem faced by the Repex project was to define a method for calculating a repetitive dive. For a variety of reasons the choice was to limit repetitive dives by the same gas loading limits used for single dives, and to monitor these limits continuously. Thus if the gas loading calculated to prevail at a given repetitive situation is within the empirically determined limits it can be presumed that the diver will be at no greater risk of getting decompression sickness (DCS) than on a single dive of similar decompression stress.

Speaking of stress, it should be **stressed** that these "gas loadings" are purely imaginary. The body does indeed contain gas following a dive, and the gas forms bubbles which may or may not cause DCS, but the hard and fast linkage between the computational algorithm or "model" and the human body does not go much beyond this point. If the algorithms work it is because they are computational copies of previous good experience.

2. DCS symptoms

Despite a lot of effort to find objective means of assessing decompression, the final decision is still the occurrence of symptoms of DCS. Here the most convincing evidence would be pain or neurological disturbances that are relieved by recompression. Less specific and less definitive symptoms might still be convincing signals of DCS. Extreme fatigue, especially if "inappropriate" because it is not a result of exercise, could be a clear indicator. Skin itching and rash would also clearly be a form of DCS. We were looking for all of these.

No classical "pain only" nor any neurological symptoms were reported. We also are grateful that we did not have to make the tough decisions that follow "skin bends" (because these may occur in exposures otherwise without problems, especially in chambers). Some divers reported fatigue after excursions, but on examination of the facts we concluded that none of these were primary DCS.

One problem to be considered is that the divers may not have reported all their feelings. If they had minor symptoms it is entirely possible that they might not be reported, given that these are typically *macho* divers and also considering in addition the Oriental propensity to avoid losing face. On the latter point the face saving could just as well be ours, and the splendid spirit of cooperation shown by these divers could cause them to conceal pain to avoid embarrassing us and disturbing the project. Even so, the general spirit of well being was so prevalent that even if there were concealed symptoms we feel confident that there could not have been many and that they were not important.

Another drawback from the overall assessment is that the divers performed moderate exercise on only a few of the excursions. Their not being immersed in water during the excursions might also be regarded in some ways as a drawback, but the actual role of immersion during a dive on the subsequent decompression is by no means clear.

Counting 60 excursions (4 divers x 15 excursions, including the last one) with no DCS, binomial analysis says that we can be 95% confident that the true incidence is no greater than 5% (King, 1971). Without the last excursion the prediction is just under 7%. This does not mean that these incidences apply, but rather that they should not be expected to be any greater.

3. Doppler bubble detection

The doppler unit failure during the early excursions was unfortunate; no useful readings were obtained during the first two dive days. We missed the long excursion (60/240) on Day 1, but otherwise this was no doubt better than a failure late in the experiment since in that case we would have lost the doppler of the "multiday" exposures. The readings were satisfactory thereafter, but signals were not strong enough to permit a clear Kisman-Masurel analysis. Our confidence in some of the individual scores is restrained, but we feel the overall evaluation is valid.

Two assessments of decompression reliability are to be made, for the excursions and for the final saturation decompression. Doppler-detectable bubbles are not those that cause DCS, but presence of many doppler bubbles is correlated with higher incidences of DCS.

The distribution of bubble scores among the divers was as one would expect, ranging from only an occasional bubble at rest in Divers 1 and 4 to many Grade II a few Grade III readings after flexing in Divers 2 and 3. To focus on Grade III (there was only one possible Grade IV and that reading was challenged), Diver 1 and Diver 4 each had only a single Grade III reading, both after flexing. Diver 2 had no Grade III's at rest but had Grade III after 5 excursions on flexing and 3 times during saturation decompression, also after flexing. Diver 3 had 2 Grade III's at rest, 3 after excursions, and in about half of the measurements during saturation decompression.

A gross overview is that the bubble load was acceptable at an operational level, but something more specific is desirable. In a recent survey of over 2800 air and heliox chamber dives at DCIEM, Dr. David Sawatzky (1989; Hamilton, 1990) identified a natural break in doppler score as an indicator of DCS incidence between grades II and III. That is, dives producing bubble grades of II or less were found to have few cases of DCS, but those with III or more were at higher risk. He found less difference between I and II or between III and IV. This overall observation is on the maximum score for a dive, without regard to timing, flexing, or breathing gas. For 1726 air dives the DCS incidence in dives with a maximum score of Grade II is about 1%, and for higher grades, III or IV, it is between 6 and 9%. In a closer look at his air dives only, the incidence associated with Grade III bubbles is twice as high if it occurs at rest than after flexing. These are summary conclusions on a relatively small data base (35 cases of DCS after air diving). Presuming that the scoring methods, etc., from this study would apply to the Chisat excursion situation (a big assumption), it would indicate that for two of the 4 divers the predicted DCS incidence would be above 1% for a series of excursions. For the group as a whole it would be less.

Nishi (1989) suggests that in table validation an upper limit can be set for the percentage of divers having each of the grades (mainly II and III); with our occasional Grade III's this gives an acceptable prediction in comparison with standard air dives.

We have not attempted to make a serious comparison of the different types of excursions and their repetitive status, but no pattern is evident. This is complicated by the loss of early doppler data on two of the long excursions and the somewhat random schedule. What role the less-than-ideal doppler signals may have played in affecting the scores is uncertain.

The doppler scores on Repex II, essentially the same decompression but preceeded by a less stressful set of excursions, were much lower than those on Chisat I. This difference includes at least a different set of divers, different doppler equipment, and different doppler operators.

4. Decompression assessment

This evaluation of some 60 man-excursions and the saturation decompression of 4 divers concludes with a reasonable validation, quite good for the excursion algorithm, good but with minor reservations for the saturation decompression.

In offering to consider Chisat as additional validation of the Repex algorithm we consider first that the exposure was as tough as we could make it, albeit without immersion and regular exercise on all excursions, and that there were no symptoms of DCS. It is highly unlikely that any real world mission will even begin to approach the excursion activity performed in Chisat. On the other hand, we are not particularly happy to see more than a few Grade III doppler bubbles, even though most of them occurred after flexing. This by no means is a valid mandate to change the algorithm or Repex tables or procedures or even to suggest that they be "used conservatively," but it is cause to say the procedure bears watching.

With regard to the nitrox saturation decompression, this is a conservative profile in comparison with past experience. This comparison, however, is not a simple matter of just comparing ascent rates, because in addition to ascent rates (or the easier value to use, "rrate" or the reciprocal of rate, in minutes per unit) one must consider the oxygen level throughout the decompression (Vann, 1984) and whether excursions were used and how they were accounted for. Comparing the use of air and relatively high PO_2's early in the decompression with the more traditional method of breathing pure oxygen in the last part of the decompression is not straightforward.

Past experience in nitrox saturation, as reviewed in detail in the Repex report (Hamilton, Kenyon, Peterson, et al, 1988) has not been particularly good using ascent rates faster than this one. Successful contemporary nitrox saturation decompression procedures are consistent with the Repex rates (Peterson and Hamilton, 1987; Chen, 1985). Again, the results of the experiment certainly do not offer any compelling reason to change, but it might signal a need for caution. In saturation decompression the DCS situation is relatively benign, since any symptoms that do develop do so slowly, are mild in nature, and are easy to treat. If any advice is to be given it is to watch the divers for the next two days after completing a saturation decompression of this sort, and after surfacing to avoid ascending to altitude or flying for several days as a minimum. These divers tolerated the oxygen exposure well enough that oxygen breathing during the latter part of decompression (3 or 4 cycles of 20 on, 5 off, after at least 12 hr at a PO_2 below 50 kpa) could be considered.

Another aspect to be considered in this assessment is the concept of the "precursory" part of the ascent. This allowed the saturation decompression to begin only 10 hr after the last excursion, while a wait of at least 24 to 36 hr would be needed if the recompression were not used.

D. Oxygen tolerance

While the Repex decompression methods were the focus of that project and are a main objective here, perhaps more meaningful overall is oxygen tolerance, the Repex method of managing exposure to excess oxygen. The approach is basically to avoid CNS oxygen toxicity by limiting exposure to toxic levels, and to avoid whole-body and lung toxicity by controlling the daily dose as a function of mission duration. Chisat was planned to push both of these limits slightly, enough to be sure that the limits are valid, but not so much as to cause symptoms that would have to be attributed to an excess dose.

This seems to have been accomplished. Some of the excursions were very slightly over the Repex CNS limits, and the daily doses for the mission were just enough higher than the Repex operational limit to test the possible use of the additional oxygen exposure of a Table 6 treatment beyond the limit.

The Repex CNS limits are relatively small steps beyond a long standing set of limits developed by the U.S. Navy and adopted by NOAA (Chen et al, 1987). Since Repex was done a new set of limits has been proposed by NOAA for the next edition of the NOAA Diving Manual that are a bit more generous than Repex (see Hamilton, 1989). The Chisat CNS exposures are meaningful, but the levels used are well under the new NOAA limits. There were no symptoms associated with the short duration exposures to the upper oxygen (CNS) limits.

The development of "numb fingertips" in 3 out of 4 divers after the switch to air at the beginning of the final decompression is a classical but mild symptom of what we call "whole body" oxygen toxicity. Though it is now well known and regarded as "classical," it is not often mentioned in the early oxygen tolerance literature; the earliest reference we could find was from Germany before WWII (Becker-Freysing and Clamann, 1939). This happens in the regime normally associated with lung toxicity, an exposure normally reckoned in OTU's (or CPTD or UPTD) per day, and the attention of both investigators and operations personnel has been toward lung problems. Our Chisat divers had this symptom for a day or two, and it went away by the end of the dive or shortly thereafter. Similar symptoms from clearly excessive exposures to hyperoxia have caused a feeling of fingertips "full of sawdust" that lasted for about 6 weeks. Robert Stenuit had this after the first open sea saturation dive (1965) and said about it that, "you will not be able to tell whether it has gone away or you have just gotten used to it." The point of all this is that the Chisat divers had a very mild and transient case, easily tolerated and acceptable as a side effect of necessary treatment or even operational necessity. This much exposure would not be used under normal circumstances, however, and the symptoms would therefore be unlikely.

We cannot say whether the divers had any reduction in vital capacity. A percent or two might be expected, but was not detected with the FVC maneuvers (next section).

E. Physiology

In general the physiological monitoring conducted by the CUTI investigators supports similar studies. Pulmonary function parameters were reduced as expected (Zheng et al, 1988; Jing et al, 1979). No change in vital capacity was detected, but the procedure did not look for small changes. The divers were aware of gas density during pulmonary function tests and during exercise. Bradycardia was seen both at rest and in exercise (Shilling et al, 1936).

1. Accommodation

One interesting aspect of this type of exposure is the "adaptation" of the individual to the exposure. Brauer (1985) has suggested that this term is normally used for genetic changes, and that "acclimation" or "accommodation" are better, with "acclimation" the choice when one or more physiological mechanisms can be identified (as would be the case with acclimation to altitude, for example) and "accommodation" when no mechanism seems to be responsible.

Vital capacity has been seen to increase slightly with time at pressure (Wright et al, 1973), but we did not see such a change here.

With the focus on only the measurements taken at 50 msw there seems to be a good indication of the accommodation to narcosis that has been seen elsewhere (Brauer, 1985). Recovery was not complete during the "bottom" phase, but reaction times which were nearly twice the predive control value (performance at sea level, pre and post dive) returned to about 25% above normal by the last day of the exposure and were essentially normal as decompression got well underway.

The divers were probably not at a learning plateau by Dive Day 1, but the learning curve on this type of test is not prominent and learning is not evident in the remainder of the data; for example, the mean postdive test time was 14.97, to compare with a predive mean for 4 divers that was essentially the same at 15.4. Most likely the high scores on Day 1 reflect the effect of an initial exposure to narcosis; the first reaction time test was given at the start of the first excursion, only 8 hr after going to pressure at 25 msw. This 60 msw exposure would be expected to cause a greater effect than one at 50 msw anyway, but the effect may have been especially prominent also because this was the first time this form of the test was used. We are not sure what the differences were between these and the predive practice, but we assume that the only difference was that at pressure the display had to be viewed through a porthole. Even if the 60 msw value is ignored the remaining 4 values at 50 msw show a consistent recovery pattern.

No systematic effects of total pressure (depth) on performance are evident. This could be because the measurements were made at different times in the course of the saturation and accommodation was in progress. Perhaps statistical techniques on the individual data points could separate these effects.

Our divers showed EEG changes that indicate they were adjusting in some way to the environment, as had been seen before by Zhao Deming (1982).

2. Pulmonary impedance measurements

When a flat top was noted by Cui Renjing on an early "PBF" reading after an excursion, our first impulse was to regard this as a restriction to flow presumably caused by bubbles. The schedule was rearranged to place the PBF measurements at periods of higher decompression stress where bubbles would most likely be encountered. These changes were reasonably successful in that several of the subsequent recordings were done at times of bubble activity, and several other flat systolic waves were seen. The relation of the doppler readings and the normal or flat S-peaks can be seen in the symbols in Figures 5 and 6. The results do not permit determination of a numerical regression of S-wave change on bubble count at the same time, but the figures reveal some consistencies. In the cases where there really should not have been any circulating bubbles—in the pre-dive period, during the 50 msw excursion on Day 3, and 30 hr after the end of decompression, for example—there were no flat tops observed, and all that were observed were seen at times when there could have been at least a few circulating bubbles. Further, the diver with the most obvious and most prevalent flat tops (#3) had high doppler bubble scores.

Historically an early application of chest impedance was to estimate cardiac output (reviewed by Geddes, 1964). The bulk of the impedance change that is seen with each heartbeat was shown to be due to blood being pumped into the pulmonary circuit (Bonjer et al, 1952, cited by Geddes, 1964). This is essentially the method used at CUTI to estimate pulmonary blood flow. A blockage can reduce the peak. In the clinical setting the flattening of the peak of the pulse wave is typical of pulmonary artery hypertension; such a condition can often be relieved by dilatory drugs in a few minutes.

The reduction in the S-peak in Mr. Cui's initial observation was about 10% of the amplitude of the predicted S-peak, but in later measurements this attained more on the order of a 50% reduction, with no great change in slope.

A restriction of blood flow could indeed cause a reduction in the peak of the impedance waveform, and since bubbles were presumed to be present, a good assumption might be that bubbles could be restricting blood flow through the lungs. This seems reasonable enough, but for pulmonary blood flow (or cardiac output) to be reduced by as much as an estimated 50% would cause other physiological reactions, and there were no such indications. A blockage of pulmonary flow enough to cause a reduction of this order should cause severe "chokes" as well as compensatory respiratory and cardiac frequency responses. This presumes that the observed reduction in peak amplitude calculates out to a reduction in flow.

Another hypothetical explanation for the flat peaks with no other symptoms was offered to us by Dr. Wayne Gerth of Duke University (personal communication, 1989), who recalled work by Sakamoto and Kanai (1979). These workers showed a change in impedance of flowing blood due to a disturbance in the orientation of erythrocytes in the laminar flow stream. In dog experiments they showed that when the current flow is along the longitudinal axis of flow as much as 50% of the measured pulsatile orientation is related to flow-dependent red cell orientation.

Dr. Gerth does not cite specific research showing how bubbles might affect red cell orientation, but suggests that it might be by aiding conversion from laminar to turbulent flow. While bubbles might not make much of a reduction in blood density (d in the equation for Reynolds number, $Re = 2rvd/\eta$), they could lower the viscosity η of the blood-bubble suspension substantially; these two changes would act in the same direction to increase Re and invoke turbulence. Circulating bubbles would thus tend to lower the flow velocity required for the transition to turbulent flow, and would reduce the most rapid part of the S-wave of pulmonary flow.

We were not able to perform any maneuvers that could have helped to sort out these effects, but a change in schedule did allow more measurements to be made during times when bubbles were more likely, and this yielded more flat waveforms.

While this finding, if it turns out to be a representative observation, might lead to a useful method of assessing decompression stress, it should be regarded with some reservations. First, the flat tops were not seen when bubble activity was at its greatest, and they were seen at times when few bubbles were actually recorded. Further, no flat tops were seen in Diver 2, yet he had about the same level of doppler bubbles as Diver 3. They were seen consistently in Diver 3 during decompression, but during that time bubble grades at rest were generally low in this diver.

To summarize these observations, flat systolic waveforms were seen mostly in Diver 3 but in two others much less often—at times when they could have had doppler-detectable bubbles—although the correlation with bubble activity seems rather loose. Bubbles in the pulmonary circulation could possibly disrupt laminar flow and cause a change in thoracic impedance, but the degree of effect seen does not quite seem consistent with the number of bubbles expected or measured. If this observation is found to be a common one it might become an objective monitor of decompression inadequacy.

F. Assessment of the project

1. Overview

Our overall assessment of the project is enthusiastically positive. We at this end learned a lot and treasure the experience. We are pleased to have the contacts with Chinese colleagues, and hope to keep them up. Both of us (RWH and WS) would do this again if given the chance. Additional joint publications are planned.

Our choice of reporting style was arbitrary. We did not try to confirm all details or to continue the dialogue with CUTI colleagues during production of this report. This was not from any personal reservations, but because it looked like the most expedient approach. In retrospect we could have perhaps gotten more final data by mail, but we did not do this for two reasons; the main one is because we felt this data belongs to the investigators and we should not be the ones to report it—even if we could do it properly, which we could not. Another reason was a naive notion that the report would be done before we would have time to exchange data and commentary. We were wrong on that one.

We hope our reporting of data of our CUTI colleagues is appropriate and appreciated; we missed some data and analyses and many analytical details, but we hope we have the essence. We have possibly given a fresh perspective to some items. We apologize if we have mis- or under-represented anything.

We give a good score for the CUTI effort and performance. Some small matters could have been done better, and we all could have communicated better both before and after the dive, but we are generally quite pleased with what we have gained from this experience and with the experimental results.

This type of collaboration is fruitful for both ends. We welcome the opportunity to do something like this again, and hope that the turn of events in the Chinese government moves so as to make it possible.

2. Critique

A few key points about the many things we could have done better include in general better logs and notes, and an ongoing writeup (which is always planned but never quite happens). We would try to have a master log, on computer or not depending on the circumstances, to confirm the timing and performance of all events. If we are going to describe our colleagues apparatus and experiments we could understand them better.

We could have been more explicit earlier in the planning about our aspirations regarding such things as accommodation to narcosis, use of vital capacity for monitoring oxygen tolerance, and a planned level of exercise during excursions.

One thing that would have made this whole operation easier, both before and after the experiment itself, would be a fax machine at CUTI, or some equivalent. If we were to consider another such project it would include early solution of this problem as a major objective.

3. Conclusions

Decompression from a full schedule of descending excursions over 5 days according to the Repex computational algorithm was without symptoms of decompression sickness. Some Grade II and a few Grade III doppler ultrasonic bubbles were found, indicating that the decompressions were somewhat stressful, but the conclusion is that the process is satisfactory.

The saturation decompression was also carried out without symptoms of DCS, but like the excursions it also caused some doppler bubbles. The results support the continued use of the profile, but have added only a little extra confidence.

Oxygen exposure of the divers was well tolerated, with some mild symptoms after the switch to air during the final decompression. This was intentionally a bit more oxygen than recommended by the Repex procedures for this range so tends to validate enough extra exposure to cover a DCS treatment.

Perhaps the most important finding is that U.S.-Chinese collaboration at this technical level can be productive.

VI.
REFERENCES

Becker-Freysing H, Clamann HG. 1939. Sauerstoffvergiftung. *Klin Wochenschr* 18:1382.

Bonjer FH, Van den Berg J, Dirken MJN. 1952. The origin of variation of body impedance occurring during the cardiac cycle. *Circulation* 6:415.

Brauer RW. 1985. Acclimation to nitrogen narcosis: A review. In: Hamilton RW, Kizer KW, eds. Nitrogen narcosis. UMS 64WS(NN)4-26-85. Bethesda, MD: Undersea Medical Soc.

Chen Baosong. 1985. Decompression from nitrogen-oxygen saturation diving. *Acta Oceanologica Sinica* 4(1): 135-142. (in English)

Chen Baosong, Jing Yanling, Zheng Jichang. 1987 Dec. [Some observations of physiological function during air excursions exceeding USN exceptional oxygen limits.] Presented at National Symposium on Engineering Technology of Ocean Development, Guangzhou, China, 17-21 Dec 1987, vol 3, pp 845-49. (in Chinese)

Fan L, Jing Yanling, et al. 1982. [*Diving technology*.] Beijing: Peoples Communication Publishers. (in Chinese).

Geddes LA, Hoff HE. 1964. The measurement of physiologic events by electrical impedance. *Am J Med Electronics* 3:16-27.

Hamilton RW. 1989 Dec. Tolerating exposure to high oxygen levels: Repex and other methods. *Marine Tech Soc J* 23(4):19-25.

Hamilton RW. 1990 May-Jun, Jul-Aug. Great Lakes Doppler Workshop. *Pressure* 19(3):7-9; (4)8-9.

Hamilton RW, Kenyon DJ, Peterson RE. 1988 May. Repex habitat diving procedures: Repetitive vertical excursions, oxygen limits, and surfacing techniques. NURP Technical Report 88-1B. Rockville, MD: U.S. Department of Commerce.

Hamilton RW, Kenyon DJ, Peterson RE, Butler GJ, Beers DM. 1988 May. Repex: Development of repetitive excursions, surfacing techniques, and oxygen procedures for habitat diving. NURP Technical Report 88-1A. Rockville, MD: U.S. Department of Commerce.

Harabin AL, Homer LD, Weathersby PK, Flynn ET. 1987. An analysis of decrements in vital capacity as an index of pulmonary oxygen toxicity. *J Appl Physiol* 63(3):1130-1135.

Jing Yanling, Chen Baosong and Zheng Jichang. 1979 Dec. [Respiratory function studies during nitrogen-oxygen saturation in depth of 20-36.5 meters and air excursion simulated diving in depth of 50-70 meters.] *Acta Oceanologica Sinica* 1(2):323-337. (In Chinese)

King JR. 1971. *Probability charts for decision making*. New York: Industrial Press.

Kinnen E. 1970. Cardiac output from transthoracic impedance variations. *Ann NY Acad Sci* 170(2):747-756.

Kinnen E, Kubicek WG, Patterson RP. 1964 Mar. Thoracic cage impedance measurements. SAM-TDR-64-15. Brooks AFB, TX: USAF School of Aerospace Medicine.

Kubicek WG, Patterson RP, Witsoe DA. 1970. Impedance cardiography as a noninvasive method of monitoring cardiac function and other parameters of the cardiovascular system. *Ann NY Acad Sci* 170(2):725-732.

Mo Rufei, Chen Baosong. 1987 Sep. [Recent development in the field of deep sea diving—Nitrox diving.] *Ocean Technology* 6(3):19-24. (in Chinese)

Nishi RY. 1990. Doppler evaluation of decompression tables. In: Lin YC, Shida KK, eds. *Man in the Sea*, Volume I. San Pedro, CA: The Best Publishing Co.

Peterson RE, Hamilton RW. 1987. Development of saturation decompression procedures for nitrogen-oxygen and air habitat diving operations. In: Bove AA, Bachrach AJ, Greenbaum LJ Jr., eds. *Underwater and hyperbaric physiology IX*. Bethesda, MD: Undersea and Hyperbaric Medical Society.

Sakamoto K, Kanai H. 1979 Dec. Electrical characteristics of flowing blood. *IEEE Trans Biomed Eng BME-26* (12):686-695.

Sawatzky D. 1989. Doppler scores and DCS: DCIEM's experience 1979-1989. Presented at Great Lakes Chapter UHMS Workshop on Use of doppler bubble detection for dive table testing, Buffalo, NY, 1989 Oct 13.

Shi Zhongyuan, Chen Baosong. 1987 Sep. [An experimental study on helium-nitrogen-oxygen saturation diving system for 300 m depth.] *Ocean Technology* 6(3):1-9. (in Chinese)

Shilling CW, Hawkins JA, Hansen RA. 1936. The influence of increased barometric pressure on the pulse rate and arterial blood pressure. *U.S. Navy Med Bull* 34:39-47.

Shilling CW, Werts MF, Schandlemeier NR, editors. 1976. *The underwater handbook: A guide to physiology and performance for the engineer.* New York: Plenum Press.

Stenuit R. 1965 Apr. The deepest days. *National Geographic* 127:534-547.

Sterk W. 1986. Intermittent hyperoxia in operational diving: What are the safe limits. In: Schrier LM, de Jong MH, Sterk W, eds. Proceedings of the XIIth Annual Meeting of the European Undersea Medical Society. Rotterdam: Foundation EUBS. pp 55-64.

Vann RD. 1984. Decompression from saturation dives. In: Cox FE, ed. Proceedings 3rd Annual Canadian Ocean Technology Congress. Toronto: Underwater Canada.

Wright WB, Fisher AB, Hendricks PL, Brody JS, and Lambertsen CJ. 1973 Jul. Pulmonary function studies during a 14-day continuous exposure to 5.2% oxygen in nitrogen at pressure equivalent to 100 fsw (4 ata). *Aerospace Med* 44(7):837-843.

Zhang Hengdu, Wang Hengxing. 1982. [Effect of exposure to stimulated N2-O2 saturation diving at 4.65 ATA for 26 days on the physiological functions of human subjects and safe decompression.] *Acta Oceanologica Sinica* 4(2):231-239. (in Chinese)

Zhao Deming, Lui Zeren, Shen Tongmei, Mei Xinhua, Shi Zhongyuan. 1982. [Effects on electroencephalography of human body during simulated nitrogen-oxygen saturation diving in depth of 36.5 m for 26 days and air excursion diving in depths of 60, 70, and 75 m.] *Acta Oceanologica Sinica* 4(2):241-248. (in Chinese)

Zheng Jichang, Lee Yuanchen, Wang Wenbo. 1988. [Effect on pulmonary ventilation and oxygen uptake of human body during simulated N_2-O_2 saturation diving at a depth of 36.5m for 26 days.] *Industrial Hygiene and Occupational Disease* 14(1)1-5. (in Chinese)

APPENDIX A.

CHISAT I SCHEDULE

A schedule was prepared for the entire time spent under pressure. This was used as a supplementary recording log of the pressure profile—the operator entered the actual time at each significant point. This copy of the log shows the original schedule in gothic type, and comments and actual times in italics.

The first column (Time) is time of day, and the second column (Depth) the current chamber pressure in metres of sea water. The figures in italics in the third column (Actual time) give the actual time of arrival at a depth or the time of an event. Chamber and excursion functions are given in the fourth column (Chamber/Excursion) and experiments to be performed in the fifth. The sixth column contains comments; all entries here, in italics, were added after the original schedule, by the operator or during the writeup. The non-specific time related comments (*"1 min late"*) refer to arrivals at and departures from depths.

Excursions are numbered by dive day followed by a hyphen and the excursion number for that day; for example, 5-1 is the first excursion on Day 5. Excursion times are shown as excursion depth followed by a diagonal and "total excursion time" in minutes from the moment of leaving storage (habitat) pressure to the beginning of decompression; for example 50/133 is 50 msw for 133 min (this is calculated in the same way "bottom time" is usually figured). The total decompression time in minutes is shown for each excursion in parentheses as $Dt=xx$. No-stop ("no-decompression") excursions show *"No-d"* followed by a backslash and the time of decompression back to the habitat in minutes; for example "*(No-d)/3*" is for a 3-min return to storage pressure after completion of the excursion time.

Doppler readings in the form 5-3A show the excursion number followed by a letter for the reading. Post-excursion readings at 45, 90, and 135 minutes after the end of the excursion are labelled A, B, and C, respectively.

CHISAT 1 SCHEDULE 88OCT27 RWH/GZZ/CBS

Note: Times are rounded
Rates 10 msw/min
Dive times include descent

Rev Oct22: Times; No-d/ascent time
Oct26: Add last days; PBF;
Oct27: Postdive; predive
89Jul: Added comments, etc.

Time min	Depth msw	Actual time	Chamber/Excursion	Experiments	Comments
PREDIVE DAY -3, WEDNESDAY 1988 OCTOBER 19--PREDIVE TESTS					
14:00	00			Pulmonary function	*Training*
15:00	00			Work load	
15:30	00			Doppler 0-1	*Training*
PREDIVE DAY -2, THURSDAY 1988 OCTOBER 20--PREDIVE TESTS					
09:30	00			EEG; Reaction time	
10:30	00			Doppler 0-2	
15:00	00			Pulmonary function	*In igloo*
12:30	00			Pulmonary blood flow; ECG	
			Medical exams		
PREDIVE DAY -1, FRIDAY 1988 OCTOBER 21--PREDIVE TESTS					
08:45	00			Brain function	
09:00	00			Pulmonary function	*In habitat*
09:30	00			EEG; Reaction time	
10:00	00			Work load	
10:50	00			Doppler 0-3A	*Training*
11:00	00	*11:00*		Pulmonary blood flow	

DIVE DAY 1, SATURDAY 1988 OCTOBER 22

Time min	Depth msw	Actual time	Chamber/Excursion	Experiments	Comments
00:00	00	*00:00*	Pressurize to 25 msw		*PO_2 0.30-0.35*
00:02	25	*00:03*	Arrive 25 msw		*PCO_2< 1500 ppm*
00:30	25		Lights out		*RH ~ 60%*
06:00	25	*06:00*	Wake up divers		*T ~ 26C*
06:45	25		Breakfast		
08.00	25	*08:00*	Begin excn 1-1, 60/43		
08:03	60	*08:03*	Excursion 1-1	EEG; Reaction time	*Rt at 0847*
08:43	60	*08:43*	Ascend to 25 msw		
08:46	25	*08:46*	End excn 1-1 *(No-D)/3*		
08:47	25			Reaction time; EEG	
09:26	25			Doppler 1-1A	*No data due to doppler*
10:11	25			Doppler 1-1B	*unit failure at pressure*
10:12	25				*WS to 25 msw in igloo to test doppler*
10:15	25		Lunch		
10:56	25			Doppler 1-1C	
11:30	25	*11:31*	Begin Excn 1-2, 60/244		*1 min late*
11:34	60	*11:35*	Excursion 1-2	Pulmonary function; VC	
14:00	60			Work load; Pulmonary blood flow	*Pulmonary blood flow changed to 2100*
15:34	60	*15:34*	Ascend to 37msw		
15:40	37	*15:40*	Ascend to 34 msw		
16:03	34	*16:03*	Ascend to 31 msw		
16:05	34		Tea		
16:36	31	*16:36*	Ascend to 28 msw		
17:30	28	*17:29*	Ascend to 25 msw		*1 min fast*
17:30	25	*17:30*	End excn 1-2 *(Dt=116)*		
18:10	25	*18:37*		Doppler 1-2A	*Poor data; 2 divers done before it quit*
18:30	25		Supper		
18:55	25			Doppler 1-2B	*Not done*
19:30	25	*19:30*		Pulmonary function; VC	
19:40	25			Doppler 1-2C	*Not done*
20:00	25			Heart; Transcutaneous O_2	*TC-O_2 apparatus failed at pressure*
		21:00			*Pulmonary blood flow*
21:30	25		Lights out		

Time min	Depth msw	Actual time	Chamber/Excursion	Experiments	Comments
DIVE DAY 2, 1988 OCTOBER 23					
06:00	25	*06:00*	Wake up divers		
06:45	25	*06:45*	Breakfast		
08:00	25	*08:00*	Begin Excn 2-1, 70/35		
08:05	70	*08:11*	Excursion 2-1	Pulmonary function; Reaction time	*6 min late*
08:35	70	*08:35*	Ascend to 28 msw		*Excursion stopped for 6 mins due to ear pain*
08:42	28	*08:42*	Ascend to 25 msw		
08:42	25	*08:42*	End excn 2-1 *(Dt=7)*		
09:22	25			Doppler 2-1A	*No data*
10:07	25			Doppler 2-1B	*No data*
10:15	25		Lunch		
10:30	25	*10:30*	Begin Excn 2-2, 50/244		
10:33	50	*10:33*	Excursion 2-2	EEG; Reaction time	
12:00	50	*10:33*		Pulmonary function; VC	
14:33	50	*14:33*	Ascend to 28 msw		
15:07	28	*15:07*	Ascend to 25 msw		
15:07	25	*15:08*	End Excn 2-2 *(Dt=34)*		
15:47	25			Doppler 2-2A	
16:00	25		Tea		
16:32	25			Doppler 2-2B	
17:17	25			Doppler 2-2C	
19:00	25	*19:00*	Begin Excn 2-3, 65/35		
19:05	65	*19:06*	Excursion 2-3	Reaction time	*1 min late*
19:35	65	*19:35*	Ascend to 25 msw		
19:38	25	*19:39*	End Excn 2-3 *(No-D)/3*		*1 min late*
19:45	25	*19:45*		Pulmonary function; VC	
20:18	25			Doppler 2-3A	*No data*
20:30	25		Supper		
21:03	25	*21:13*		Doppler 2-3B	
21:48	25	*21:52*		Doppler 2-3C	*One diver*
22:00	25	*22:00*	Begin Excn 2-4, 60/64		
22:04	60	*22:04*	Excursion 2-4	Pulmonary function; VC	
23:04	60	*23:04*	Ascend to 28 msw		
23:13	28	*23:13*	Ascend to 25 msw		
23:14	25	*23:14*	End Excn 2-4 *(Dt=10)*		
23:59	25	*00:00*		Doppler 2-4A	
00:30	25		Lights out		

DIVE DAY 3, 1988 OCTOBER 24

Time min	Depth msw	Actual time	Chamber/Excursion	Experiments	Comments
06:00	25		Wake up divers		
06:45	25		Breakfast		
08:00	25	*08:00*	Begin Excn 3-1, 50/242		*Suunto*
08:02	50	*08:03*	Excursion 3-1	Pulmonary function; VC	*1 min late*
		09:00			*Pulmonary blood flow*
09:00	50	*09:00*		Work load	
10:00	50	*10:00*		EEG; Reaction time	
11:00	50		Divers take 1-hr nap		
12:02	50	*12:02*	Ascend to 28 msw		
12:24	28	*12:24*	Ascend to 25 msw		
12:25	25	*12:25*	End Excn 3-1 ~~*(No-D)*~~ *(Dt=23)*		*"No-d" shown on original schedule in error*
12:45	25		Lunch		
13:07	25	*13:14*		Doppler 3-1A	
13:52	25	*13:42*		Doppler 3-1B	
14:00	25	*14:02*	Begin Excn 3-2, 60/43		*2 min late*
14:03	60	*14:05*	Excursion 3-2	EEG; Reaction time	
14:43	60	*14:43*	Ascend to 25 msw		
14:46	25	*14:47*	End Excn 3-2 *(No-D)/3*	Heart	*1 min late*
		15:08			*Pulmonary blood flow*
15:26	25	*15:32*		Doppler 3-2A	
16:11	25	*16:04*		Doppler 3-2B	
16:30	25	*16:30*	Begin Excn 3-3, 60/44		
16:34	60	*16:34*	Excursion 3-3	Pulmonary function; VC	
17:14	60	*17:14*	Ascend to 25 msw		
17:17	25	*17:18*	End Excn 3-3 *(No-D)/3*		*1 min late*
17:30	25			Pulmonary function; VC	
17:57	25	*17:55*		Doppler 3-3A	
18:30	25		Supper		
18:42	25	*18:44*		Doppler 3-3B	
19:27	25	*19:27*		Doppler 3-3C	
21:30	25		Lights out		

Time min	Depth msw	Actual time	Chamber/Excursion	Experiments	Comments
DIVE DAY 4, 1988 OCTOBER 25					
06:00	25		Wake up divers		
06:45	25		Breakfast		
08:00	25	*08:00*	Begin Excn 4-1 75/22		
08:06	75	*08:06*	Excursion 4-1	Pulmonary function; VC Reaction time	
08:22	75	*08:22*	Ascend to 25 msw		
08:26	25	*08:26*	End Excn 4-1 *(No-D)/4*		
09:11	25	*09:12*		Dopler 4-1A	
09:45	25		Lunch		
09:56		*10:01*		Doppler 4-1B	
10:41	25	*10:47*		Doppler 4-1C	
11:00	25	*11:03*	Begin Excn 4-2 50/131		*3 min late*
11:03	50	*11:05*	Excursion 4-2	EEG; Reaction time	*2 min late*
13:11	50	*13:11*	Ascend to 25 msw		
13:13	25	*13:14*	*End Excn 4-2 (No-D)/2*	*1 min late*	
13:53	25	*13:53*		Doppler 4-2A	
14:00	25		Tea		
14:38	25	*14:40*		Doppler 4-2B	
15:20	25	*15:26*		Doppler 4-2C	
16:00	25		Begin Excn 4-3 75/25		*Suunto*
16:05	75	*16:04*	Excursion 4-3	Pulmonary function; VC	*1 min fast*
16:25	75	*16:25*	Ascend to 28 msw		
16:31	28	*16:30*	Ascend to 25 msw		*1 min fast*
16:31	25	*16:32*	End Excn 4-3 *(Dt=6)*		
17:11	25	*17:11*		Doppler 4-3A	
17:56	25	*17:59*		Doppler 4-3B	
18:30	25		Supper		
18:41	25	*18:44*		Doppler 4-3C	
19:00	25			Pulmonary function; VC	
		19:30			*Doctors visit divers (WS, ZXR, YHC)*
21:30	25		Lights out		

Time min	Depth msw	Actual time	Chamber/Excursion	Experiments	Comments
DIVE DAY 5, 1988 OCTOBER 26					
06:00	25		Wake up divers		
06:45	25		Breakfast		
08:00	25	*08:00*	Begin Excn 5-1 50/133		*Suunto*
08:03	50	*08:03*	Excursion 5-1	EEG; Reaction time	
08:30	50			Work load	
10:13	50	*10:13*	Ascend to 25 msw		
10:16	25	*10:16*	End Excn 5-1 *(No-D)/3*		
10:56	25	*11:01*		Doppler 5-1A	
11:00	25		Lunch		
		11:25		Pulmonary blood flow	
11:41	25	*11:48*		Doppler 5-1B	
12:26	25	*12:31*		Doppler 5-1C	
13:10	25			Pulmonary function; VC	
16:30	25	*16:30*	Begin Excn 5-2 75/20		
16:35	75	*16:35*	Excursion 5-2	Pulmonary function; Reaction time; Pulmonary blood flow	*PBF not done here*
16:50	75	*16:50*	Ascend to 25 msw		
16:54	25	*16:55*	End Excn 5-2 *(No-D)/4*		*1 min late*
17:30	25		Supper		
17:34	25	*17:40*		Doppler 5-2A	
18:19	25	*18:30*		Doppler 5-2B; PBF	*PBF done 19:30*
19:04	25	*19:07*		Doppler 5-2C	
19:20	25	*19:30*		Pulmonary blood flow	
20:00	25		Begin switch to air		
21:00	25	*21:00*	Begin Excn 5-3 50/63		
21:03	50	*21:03*	Excursion 5-3		*Reset Auto Control to air*
22:03	50	*22:03*	Ascend to 25 msw		
22:07	25	*22:08*	Recompress to 40 msw		*1 min late* *Auto Control from here on*
22:09	40	*22:10*	Begin precursory decomp		
22:15	40		Tea		
22:29	40	*22:40*		Doppler 5-3A	
22:38	40	*22:38*	Ascend to 39 msw		
22:49	39	*23:06*		Doppler 5-3B	
23:07	39	*23:07*	Ascend to 38 msw		
23:09	38	*23:33*		Doppler 5-3C	
23:36	38	*23:36*	Ascend to 37 msw		
24:00	37		Lights out		

DIVE DAY 6, 1988 OCTOBER 27--DECOMPRESSION

Time min	Depth msw	Actual time	Chamber/Excursion	Experiments	Comments
00:05	37		Ascend to 36 msw		
00:34	36		Ascend to 35 msw		
01:13	35		Ascend to 34 msw		*Computer off*
01:53	34		Ascend to 33 msw		
02:32	33		Ascend to 32 msw		*Computer on again*
03:11	32		Ascend to 31 msw		
03:50	31		Ascend to 30 msw		
04:29	30		Ascend to 29 msw		
05:08	29		Ascend to 28 msw		
05:47	28		Ascend to 27 msw		
06:26	27		Ascend to 26 msw		
07:00	27		Wake up divers		
07:05	26		Ascend to 25 msw		
07:05	25			Pulmonary function	
07:45	25		Breakfast		
08:08	25	*08:07*	Ascend to 24 msw		
08:30	24	*08:30*		Pulmonary blood flow	
09:14	24	*09:14*	Ascend to 23 msw		
09:15	23	*09:17*		Doppler 6-1	
09:30	23			EEG; Reaction time	
10:21	23	*10:21*	Ascend to 22 msw		
11:30	22	*11:30*	Ascend to 21 msw		
11:30	21		Lunch		
12:42	21	*12:42*	Ascend to 20 msw		
12:43	20	*12:43*		Doppler 6-2	
13:56	20	*13:56*	Ascend to 19 msw		
15:00	19	*15:00*		Pulmonary blood flow	
15:12	19	*15:12*	Ascend to 18 msw		
16:31	18	*16:32*	Ascend to 17 msw		
16:32	17	*16:12*		Doppler 6-3	
17:30	17		Supper		
17:53	17	*17:53*	Ascend to 16 msw		
19:18	16	*19:18*	Ascend to 15 msw	Pulmonary function	
20:47	15	*20:48*	Ascend to 14 msw		
20:48	14	*20:46*		Doppler 6-4	
21:00	14		Tea		
22:00	14		Lights out		
22:20	14	*22:20*	Ascend to 13 msw		
23:56	13	*23:56*	Ascend to 12 msw		

DIVE DAY 7, 1988 OCTOBER 28--DECOMPRESSION

Time min	Depth msw	Actual time	Chamber/Excursion	Experiments	Comments
01:37	12		Ascend to 11 msw		
03:22	11		Ascend to 10 msw		
05:13	10		Ascend to 09 msw		
07:00	09		Wake up divers		
07:09	09	*07:09*	Ascend to 08 msw	Pulmonary function	
07:45	08		Breakfast		
09:12	08	*09:12*	Ascend to 07 msw		
09:13	07	*09:15*		Doppler 7-1	
09:30	07			EEG; Reaction time	
11:22	07	*11:22*	Ascend to 06 msw		
11:30	06		Lunch		
13:00	06	*13:04*		Doppler 7-2	
13:40	06		Ascend to 05 msw		
16:07	05		Ascend to 04 msw		
16:08	04	*16:07*		Doppler 7-3	
17:30	04		Supper		
		18:15		Pulmonary blood flow	
18:46	04		Ascend to 03 msw		
18:46	03			Pulmonary function	
20:40	03	*20:37*		Doppler 7-4	
21:00	03		Tea		
21:36	03		Ascend to 02 msw		
22:00	02		Lights out		

Time min	Depth msw	Actual time	Chamber/Excursion	Experiments	Comments

DIVE DAY 8, SATURDAY 1988 OCTOBER 29--DECOMPRESSION; POSTDIVE STUDIES

00:39	02		Ascend to 01 msw		
03:59	01		Ascend to surface; divers remain asleep		
07:00	00		Wake up divers; divers stay in chamber		
07:10	00	*06:21*		Doppler 8-1	
07:30	00		Divers leave chamber		
07:45	00		Breakfast		
09:30	00	*10:00*		Doppler 8-2	
09:45		*09:45*			*Pulmonary blood flow*
11:30	00		Lunch		
12:30	00	*12:40*		Doppler 8-3	
14:00	00		"Results" meeting:	Investigators and divers	
16:00	00	*16:12*		Doppler 8-4	

Time min	Depth msw	Actual time	Chamber	Experiments	Comments

POSTDIVE DAY 1, SATURDAY 1988 OCTOBER 30--POSTDIVE STUDIES

08:30	00	*09:11*		EEG; Reaction time	*Doppler 9-1*
10:00	00			Pulmonary function	
10:30	00	*09:45*		Pulmonary blood flow; EEG	*Doppler 9-2*
13:10	00	*10:50*		Work load	

APPENDIX B.

CHISAT I TABLE AND BASECASE

The calculation of the excursions was made on the entire "bottom" phase of the exposure as a single "dive." The Chisat excursions were done with DCAP, version 5.506, using the same criteria as were used for the Repex excursion tables. Therefore, Chisat tested the algorithm rather than just the Repex tables.

The table which follows shows 5 columns of data, a comment section, and another data column. The first column gives the depth of the current stop in msw (1 msw = 0.1 bar or 10^4 Pa). The second column is stop time, the time in minutes spent at the stop; it does not include travel time. That is, the time shown is the time to be spent at the stop or at "bottom" on an excursion. The third column gives the time the stop is departed, as time of day. The next column is the name of the gas mixture, and the fifth is the PO_2 calculated at the depth of the stop. The comments are more or less self-explanatory. The CPTD (OTU) column gives the day's accumulated oxygen tolerance units at the end of the stop.

The table is essentially as produced by DCAP. Daily totals were inserted with a word processor. The word processor was also used to change the month in the daily dates from a number to alpha characters and to add the dive day number.

Following the 3-page table is the Basecase D87AN1.Y00, which was used to produce the table.

CHISAT I 25 MSW SATURATION-EXCN.

STORAGE DEPTH 25 MSW
SATURATION MIX NITROX
EXCURSION MIX AIR

RWH/YCL/ZYS 88Aug25
D87AN1.Y00

HABITAT PO2 0.32-0.33 ATM

DEPTH MSW	STOP TIME	CLOCK TIME HR:MIN	MIXTURE	PO2 ATM	COMMENTS	CPTD
00	00	00:00	AIR	0.21	ALL ASCENTS AND DESCENTS AT 10 MSW/MIN.	
					HABITAT ATMOSPHERE PO2 = 0.32-0.33.	
					TRAVEL TIME NOT INCLUDED IN STOP TIME.	00
	00	00:00	AIR	0.21	BREATHE AIR ON ALL EXCURSIONS.	
					DAY 22 OCT 88 (DIVE DAY 1)	
	00	00:00	AIR	0.21	START COMPRESSION	00
	00	00:00	AIR	0.21	ADJUST ATMOSPHERE TO PO2 = 0.32-0.33 ATM.	00
25	478	08:00	.32_PO2	0.32	REMAIN IN HABITAT FOR 480 MIN	00
					BEGIN EXCURSION 1-1	00
60	40	08:43	AIR	1.47	EXCURSION 1-1: 60 MSW FOR 40 MIN	73
25	00	08:46	.32_PO2	0.32	RETURN TO HABITAT	
	164	11:30	.32_PO2	0.32	BEGIN EXCURSION 1-2	77
60	240	15:34	AIR	1.47	EXCURSION 1-2: 60 MSW FOR 240 MIN	493
37	04	15:40	AIR	0.99		500
34	22	16:03	AIR	0.92		519
31	33	16:36	AIR	0.86		544
28	54	17:30	AIR	0.80		578
25	00	17:30	.32_PO2	0.32	RETURN TO HABITAT OVERNIGHT	
					----------------------------TOTAL CPTD :	578
					DAY 23 OCT 88 (DIVE DAY 2)	
	870	08:00	.32_PO2	0.32	BEGIN EXCURSION 2-1	00
70	30	08:35	AIR	1.68	EXCURSION 2-1: 70 MSW FOR 30 MIN	67
28	03	08:42	AIR	0.80		74
25	00	08:42	.32_PO2	0.32	RETURN TO HABITAT	
						74
	108	10:30	.32_PO2	0.32	BEGIN EXCURSION 2-2	74
50	240	14:33	AIR	1.26	EXCURSION 2-2: 50 MSW FOR 240 MIN	413
28	32	15:07	AIR	0.80		435
25	00	15:07	.32_PO2	0.32	RETURN TO HABITAT	
						435
	233	19:00	.32_PO2	0.32	BEGIN EXCURSION 2-3	435
65	30	19:35	AIR	1.58	EXCURSION 2-3: 65 MSW FOR 30 MIN	497
25	00	19:38	.32_PO2	0.32	RETURN TO HABITAT	
						501
	142	22:00	.32_PO2	0.32	BEGIN EXCURSION 2-4	501
60	60	23:04	AIR	1.47	EXCURSION 4: 60 MSW FOR 60 MINS	609
28	06	23:13	AIR	0.80		616
25	00	23:14	.32_PO2	0.32	RETURN TO HABITAT OVERNIGHT	
					----------------------------TOTAL CPTD :	1194

CHISAT I 25 MSW SATURATION-EXCN.

DEPTH MSW	STOP TIME	CLOCK TIME HR:MIN	MIXTURE	PO2 ATM	COMMENTS	CPTD
					DAY 24 OCT 88 (DIVE DAY 3)	
	526	08:00	.32_PO2	0.32	BEGIN EXCURSION 3-1	00
50	240	12:02	AIR	1.26	EXCURSION 3-1: 50 MSW FOR 240 MIN	338
28	20	12:24	AIR	0.80		353
25	00	12:25	.32_PO2	0.32	RETURN TO HABITAT	
						353
	95	14:00	.32_PO2	0.32	BEGIN EXCURSION 3-2	353
60	40	14:43	AIR	1.47	EXCURSION 2-2: 60 MSW FOR 40 MIN	426
25	00	14:46	.32_PO2	0.32	RETURN TO HABITAT	
						430
	104	16:30	.32_PO2	0.32	BEGIN EXCURSION 3-3	430
60	40	17:14	AIR	1.47	EXCURSION 3-3: 60 MSW FOR 40 MIN	503
25	00	17:17	.32_PO2	0.32	RETURN TO HABITAT OVERNIGHT	
					----------------------------TOTAL CPTD :	1701
					DAY 25 OCT 88 (DIVE DAY 4)	
	883	08:00	.32_PO2	0.32	BEGIN EXCURSION 4-1	00
75	16	08:22	AIR	1.79	EXCURSION 4-1: 75 MSW FOR 16 MIN	42
25	00	08:26	.32_PO2	0.32	RETURN TO HABITAT	
						49
	154	11:00	.32_PO2	0.32	BEGIN EXCURSION 4-2	49
50	128	13:11	AIR	1.26	EXCURSION 4-2: 50 MSW FOR 128 MIN	230
25	00	13:13	.32_PO2	0.32	RETURN TO HABITAT	
						233
	167	16:00	.32_PO2	0.32	BEGIN EXCURSION 4-3	233
75	20	16:25	AIR	1.79	EXCURSION 4-3: 75 MSW FOR 20 MIN	283
28	01	16:31	AIR	0.80		291
25	00	16:31	.32_PO2	0.32	RETURN TO HABITAT OVERNIGHT	
					----------------------------TOTAL CPTD :	1992
					DAY 26 OCT 88 (DIVE DAY 5)	
	929	08:00	.32_PO2	0.32	BEGIN EXCURSION 5-1	00
50	130	10:13	AIR	1.26	EXCURSION 5-1: 50 MSW FOR 130 MIN	184
25	00	10:16	.32_PO2	0.32	RETURN TO HABITAT	
						187
	374	16:30	.32_PO2	0.32	BEGIN EXCURSION 5-2	187
75	15	16:50	AIR	1.79	EXCURSION 5-2: 75 MSW FOR 15 MIN	226
25	00	16:54	.32_PO2	0.32	RETURN TO HABITAT	
						233
	186	20:00	AIR	0.74	MAIN CHAMBER SWITCH TO AIR(ADD O2) @20:00	329
	60	21:00	AIR	0.74	BEGIN EXCURSION 5-3	360
50	60	22:03	AIR	1.26	EXCURSION 5-3: 50 MSW FOR 60 MIN	446
25	02	22:07	AIR	0.74	RECOMPRESS TO 40 MSW QUICKLY	
						450
					------------------------------TOTAL CPTD :	2442

CHISAT I 25 MSW SATURATION-EXCN.

DEPTH MSW	STOP TIME	CLOCK TIME HR:MIN	MIXTURE	PO2 ATM	COMMENTS	CPTD
40	00	22:09	AIR	1.05	BEGIN PRECURSORY DECOMPRESSION	01
	29	22:38	AIR	1.05		32
39	29	23:07	AIR	1.03		62
38	29	23:36	AIR	1.01		91
					DAY 27 OCT 88 (DIVE DAY 6)	
37	29	00:05	AIR	0.99		119
36	29	00:34	AIR	0.97		146
35	39	01:13	AIR	0.95		181
34	39	01:53	AIR	0.92		214
33	39	02:32	AIR	0.90		246
32	39	03:11	AIR	0.88		277
31	39	03:50	AIR	0.86		306
30	39	04:29	AIR	0.84		334
29	39	05:08	AIR	0.82		360
28	39	05:47	AIR	0.80		385
27	39	06:26	AIR	0.78		408
26	39	07:05	AIR	0.76		429
25	63	08:08	AIR	0.74	START MAIN SATURATION DECOMPRESSION	462
24	65	09:14	AIR	0.71		493
23	67	10:21	AIR	0.69		522
22	69	11:30	AIR	0.67		549
21	72	12:42	AIR	0.65		574
20	74	13:56	AIR	0.63		597
19	76	15:12	AIR	0.61		617
18	79	16:31	AIR	0.59		634
17	82	17:53	AIR	0.57		647
16	85	19:18	AIR	0.55		657
15	89	20:47	AIR	0.52		661
14	92	22:20	AIR	0.50		661
13	96	23:56	AIR	0.48		661
					DAY 28 OCT 88 (DIVE DAY 7)	
12	101	01:37	AIR	0.46		661
11	105	03:22	AIR	0.44		661
10	111	05:13	AIR	0.42		661
09	116	07:09	AIR	0.40		661
08	123	09:12	AIR	0.38		661
07	130	11:22	AIR	0.36		661
06	138	13:40	AIR	0.34		661
05	147	16:07	AIR	0.32		661
04	158	18:46	AIR	0.29		661
03	170	21:36	AIR	0.27		661
					DAY 29 OCT 88 (DIVE DAY 8)	
02	183	00:39	AIR	0.25		661
01	200	03:59	AIR	0.23		661
00	00	03:59	AIR	0.21	AT SURFACE	661

TOTAL TIME = 171 HRS 59 MINS
DECOM TIME = 53 HRS 50 MINS
TOTAL CPTD = 3103

```
DCAP VERSION 5.506 87Jun12 RUN ON 88Aug25    AT 13:53:54

 BASE.CASE  D87AN1.Y00
C           <----------------------51------------------------>
 REVISION   25 MSW REPEX TYPE, FULL REPEX ALGORITHM, 5-DAY SAT
            WITH EXCNS.  DEVELOPMENT OF METRIC PARAMETERS.
            EXCNS W/STOPS; FULL STRESS, O2 ABOVE REPEX LIMITS.
C
 SET        FILE=IN08M1.DCP
            TITLE=CHISAT I 25 MSW SATURATION-EXCN.
            AUTHOR=RWH/YCL/ZYS
            TIME.HEADING=5
            STOP.TIME.INCR=1
            BOTTOM.MIX=2
            CPTD.PRINT=ON
            STORAGE.DEPTH=25
            SATURATION_MIX=3
 NOTEBOOK   FILE=NBCHISAT.DCP
C
 MATRIX     FILE=MM0805.DCP
 DB=21 BASE=57.2  50.0  42.4  38.4  35.6  33.8  32.4  31.7
 DS=21 SLOPE= 1    1     1     1     1     1     1     1
 DB=0 BASE= 23.6  19.5  16.1  13.2  11.9  11.1  11.0  10.7
 DS=0 SLOPE=1.60  1.45  1.25  1.20  1.13  1.08  1.02  1.00
C              <--8--->
 MIX        1=BELLMIX
            2=AIR O2=21 % N2=100 BALANCE%
            3=.32_PO2 O2=0.32 ATM N2=100 BALANCE%
C             <------------------40------------------>
 COMMENT    FILE=CMTM00.DCP
C
C        BEGIN DIVE DAY 1     1988 OCT 22
C
 POSITION   DEPTH=0 STOP=0 MIX=2 COMMENT=22 2.COM=25 3.COM=31
            COMMENT=33 2.COM=40 3.COM=23
 SET        DAY=1088:22
            CLOCK=0:00
 POSITION   DEPTH=0 TRAVEL=0 STOP=0 RATE=10 MIX=2 COMMENT=20
 POSITION   DEPTH=0 COMMENT=38 2.COM=40
 POSITION   DEPTH=25 CLOCK.STOP=8:00 MIX=3 COMMENT=27 2.COM=21
C
 POSITION   DEPTH=60 STOP=40 MIX=2 COMMENT=28
 DECOMPRESS DEPTH=25
 POSITION   DEPTH=25 MIX=3 COMMENT=35 2.COM=40
C
 POSITION   DEPTH=25 CLOCK.STOP=11:30 COMMENT=21
 POSITION   DEPTH=60 STOP=240 MIX=2 COMMENT=29
 DECOMPRESS DEPTH=25
 POSITION   DEPTH=25 MIX=3 COMMENT=26 2.COM=40 3.COM=23
C
C        BEGIN DIVE DAY 2     1988 OCT 23
C
 SET        CPTD=0
```

```
 POSITION   DEPTH=25 DAY.STOP=1088:23 CLOCK.STOP=8:00 COMMENT=21
 POSITION   DEPTH=70 STOP=30 MIX=2 COMMENT=28
 DECOMPRESS DEPTH=25
 POSITION   DEPTH=25 MIX=3 COMMENT=35 2.COM=40
 POSITION   DEPTH=25 CLOCK.STOP=10:30 COMMENT=21
 POSITION   DEPTH=50 STOP=240 MIX=2 COMMENT=29
 DECOMPRESS DEPTH=25
 POSITION   DEPTH=25 MIX=3 COMMENT=35 2.COM=40
 POSITION   DEPTH=25 CLOCK.STOP=19:00 COMMENT=21
 POSITION   DEPTH=65 STOP=30 MIX=2 COMMENT=32
 DECOMPRESS DEPTH=25
 POSITION   DEPTH=25 MIX=3 COMMENT=35 2.COM=40
 POSITION   DEPTH=25 CLOCK.STOP=22:00 MIX=3 COMMENT=21
 POSITION   DEPTH=60 STOP=60 MIX=2 COMMENT=36
 DECOMPRESS DEPTH=25
 POSITION   DEPTH=25 MIX=3 COMMENT=26 2.COM=40 3.COM=23
C
C        BEGIN DIVE DAY 3     1988 OCT 24
C
 SET        CPTD=0
 POSITION   DEPTH=25 DAY.STOP=1088:24 CLOCK.STOP=8:00 COMMENT=21
 POSITION   DEPTH=50 STOP=240 MIX=2 COMMENT=28
 DECOMPRESS DEPTH=25
 POSITION   DEPTH=25 MIX=3 COMMENT=35 2.COM=40
 POSITION   DEPTH=25 CLOCK.STOP=14:00 COMMENT=21
 POSITION   DEPTH=60 STOP=40 MIX=2 COMMENT=29
 DECOMPRESS DEPTH=25
 POSITION   DEPTH=25 MIX=3 COMMENT=35 2.COM=40
 POSITION   DEPTH=25 CLOCK.STOP=16:30 COMMENT=21
 POSITION   DEPTH=60 STOP=40 MIX=2 COMMENT=32
 DECOMPRESS DEPTH=25
 POSITION   DEPTH=25 MIX=3 COMMENT=26 2.COM=40 3.COM=23
C
C        BEGIN DIVE DAY 4    1988 OCT 25
C
 SET        CPTD=0
 POSITION   DEPTH=25 DAY.STOP= 1088:25 CLOCK.STOP=08:00 COMMENT=21
 POSITION   DEPTH=75 STOP=16 MIX=2 COMMENT=28
 DECOMPRESS DEPTH=25
 POSITION   DEPTH=25 MIX=3 COMMENT=35 2.COM=40
 POSITION   DEPTH=25 CLOCK.STOP=11:00 COMMENT=21
 POSITION   DEPTH=50 STOP=128 MIX=2 COMMENT=29
 DECOMPRESS DEPTH=25
 POSITION   DEPTH=25 MIX=3 COMMENT=35 2.COM=40
 POSITION   DEPTH=25 CLOCK.STOP=16:00 COMMENT=21
 POSITION   DEPTH=75 STOP=20 MIX=2 COMMENT=32
 DECOMPRESS DEPTH=25
 POSITION   DEPTH=25 MIX=3 COMMENT=26 2.COM=40 3.COM=23
C
C        BEGIN DIVE DAY 5  1988 OCT 26
C
 SET        CPTD=0
 POSITION   DEPTH=25 DAY.STOP= 1088:26 CLOCK.STOP=8:00 COMMENT=21
```

```
 POSITION   DEPTH=50 STOP=130 MIX=2 COMMENT=28
 DECOMPRESS DEPTH=25
 POSITION   DEPTH=25 MIX=3 COMMENT=35 2.COM=40
 POSITION   DEPTH=25 CLOCK.STOP=16:30 COMMENT=21
 POSITION   DEPTH=75 STOP=15 MIX=2 COMMENT=29
 DECOMPRESS DEPTH=25
 POSITION   DEPTH=25 MIX=3 COMMENT=35 2.COM=40
 POSITION   DEPTH=25 CLOCK.STOP=20:00 MIX=2 COMMENT=39
 POSITION   DEPTH=25 CLOCK.STOP=21:00 COMMENT=21
 POSITION   DEPTH=50 MIX=2 STOP=60 COMMENT=32
 POSITION   DEPTH=25 STOP=2 MIX=2 COMMENT=37 2.COM=40
C
C  BEGIN PRECURSORY DECOMPRESSION
C
 SET        CPTD=0
 POSITION   DEPTH=40 STOP=0 MIX=2 COMMENT=24
 DECOMPRESS DEPTH=40
 POSITION   DEPTH=40 STOP=29
 DECOMPRESS DEPTH=39
 POSITION   DEPTH=39 STOP=29
 DECOMPRESS DEPTH=38
 POSITION   DEPTH=38 STOP=29
 DECOMPRESS DEPTH=37
 POSITION   DEPTH=37 STOP=29
 DECOMPRESS DEPTH=36
 POSITION   DEPTH=36 STOP=29
 DECOMPRESS DEPTH=35
 POSITION   DEPTH=35 STOP=39
 DECOMPRESS DEPTH=34
 POSITION   DEPTH=34 STOP=39
 DECOMPRESS DEPTH=33
 POSITION   DEPTH=33 STOP=39
 DECOMPRESS DEPTH=32
 POSITION   DEPTH=32 STOP=39
 DECOMPRESS DEPTH=31
 POSITION   DEPTH=31 STOP=39
 DECOMPRESS DEPTH=30
 POSITION   DEPTH=30 STOP=39
 DECOMPRESS DEPTH=29
 POSITION   DEPTH=29 STOP=39
 DECOMPRESS DEPTH=28
 POSITION   DEPTH=28 STOP=39
 DECOMPRESS DEPTH=27
 POSITION   DEPTH=27 STOP=39
 DECOMPRESS DEPTH=26
 POSITION   DEPTH=26 STOP=39
 DECOMPRESS DEPTH=25
 POSITION   DEPTH=25 STOP=63 COMMENT=30 2.COM=40
 DECOMPRESS DEPTH=24
 POSITION   DEPTH=24 STOP=65
 DECOMPRESS DEPTH=23
 POSITION   DEPTH=23 STOP=67
 DECOMPRESS DEPTH=22
```

```
 POSITION   DEPTH=22 STOP=69
 DECOMPRESS DEPTH=21
 POSITION   DEPTH=21 STOP=72
 POSITION   DEPTH=20 STOP=74
 POSITION   DEPTH=19 STOP=76
 POSITION   DEPTH=18 STOP=79
 POSITION   DEPTH=17 STOP=82
 POSITION   DEPTH=16 STOP=85
 POSITION   DEPTH=15 STOP=89
 POSITION   DEPTH=14 STOP=92
 POSITION   DEPTH=13 STOP=96
 POSITION   DEPTH=12 STOP=101
 POSITION   DEPTH=11 STOP=105
 POSITION   DEPTH=10 STOP=111
 POSITION   DEPTH=9  STOP=116
 POSITION   DEPTH=8  STOP=123
 POSITION   DEPTH=7  STOP=130
 POSITION   DEPTH=6  STOP=138
 POSITION   DEPTH=5  STOP=147
 POSITION   DEPTH=4  STOP=158
 POSITION   DEPTH=3  STOP=170
 POSITION   DEPTH=2  STOP=183
 POSITION   DEPTH=1  STOP=200
 POSITION   DEPTH=0  COMMENT=34
C
 END
```

APPENDIX C.

EVALUATION OF THE SUUNTO DIVE COMPUTER AS A DIVE LOGGER IN HABITAT DIVING

A. Introduction

The Suunto SME/ML dive computer (DC) is designed to assist a recreational diver in the decompression aspects of no-stop and multi-level diving. It also has a unique feature in that it can act as a dive recorder, recording and storing in its memory the last 10 hours of diving time. It stores the deepest depth encountered over every 3-min interval. This can be recalled on its display, from which it can be copied (by hand) into a diver's logbook.

We wanted in Chisat 1 to evaluate the SME/ML for recording laboratory and professional diving activities. We put the Suunto SME/ML dive computer (DC) into the chamber during several excursions to evaluate its ability to log deep excursion dives. The coverage was much less than we had hoped, because during the period when we might have been doing training and making measurements we were more concerned with problems with the doppler ultrasound device.

The depth conversions used here are rounded according to Suunto/Sea Quest literature and are not necessarily exact.

B. Methods

1. Relevant characteristics

The DC has to be activated before a dive by touching a pair of external contacts, and has to be kept wet during the pressure phase. A pressure of 2 msw (5 fsw) will start a dive. The DC stops computing a dive when taken deeper than 57 msw (190 fsw) or when more than one-half hour of decompression is needed, at which time it goes into "error mode." In error mode it continues to provide depth and time information but it no longer calculates decompression; it will read to 70 msw (230 fsw).

The unit normally initializes at the ambient pressure when it is turned on. However, we could not use the storage depth of 25 msw (82 fsw) as the "surface" because the range of the unit's surface initialization is not great enough.

2. Procedure

The procedures for use in Chisat were as follows.

(1). Before the first excursion Topside activates the dive computer and places it in a teacup full of water.

(2). The cup with the DC is locked into the chamber through the food lock about one-half hr before its first excursion.

(3). The divers take the cup into the igloo chamber with them. On return to storage depth they remove the DC from the cup. That is, when the divers are simulating a dive the unit should be in the cup, and when they are at storage depth the unit should be dry. The DC should stay with the divers as they move between chambers.

(4). When the divers go into the wet chamber for the next excursion they put the unit back in the cup of water and take it into the wet chamber.

(5). After the last excursion of the day the DC is locked out.

Before each day's use the dive computer (DC) should be clear. If it is operating (it will be if it still has gas from the day before) it should be restarted by removing and reinserting the battery.

The excursions for the day will be recalled and copied at the end of the day. Recall is started by a special procedure of touching the contacts for 3 sec (3 flashes of the little airplane), releasing for 3 sec, then touching for 3 sec again. If done correctly, after 5 sec the word "stop" appears. Within 15 seconds after the word stop appears the contacts are touched again to start the scrolling. The display gives depth and time in the upper two displays for each 3-min period, for up to 10 hr or 200 3-min periods. These should be copied. The display starts with the first dive.

3. Methods used in Chisat

The original plan was to put the DC in the chamber in the morning and keep it in until the end of the day, or take it out early if the diving day exceeded 10 hr. Problems with other equipment diverted our attention during the first two days, and we were unable to try the DC.

We were able to put it in on the 3rd dive day. The unit was activated and locked into the chamber at 25 msw (82 fsw) a few minutes before the first excursion (3-1), which was to 50 msw (163 fsw) for 242 min. It was immersed in water during the bottom time, then taken out after the divers reached storage depth; it was wet when they would have been wet. Shortly after the first dive the unit was removed from the water and locked out.

On the 4th dive day the unit was used for a 75 msw (244 fsw)/25 min dive in the same manner. Again only one dive was recorded. Because there was still gas loading from the earlier dives we reset the DC by opening the case and loosening a battery momentarily.

On Dive Day 5 the process was repeated for Excursion 5-1.

C. Results

From the 50/240 dive we were able to recover a suitable profile covering the 240 min bottom time and the first decompression stop at 28 msw (Figure C-1). However, at the end of the first stop after decompression to 25 msw the recording stopped and no further recording was done. It could have stopped because the DC was taken out of water, or it could have stopped because the gas loading at that point put it into error mode.

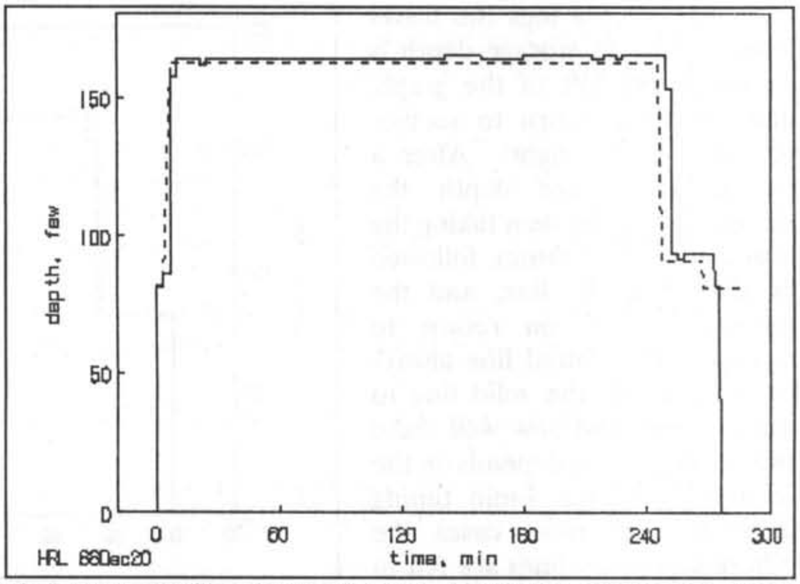


Figure C-1. Profile of Excursion 3-1. Dotted line is chamber track, and solid line is Suunto SME-ML log.

Following the second dive 4-3 for 75msw (244fsw)/25min we recovered the profile shown in Figure C-2. The profile in Figure C-3 was recovered after Excursion 5-1, 50msw (163fsw)/133min.

Following dive 4-3 the instrument was clearly not behaving properly. It would not cycle no-d times, the airplane was appearing for various times on what appeared to be a random basis, and we were unable to get it into the recall mode. Some moisture got into the case, but we could not tell if this had anything to do with the problems; after the battery was loosened to reset the computer it began to work normally.

The figures all show the same characteristics. The actual pressure profile (in fsw) as near as we could reconstruct it is shown by dotted lines, and the profile recovered from the SME-ML is shown as a solid line.

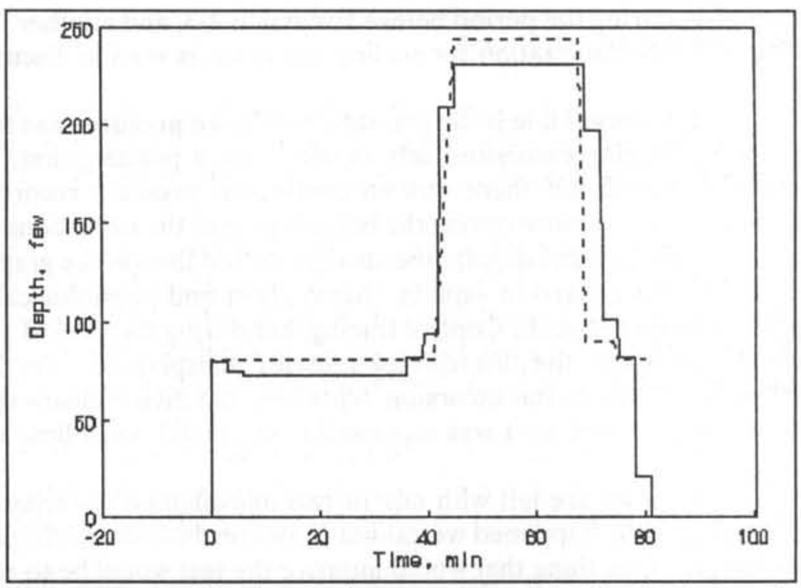


Figure C-2. Profile of Excursion 4-3. Dotted line is chamber track, and solid line is SME-ML log.

D. Discussion

In all the logs the travel from surface to storage depth is shown at the left of the graph, and the final return to surface pressure at the right. After a period at storage depth the dotted line can be seen taking the chamber to the bottom, followed by the SME-ML line, and the reverse is true on return to storage. The dotted line always has to precede the solid line to some extent, and how well these two are registered depends on the sequencing of the 3-min timing intervals. In most cases the differences in the lines are felt to be due to this relationship.

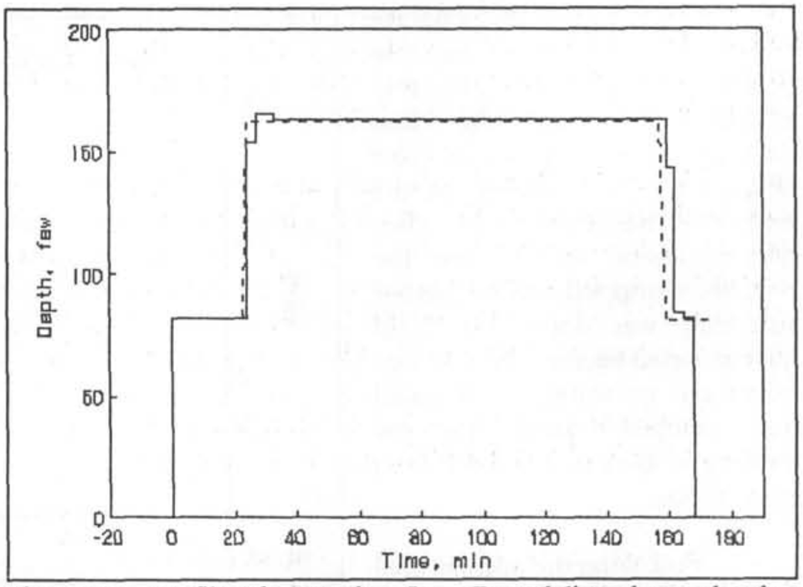


Figure C-3. Profile of Excursion 5-1. Dotted line shows chamber track, and solid line shows SME-ML log.

In other cases there seem to be discrepancies. In Excursion 3-1 the beginning and bottom time seem all right, but on the main decompression the lines seem to be 5 or 6 min apart, perhaps too much to be explained by the registration (however the decompression was logged as being 1 min early); it is a question as to which log was the one that varied if in fact a variation exists. There is also a 9 fsw pressure deviation during the period before Excursion 4-3, and another one at the bottom of that same dive. The initial pressurization for sealing the hatch is seen in Excursions 3-1 and 4-3.

The dotted line is the pressure profile we **presume** was followed. The nature of the pressure recording during excursions left us with only a presumption; deviations from the schedule were normally noted, but there was no continuous pressure recording except for the living chamber. Deviations in pressure during the bottom time of the excursions are likely to have actually happened (due to dive activity) despite the straight dotted line on the graph. The period in the habitat before excursion 4-3 is hard to explain. Many short and physiologically insignificant pressure deviations are shown on the Auto Control tracing, but during the period 1520 to 1600 on Day 4 no deviations can be seen and the discrepancy remains unexplained. On the other hand the reason for the difference between the excursion depths on that dive is clear—the instrument reached its maximum depth of msw and, as it was supposed to do, it did not follow any deeper.

Thus we are left with one or two unexplained discrepancies, but without better knowledge of what actually happened we cannot draw conclusions except perhaps to criticize the experimental technique. One thing that would improve the test would be to read the DC display periodically and compare it with the chamber pressure.

For purposes of recording pressure exposures for assessment of decompression, 3 min should be considered the outside limit of acceptable precision. It is a great deal better than a diver's recollection, however, and in this context it is acceptable. In fact, the "registration" errors tend to offset each other if each dive has a descent and an ascent (let's hope they all do). The use of the deepest point attained during each 3-min period is not the best choice; a weighted mean or even simple arithmetic mean would be better. The deepest point is more satisfying to the macho diver logging his exploits, but it will always overestimate the pressure exposure. This effect would be much worse in random depth dives than in these that are relatively "square."

The SME-ML is clearly useful as a dive logger. It is not ideal for the habitat diving situation because the range at which it will initialize is not great enough to allow it to be used in the normal way for excursions from a habitat. It is not expected to calculate the excursions correctly. It is a tedious task to copy down the steps, and on occasion it may be impossible to recover the profile. SME-ML's have been used by Dr. Carolyn Fife for logging on an archaeological project offshore Turkey covering over 5000 dives, with good success but with the problems mentioned (1990).

Incidentally, Suunto and other manufacturers are now marketing recreational dive computers that can download dive logs to a personal computer.

Our thanks to Sea Quest for the use of the Suunto SME-ML, especially to Ron Coley, and to Ari Nikkola of Suunto for detailed information on the SME-ML.

E. Reference

Fife C. 1989 Oct 13. Doppler monitoring at an underwater archaeological site. Presented at Great Lakes Chapter UHMS Workshop on use of doppler bubble detection for dive table testing, Buffalo, NY.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1991 — 281-559 / 20772