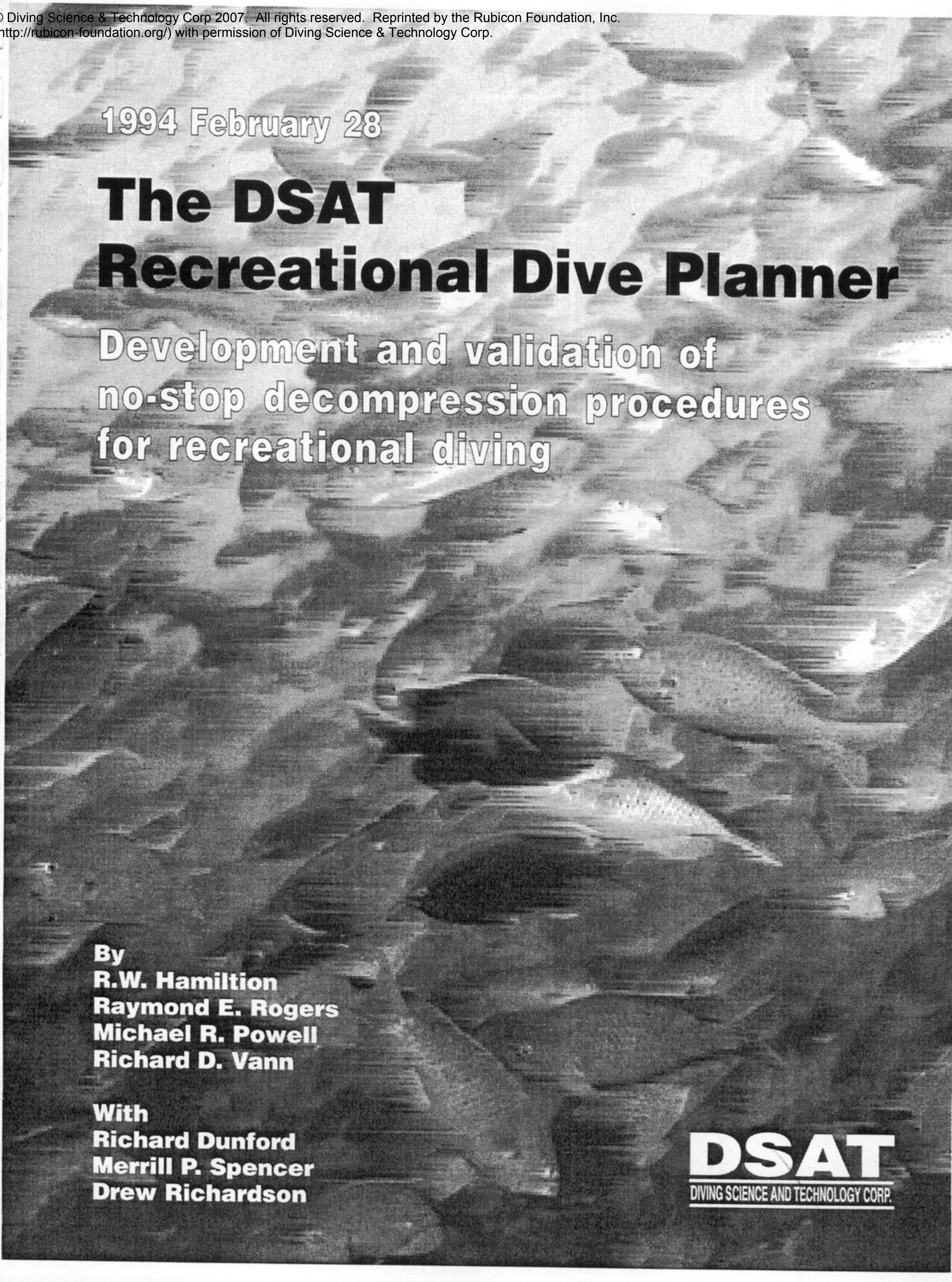

1994 February 28

The DSAT Recreational Dive Planner

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DSAT
DIVING SCIENCE AND TECHNOLOGY CORP.

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PREFACE

As the text occasionally suggests, this document was prepared to disseminate information about the Recreational Dive Planner, developed and tested by Diving Science and Technology, Corp., (DSAT), a corporate affiliate of the Professional Association of Diving Instructors (PADI). This development included the formulation of a computational method for producing new no-stop decompression tables, and it also involved a comprehensive laboratory and open water evaluation program using informed volunteer divers; the primary basis for the evaluation was avoiding the development of decompression sickness, but the diver-subjects were also monitored for circulating bubbles using Doppler ultrasound.

Several early reports were prepared on parts of this evaluation program, but in order to provide a single report covering all phases, DSAT contracted with Hamilton Research, Ltd., to review the available materials and, in collaboration with the original investigators, to produce a comprehensive report. This report covers in detail the development of the method for producing the RDP, and it reports both the methods used for evaluation and the resulting data. Some of the history of the project is included as well. The report did not have as an objective a detailed study of peripheral facets such as the role of gender or age, nor did it intend to examine critically the Doppler techniques themselves; we hope data are reported in enough detail to facilitate such studies by others. Data in electronic form can be made available from DSAT for appropriate collaborative investigations.

The RDP was successful in the field from the beginning, but because it took a new approach to managing decompression in recreational diving it was examined critically by many interested parties; although field results are mentioned, reviewing or evaluating field data was not part of this project.

We are grateful to many who contributed; first to the divers who gave their time and embraced the then-unknown risks. We thank DSAT and PADI for the sponsorship, the Institute of Applied Physiology and Medicine where the dives were done, and the Diver's Alert Network and their volunteer Advisory Board who gave advice and impetus and who supported some of the work. Thanks to Bruce Higgins and Karl Huggins for help in collating old data. We thank David Rogers for computational work, and especially Eileen Whitney for patiently typing and formatting the text with an as-yet-not-bug-free WordPerfect 6.0a, and for printing it on an HP Laser Jet II in a Times Roman 11 point font by IQ Engineering.

A number of different investigators took part, over a period of several years, so it is necessary at times to allocate ideas and effort to individuals; to do this we refer to the authors in the text by their initials.

RWH
Tarrytown, NY
1994 February 28

Prepared by Hamilton Research Ltd., 80 Grove Street, Tarrytown, NY 10591-4138.

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I.
ABSTRACT

Hamilton RW, Rogers RE, Powell MR, Vann RD. 1994. Development and validation of no-stop decompression procedures for recreational diving: The DSAT Recreational Dive Planner. Santa Ana, CA: Diving Science and Technology Corp.

The RDP was developed by adapting the Haldane computational algorithm used by the U.S. Navy to the special needs of recreational divers. We derived no-stop limits for the recreational range of 40 to 130 fsw from Spencer's (1976) empirical data on bubble development in divers detected using Doppler ultrasonics. These times were fitted to a smooth curve having essentially a square root relationship between depth and allowable exposure time. A set of ascent-limiting M-values were "back calculated" from the no-stop limits, and we used these to prepare multilevel dive procedures for the RDP. The RDP took a fresh approach to repetitive diving, using the 60 min compartment instead of the 120 min compartment used for the U.S. Navy tables. Because the RDP diver makes only no-stop dives a shorter half time for repetitive dives is more appropriate and it provides more efficiency. The RDP follows familiar techniques of using "pressure groups" and the decay of residual nitrogen during the surface interval. Because the algorithm was new, it required testing; DSAT was formed as a corporate affiliate of PADI for this purpose. Tests were run at the Institute of Applied Physiology and Medicine in Seattle. Phase I tested repetitive and multilevel dive profiles, based on a single day of diving. A total of 911 individual dives were run, in 437 daily sequences (sets); some were multilevel, 809 were with exercise; a significant portion of these, 228 dives, were open water dives in Puget Sound. Monitoring of intravenous gas bubbles using Doppler ultrasonics and careful examination for symptoms of DCS revealed no DCS symptoms and few bubbles, allowing us to conclude that the RDP is reliable for single days of repetitive and multilevel diving. Uncertainty about the efficacy of basing repetitive dives on the 60 min compartment when used for multiple dives over several days led to another (Phase II) test program. Phase IIa started with 6 dives per day and after only 2 days a case of DCS caused that regime to be abandoned, with the conclusion—based on limited data—that 6 dives per day may be too many. Phase IIb involved 4 dives per day for 6 days; 475 dives were conducted with no DCS, but with more bubbles than were seen in Phase I. Overall we conclude that this program succeeded in developing and validating a new mode of decompression management for recreational diving. The validation programs found no evidence that the special repetitive and multilevel diving procedures developed for the RDP are not reliable, nor did they suggest that they offer any more risk than customary recreational diving practice. From the test results we further conclude that performing multiple dives over multiple days with the RDP is acceptable, and can be done with no greater risk than is encountered in many common practices of recreational divers. Even so, based on this evidence and the suggestions of other experts, we recommend limiting the number of full-time dives per day to 3 or at most 4, and suggest including a day with a reduced level of diving (or none) every 2 or 3 days.

II. INTRODUCTION

This report covers the philosophy, background, development, and validation testing of DSAT's Recreational Dive Planner.

This chapter reviews decompression in general, describes the RDP, discusses testing of decompression tables, and provides some definitions.

The development of the "model" for the RDP is covered in Chapter III, along with a brief history of the development of the U.S. Navy Standard Air Decompression Tables. The two test phases and their results are in Chapters IV and V, and an analysis and discussion of the testing are in Chapters VI and VII. Conclusions regarding the project are given in Chapter VIII. Because it has taken some time to reach this point, the history of the whole project has been included as Chapter IX. A great deal of effort was involved in planning a third phase of testing which was not conducted; the essence of this planning effort is also included in Chapter IX.

A. Objective of this report

This report describes an ongoing development project lasting over nearly a decade that has evolved into a refined decompression concept designed exclusively for recreational diving. Since the invention of self-contained underwater breathing apparatus or *scuba* (now no longer an acronym), recreational divers have based their decompression practice almost exclusively on the venerable Standard Air decompression tables of the United States Navy, the "Navy Tables" (1959; 1991). The USN tables and procedures were not designed with the recreational diver in mind, but they have served that purpose, partly because they work quite well, but also because until recently there have been few acceptable alternatives. However, relative inefficiencies and perhaps a slight amount of unnecessary risk have accompanied the use of the USN tables in recreational diving.

This project has led to the development of a new mode of managing decompression that addresses specifically the needs and diving patterns of recreational divers. This system is known as the RDP (Recreational Dive Planner).

This project involved two major steps, the development of a new computational model or algorithm specifically dedicated to recreational diving, and an extensive testing program. This was the first such integrated program for recreational diving to follow through from the concept of a new model to the validation of the resulting tables. The first phase involved testing a series of multilevel, square (a dive to a constant bottom depth), and repetitive RDP dives, and a second phase extended these types of dives into multiday diving operations. The report has two purposes, first to provide a technical treatise on the development and testing of the model and a quantitative analysis of the results and to place the data in the public record, and second to tell the story of how all this came about.

There have been some earlier reports on aspects of this project (Powell et al, 1988; Powell, 1991; Richardson, 1987).

B. Decompression and table development

1. Decompression and decompression sickness

Before going into detail about a decompression procedure development project it is relevant to review the nature of decompression itself. The term, obviously, means a reduction in pressure, but as used in diving it implies also that the individual has been exposed to excess pressure (above atmospheric pressure) and has absorbed some inert gas, which is **nitrogen** in the case of recreational divers because they use air as the breathing gas. Although effects like narcosis may occur, dissolved gas itself does no lasting harm as long as it remains dissolved. On ascent, however, the reduction of pressure—called "decompression" of course—may cause the gas to come out of solution and form bubbles. It is bubbles (or "free gas phase") and the body's reaction to bubbles that result in the condition known as decompression sickness or DCS. Decompression sickness may vary from mild pain or skin itching to severe pain and neurological and/or sensory deficits; it is a complex disease (Bove and Davis, 1990). Bubbles may be present when there is no overt indication of DCS; the exact significance of asymptomatic bubbles is not known. Bubbles (or more specifically, gas phase) are without a doubt the cause of DCS.

On occasion, fortunately very rarely, a diver has bubbles that escape into the arterial system, a condition known as arterial gas embolism. This may be caused by any of several physiological or exposure conditions. When embolism of the brain or spinal cord occurs it usually results in neurological and sensory effects, which are often quite disabling or can even be fatal. The situation is complicated by the fact that embolism may or may not be accompanied by an excess gas loading in the body due to a dive and subsequent reduction of pressure. The definitive treatment for both DCS and embolism is recompression in a pressure chamber with oxygen breathing.

The distinction between DCS and embolism is not always clear. The current trend in diving medicine is to describe the decompression disorders according to the symptoms, their progression, and the response to treatment, rather than by terms that presume to know the cause (Francis and Smith, 1991). This new approach—which collects all decompression disorders into the term "DCI"—has an important objective of providing better epidemiology data. The traditional and still practical method for distinguishing between cases involving pain only and those with neurological involvement is to classify DCS as Type I or Type II, respectively. Although this latter classification provides poor descriptions, it is still valuable for defining initial treatment procedures; it can cause a more aggressive treatment to be used for neurological or more serious symptoms, which is appropriate.

Although the incidence of DCS is of course influenced by the pressure exposure and decompression pattern, there is still a finite chance that DCS will occur even when a dive is performed properly and within table limits; thus the occurrence of decompression sickness has a statistical or probabilistic component. For a given set of conditions which determine the degree of risk, it may or may not happen. For **all** diving there is a finite probability that DCS will occur. The objective of decompression procedures (tables, computers, etc.) is to reduce the probability of DCS to an acceptable minimum.

Since our effort here is to address the "preventable" decompression sickness normally encountered by recreational divers—manifested mostly as joint pain and skin itching—we use the term "decompression sickness" or "DCS" in this report, rather than the recently popular "DCI," we hope without getting into a semantic argument; we feel the term meets our needs better. Reducing the probability of DCS will reduce the probability of other aspects of DCI as well.

2. Bubbles and bubble detection

Another important characteristic about decompression bubbles in addition to their role in causing DCS is their ubiquitous nature. Bubbles appear not only to be **present** but they are **detectable** in most cases of DCS, but not necessarily all. Bubbles circulating in the blood stream can be detected by ultrasound techniques which use the Doppler shift; such a device only detects moving bubbles or other moving particles which reflect high-frequency sound waves (or the parts of the heart that are moving). Doppler-detectable bubbles have been correlated with DCS, but somewhat loosely. Decompression tables that cause more bubbles are associated with more DCS (Nishi, 1993), but Doppler bubbles have not been found to be widely dependable in predicting the future occurrence of DCS in a given individual (Vann and Thalmann, 1993). One reason for this is the large number of "false positives" that are heard. Doppler bubbles have been detected in some divers performing well established recreational diving patterns, even ones that have a strong history of being free of DCS symptoms and other overt problems (Dunford et al, 1992).

This apparent dichotomy between bubbles being clearly the cause of DCS and not being premonitory (useful for prediction) is due to the nature of Doppler-detectable bubbles (Powell, 1972 Nov). These bubbles have left the body tissues and are in the venous circulation on their way to the heart and lungs, where they normally diffuse into the lung alveoli and are exhaled from the body as a gas. It is felt that highly localized, extravascular bubbles and those in the arterial circulation are more likely to be the ones causing symptoms. However, all bubbles are "foreign bodies" to the body's defense mechanisms; they activate platelets and coagulation mechanisms, and can do physical damage to the endothelium (lining) of small blood vessels. This damage to the blood system by a few circulating bubbles is normally tolerated by healthy divers, and this sort of damage is believed to be quickly repaired. Occasionally a diver stricken with a serious case of decompression sickness may exhibit symptoms typical of damage to the blood and vascular system along with the traditional DCS symptoms. The "inappropriate fatigue" (not accounted for by exercise or exertion) that follows stressful dives is likely to be due to damage by circulating bubbles.

Another class of decompression disorders are the cases generally regarded as arterial gas embolism. These may result from gas being forced into the arterial blood by lung overpressure ("pulmonary barotrauma") or other reasons which allow bubbles to get into the arterial system. It is generally accepted that certain diving behavior such as yo-yo dives, closely spaced deep repetitive dives, and doing a deep dive after a shallow one are conducive to decompression illness (Lang and Hamilton, 1989; Lang and Egstrom, 1990), and the symptoms of these cases often have the "arterial" character. It has been suggested that these cases are often associated with arterial bubbles (Imbert et al, 1992).

Another pathway exists for venous Doppler bubbles, especially when many of them are present, to find their way into the arteries. This is the situation where bubbles pass from the central venous circulation through the heart-lung system into the arterial circulation. These bubbles are believed either to pass through the lung circulation, to bypass the alveoli via shunts, or to go through an open *foramen ovale*. This is a small hole between the right and left (venous and arterial) sides of the heart, which is normally open in the fetal circulation but which partially or completely closes after birth in most individuals. In some people this "PFO" (patent foramen ovale) remains partially open or acts as a valve and can open under certain differential pressure conditions. Opinions differ widely among experts as to what this really means, but this could be an explanation for some of the unexpected and "undeserved" cases of DCS or more likely, embolism. For example, it is not yet certain what conditions provoke the opening of a PFO so as to cause a reversal of the normal left-to-right pressure gradient. One thing does seem clear, that it is not to a diver's advantage to have a lot of circulating bubbles.

3. Decompression testing and statistics

Since people first began to produce decompression tables, the need to test them has been recognized, but the methods and consequences of "testing" of tables are not well understood. The objective of testing is to establish an **incidence of DCS** (or other outcome) resulting from the use of a table, a set of tables, or more recently of a computational algorithm or model or of a dive computer. In its simplest form the "incidence" is the number of cases of DCS for a number of dives on a given table, best expressed as 1/10, 2/20, or 10/100. Sometimes these are converted to percentages, but right away the need for a better way to represent the data (more sophisticated statistics) becomes apparent. It is obvious that the three examples give the same **percentage** of DCS, but one would clearly have greater confidence in the examples with higher numbers.

It is possible to include that "confidence" information as a **confidence interval** using binomial statistics (King, 1971; Diem, 1962). If one wants to be 95% confident of the incidence, this means the estimate will be right 19 times out of 20. At the 95% confidence level for an observed 1 "hit" in 10 dives the predicted incidence (the true incidence in the population from which this sample is taken) is less than 44% (but no better); for 2/20 it is less than 31%, and for 10/100 it is less than 17%. If one wants to be 99% confident, then 1/10 means one can only be sure (99% sure, that is) that the true incidence is less than 60%; and so on. A developer who gets 1 hit in a series of 10 dives and then assumes that this means the table being used has a 10% incidence may be in for a big surprise; chances are best that it is close to 10%, but it could be as high as 60% with the same degree of confidence. In another perspective, if one wants to be 99% confident that the true incidence of DCS is 1% or less then 465 dives, all DCS-free, are needed.

Now for this to be strictly meaningful all the dives have to be on the same table, under the same conditions, and each has to be run to the full time and depth limits allowed by the table. The DCS results are in "yes-no" format. There will of course still be many variables such as individual differences in susceptibility and dive conditions that are not accounted for specifically.

The importance of this is to emphasize that running a few tests does not tell us very much, and to make the point that this fact is not widely appreciated. In the early days (what that means is relative) it was fairly easy to get an idea of the incidence because tables were not particularly reliable and only a few dives would often yield enough cases to indicate an "incidence." If one is willing to accept a 20% incidence of DCS and wants to be 95% confident that the incidence is that or below, it would take only 14 successive clean dives to establish this.

The real testing of the RDP, of course, was based on a low incidence of DCS in hundreds of dives.

For recreational diving the DCS incidence in the field in overall practice of the sport is estimated to be one hit in about 5000 dives (see the discussion after the commercial diving session, pp 105-112, Lang and Vann, 1992). This is with an estimated denominator since the total diving activity is not known, and it lumps all types of dives together including those not carried out to the limits. It is interesting to speculate what the "true" incidence would be of tables that produce this score in field use, but it would surely be less than a 1% DCS incidence. As a reference, the upcoming new USN no-stop tables are calculated so as to produce a 2% predicted DCS in full-depth-and-time use. This level is considered acceptable for Navy use. Results from the new tables are expected to be equivalent to the prevailing incidence in the deeper end of the no-stop air range, but to be more conservative (shorter allowable times) in the shallow range where allowable times have been rather long (Survanshi et al, 1993).

While on the subject of statistics it should be pointed out that the computational method now being used by the U.S. Navy for calculation of tables is a highly sophisticated statistical approach. It uses a statistical method known as maximum likelihood to compare the profiles of previous dives on which both the time-pressure-gas profile and the DCS outcome are well documented. The analysis method allows different profiles to be compared, somewhat in the manner that a "least squares" fit draws the best (i.e., most likely) line through a swarm of data points. After a large number of carefully controlled dives are analyzed and the model "calibrated" it can then be used to calculate new dives.

4. The validation process

The process of developing and validating decompression tables is discussed in an Undersea and Hyperbaric Medical Society workshop report (Schreiner and Hamilton, 1989). Participants in this Workshop represented a high level cross section of experts from the decompression community, and its report presents a level of consensus on many of the steps to be taken in a proper validation program. The steps in the overall development process (which includes validation) consists essentially of developing a "model" or computational algorithm for producing the decompression tables, performing laboratory trials of selected profiles using "informed" subjects, when ready moving into the field for a provisional "operational evaluation" stage using ordinary divers (not informed subjects), and, when this is shown to be acceptable, declaring the procedures operationally ready; numerous documentation and feedback loops operate throughout this process. The Workshop produced this more or less as a brief guideline of what a responsible organization does to develop tables.

With regard to validation, the Workshop confirmed that the Developing Organization retains the responsibility for the quality or reliability of the new tables, described the distinction between experiments and operations (and the distinction between an experimental subject and a working diver), and established how the Organization goes about making the judgmental decisions necessary in the table development process.

As mentioned above, an important characteristic of the development of the RDP is the test program conducted to validate it; this is the main topic of this report. The Validation Workshop report came out after the development of the RDP system was well under way, but the RDP development followed essentially the same steps as those described by the Workshop; this is to be expected since the findings of the Validation Workshop reflected current ethical practice in decompression development. Some additional vetting was done by the DAN Decompression Advisory Board, covered later in Chapter 7.

C. Definitions: Recreational diving

This report is extensive enough that it may be helpful to include some definitions.

1. Recreational diving

The term "recreational diving" is used to describe the leisure diving activity practiced the world over by a wide assortment of people. To maintain this almost universal accessibility—plenty of grandmothers are active and competent divers—the bounds of recreational diving are set so as to dictate a high degree of safety but still permit enough latitude for extensive enjoyment of the sport. Recreational diving has shed the older "sport diving" label in order to avoid any implication of competition; competition leads to risky activities.

It is generally agreed that **recreational diving** is limited to depths not exceeding 130 feet (40 metres), with air as the breathing gas, and with no dives requiring decompression stops. These limits were not merely set by decree; they are in fact based on experience.

2. Decompression and stops

In the vernacular of recreational diving the words "decompression" or "decompression diving" usually refer to an ascent which requires that decompression **stops** be made (for the purpose of avoiding DCS). If the amount of dissolved gas is too great to permit direct ascent to the surface, decompression "stops" are necessary. This involves an interruption of ascent at specified depths for specified times; it is sometimes called "stage decompression." Thus a "decompression dive" is one requiring stops, while a "no-decompression" ascent requires no stops. The fact is, all dives involve decompression since dissolved nitrogen must be eliminated at the end of the dive, but they do not all require stops. To further confuse the issue, a sufficiently slow ascent can take the place of stops (Lang and Egstrom, 1990). We prefer in this report to refer to dives without stops as "no-stop" dives, to avoid the implication that decompression is not involved; it always is.

A "safety stop" at 10 to 20 fsw for 3 min is required by the RDP on all dives exceeding certain limits. A "safety stop" is a stop that is not required by the computational algorithm, but is there because of prudence. These "safety" stops were included in the Phase II simulations. Some may have preferred to have a term for this stop that does not imply that it is optional, as the term "safety stop" might, but this is the term that has become widely used and is applied to the 3-min **required stop** which is required on all dives. It is not included in the calculations, so in that sense it is indeed a "safety" stop.

Using the definitions of the USN air tables, any dive within the next 12 hours following a previous dive is a **repetitive dive.** Using the RDP, any dive within 6 hr of a previous dive is a repetitive dive. Physiologically, any dive whose decompression is influenced by a previous dive is a repetitive dive; the full scope of this is not known.

3. Decompression disorders

Traditional decompression sickness or DCS is presumed here to be the familiar "bends" or joint pain, the condition one tries to prevent with tables and computers; a relatively new and more general term "decompression illness" or "DCI" comprises this and arterial gas embolism as well.

4. PADI, DSAT, The Wheel

This project was sponsored for International PADI, Inc., through its research affiliate, Diving Science and Technology Corporation, DSAT.

The project resulted in a new system for managing decompression in recreational diving known as the "Recreational Dive Planner." The RDP comprises both a set of decompression procedures in the usual table configuration ("flat"), and a circular slide rule calculator known as "The Wheel;" these two display formats produce the same decompression, but The Wheel allows interpolation and thus provides more flexibility. The Wheel is not an electronic dive computer. Both are trade marks of DSAT in 1988. The Wheel is patented by RER (Rogers, 1989 May).

The experimental chamber work was done at IAPM, the Institute of Applied Physiology and Medicine, Seattle, and the open water dives were made in nearby Puget Sound. These phases of the project were conducted by one of us (MRP).

5. Units

In this report we use the common definition of the basic unit of **pressure** or depth used in the project, the foot of sea water or fsw, defined as 1/33 standard atmosphere or 3.070 kPa. Normally the metric unit of depth and pressure, the metre of sea water or msw, is defined as 1/10 bar or 10 kPa. The conversion between these is 1.00 msw = 3.2568 fsw, but some of the few metric calculations reported here were done with a definition of 1 msw = 3.251 fsw (we ignore the difference). The conversion 3.2808 ft/m is inappropriate in this application; that is the conversion of feet and metres as units of **length**, not as units of pressure.

6. Safe or reliable; DCS is not an accident

People working in decompression development occasionally use the word **"safe"** to refer to a situation that meets a chosen set of criteria. For example, an exposure that is below a theoretical limit might be described by some as "safe." Although a case can be made that if something has an **acceptable level of risk** it is safe, there are some disturbing aspects of using the word safe in the context mentioned. First, most limits are determined to be acceptable according to criteria which may be questionable, theoretical, or even arbitrary. Many limits once considered proper have been found to be unacceptable over time as data poured in and standards of acceptability evolved. Also, a limit that avoids a known hazard may not avoid other occult hazards not seen or known at the time. This is to say, being below the limits may not be "safe" in all respects, although it may indicate an acceptable degree of decompression risk.

But the nature of decompression and decompression sickness presents a more complex picture. The specific numerical limits are regarded by the computer as "hard," but, as discussed earlier, there is a probabilistic or statistical aspect to decompression, such that being slightly below a limit (e.g., being shallower than the table depth or spending less than the allowable bottom time) does not guarantee that DCS will not occur. It only presumes a sufficiently low probability to make it acceptable. It can be argued that the word "safe" is inappropriate in this context. Decompression sickness is an integral part of diving; it cannot be completely avoided, only made acceptably improbable.

On the other hand, the capacity exists to treat DCS when it occurs in most stressful diving situations and even in many more advanced recreational diving settings. The overwhelming fraction of DCS and other decompression disorders are resolved completely when proper treatment is started soon enough. If at the end of the day there is no remaining injury (despite possible major inconveniences and perhaps expenses), was the situation really "unsafe"?

Therefore to avoid the implication that a diver can ever be completely "safe" from decompression disorders, we prefer words like "reliable" to describe situations considered to be within proper limits or believed to have an acceptable level of risk.

One final point. Decompression sickness can be expected to happen occasionally, even in relatively benign recreational diving situations. Thus it should not be regarded as an "accident." It can be painful, expensive, inconvenient, and even life-threatening, but because it is **expected** to happen occasionally its occurrence does not represent the "loss of control" implied by the term "accident."

III. DEVELOPMENT OF THE RDP COMPUTATIONAL MODEL

The time-depth-gas profiles used to effect a trouble-free decompression are based on two factors. These are, first, empirical experience, and second, some type of algorithm—usually mathematical—for extrapolating from yesterday's experience to tomorrow's dive. The method used as a basis for the RDP originated with John Scott Haldane around the turn of the century, and since then, numerous variations have appeared. The U.S. Navy tables and the Recreational Dive Planner are two of many in a long line of such procedures. The development of both the U.S. Navy tables and the RDP model are covered in this chapter.

The RDP was derived from the basic Haldane technique; therefore it is appropriate to review that here in some detail.

A. Introduction: Initial motivation for development

Since the advent of recreational scuba diving following WWII, the Standard Air Decompression Tables from the U.S. Navy Diving Manual (1959; 1991) have been the standard. This came to pass for many reasons, and in general they have served the recreational community well; the USN tables for short dives are highly reliable, straightforward to use, and readily available. These procedures also meet the needs of the military, and partly because of military practice they follow rather rigid rules. They were not designed with recreational scuba divers in mind, and suffer from some shortcomings in that application. Nevertheless, through the mid-1980's the Navy tables were taught literally and dogmatically to recreational divers by all the training agencies, and there were few credible alternatives. Even though diving patterns involving required decompression stops were not considered routine in North America, most recreational divers did use the USN procedures for performing repetitive dives as well as for timing no-stop dives.

One of us (RER) became concerned with a quirk in the strict interpretation of the USN tables. A repetitive no-stop dive in the range just under 40 fsw (not exceeding 40 fsw) could be dramatically influenced by a short excursion to deeper than 40 fsw, which reduced considerably the allowable dive time. Allowable no-stop time for a repetitive dive in repetitive group "I" at 40 fsw will go from 99 to 24 min if the dive is deeper than 40 fsw; a "J diver" will go from 84 to 13 min. A 45 fsw column in the tables that would interpolate this zone between 40 and 50 fsw would have more or less solved the problem, but none existed and divers were expressly trained never to interpolate the Navy tables.

When RER asked instructors and other authorities about how to deal with this, they were resigned to the fact that "these are the Navy tables," and expressed reverence for the tables and annoyance at the question. As a result of this blind alley, RER began a process that led to the development of the DSAT Recreational Dive Planner. The story of this development is covered in Chapter IX, and the model itself is described in this chapter.

This reveals an important point to keep in mind in a review of the basic Haldane method. It was devised for **stage decompressions**, whereas the main activity of the recreational diver is to be able to do efficient, effective, and highly reliable **no-stop** diving.

B. Review of the Haldane computational method

The basis of the DSAT Recreational Dive Planner is a computational algorithm or "model" originally conceived by British physiologist John Scott Haldane in the first decade of this century. Haldanian methods were used for the computation of the U.S. Navy Standard Air Tables, and they are at least partially used in computation of virtually all other recognized air decompression tables and are the basis of most dive computers. Exceptions are the DCIEM 1983 tables (which use a "series compartment" model that behaves in a way quite similar to Haldane models; DCIEM, 1992) and those of the British Sub-Aqua Club (BSAC, 1988). Because it is the basis of the RDP the Haldane method is reviewed here in some detail.

1. Basic assumptions of the Haldane "model"

The Haldane method is considered today to be more of a bookkeeping system for keeping track of gases in the body which works in concert with a method of setting numerical ascent limits, rather than a "model." The combination of gas accounting and controlling ascent with proper limits allows divers to reduce pressure in a trouble free manner. Despite its mathematical rigor and occasional complexity, the Haldane method—and all other methods at the present time—rely on **empirical experience** for adjusting the limits (Boycott et al, 1908; Dwyer, 1955; Workman, 1965; Schreiner and Kelley, 1967, 1971; Berghage, 1980). This discussion and many others deal with fine points of the **theory,** but the bottom line to decompression table development is **experience;** to forget this point, in the words of decompression theorist Brian Hills, is to succumb to "computer narcosis."

Divers equilibrated to sea level pressure and exposed to pressure under water have to breathe gas delivered at essentially the same pressure as their lungs. This increased pressure gradient expedites the transport of gas—the gas of concern here is nitrogen—through the lungs and into solution in the blood, which delivers it to the body tissues. A variety of factors affect how much gas is delivered, where it goes, and how it leaves; to track this absorbed gas precisely is beyond the capacity of present day technology. However, given certain assumptions that define a computational "model," it is possible to manipulate this gas theoretically, compare the calculated results with experience, and to be able to predict future dives. Although most table practitioners (including us) refer to this mechanism as a model, it is more properly identified as a computational algorithm since it probably is not a true reflection of physiological function in the sense that physiologists use the term "model."

The model assumes that the limiting factor in gas uptake and elimination is **perfusion** of the tissues by blood, and further that the measure of the quantity of a gas component in the body or a compartment of the body is the **partial pressure** of that gas. This can be related to the volume of a gas as the product of the partial pressure of the gas times the solubility of that gas in the tissue, but the model manipulates only partial pressures. As a diver's time under pressure increases, the tissues approach equilibrium with the ambient (inspired) gas pressure.

When a diver ascends to the surface, thus moving to a lower ambient pressure, the reverse process occurs. Since the lungs are now exposed to a lower pressure, the tension or partial pressure of nitrogen dissolved in the tissues is now higher than that of the blood, and the gas now has a gradient to cause it to pass into the blood and out through the lungs. This continues until the tissues are once again equilibrated with the gas in the lungs at atmospheric pressure. Within limits, this process is infinitely repeatable, so long as the pressure changes are not too great or too fast. If a diver ascends too quickly nitrogen pressures in the tissues may exceed the limit at which the body can eliminate gas by the normal process, and gas bubbles may form; this may lead to decompression sickness.

Another assumption is that gas uptake and elimination follows an **exponential** pattern. That is, the rate of exchange of gas between two regions (here a body tissue compartment and the ambient environment) is proportional to the difference in partial pressure between them. When the difference is great, exchange is rapid; it slows down as equilibration is approached. An exponential exchange is characterized by its time constant, but it is more convenient to use its half time, the time it takes to reach halfway to equilibrium; this time is independent of the size of the differential. In one half time the difference between compartment pressure and ambient pressure is reduced by one-half; in each succeeding half time, the difference is reduced by yet another half of the remainder. The process theoretically is never complete; it is considered to be effectively "complete" at the end of six half-times, when 98.4% of the potential change has occurred. A further assumption here is that this exponential exchange is **symmetrical** and operates with the same equations in both directions.

Generally the model equilibrates the body with the **inspired** gas mixture. The carbon dioxide and water vapor in the lungs are dealt with differently by different versions of the Haldane algorithm; some models consider them, but in most cases they are ignored.

2. Gas loadings

The "bookkeeping" done with the Haldane algorithm assumes that the body's gas stores—"**gas loadings**"—are in a series of theoretical **compartments.** These compartments are not presumed to be anatomical structures, although they are sometimes referred to as "tissues." A given compartment is identified by its half time; any part of the body that takes up and eliminates gas according to a particular half time is in that compartment.

The equation for calculating a gas loading in a

$$P = P_O + (P_I - P_O)\ (1 - e^{-kt}) \qquad (1)$$

compartment is shown here; gas partial pressures are usually expressed in depth units, where

- P is the partial pressure of the gas in the compartment,
- P_0 is the initial partial pressure at the beginning of a time interval t,
- P_I is the ambient (inspired) partial pressure of the gas,
- e is the base of natural logarithms,
- t is the time interval over which the gas loading takes place,
- $t_{1/2}$ is the half time of the compartment, and
- k is a constant, the natural logarithm of 2 divided by the half time:

$$k = \frac{\ln 2}{t_{1/2}} = \frac{0.693}{t_{1/2}} \qquad (2)$$

The Haldane model requires several compartments with different half times; a single compartment does not provide an adequate fit to empirical observations of gas exchange rates for a full range of dive conditions. The compartments are in parallel, with each presumed to be exchanging gas with the ambient environment, simultaneously and independently, at varying rates. The ambient environment is sometimes considered to be the lung alveoli, in which case an adjustment is made for water vapor and carbon dioxide (Schreiner and Kelley, 1971); in the present analysis that factor is not used, so exchange is between the compartments and the ambient atmosphere, the gas the diver is breathing. Haldane did not make any allowance for the oxygen in air; from today's perspective we would say that he considered that the gas the diver was breathing behaved as pure nitrogen.

Haldane used 5 compartments, with half times in a nearly geometric sequence of 5, 10, 20, 40 and 75 min. The U.S. Navy tables were done with 6 compartments, with half times of 5 through 120 min; later USN work used 8 compartments, 5 through 240 min. The Rogers/RDP model uses 14 compartments, 5 to 480 min.

One of the more confusing questions to students of decompression has been the issue of "inert gas percentage." Haldane, and later the U.S. Navy, treated air as 100% nitrogen, not the true 79.1%. This conscious choice simplified their tedious hand calculations by eliminating a step. It made no practical difference, because Haldanian calculations dealt with the **ratio** of internal pressure to ambient pressure. As a result, their answers were too high by a factor of 100/79.1, but this did not matter as long as tolerable surfacing ratios and M-values were also adjusted by the same factor. Nowadays, it is the norm to use the true partial pressures of inert gas, and M-values are accordingly lower. Converting between the methods is done by multiplying or dividing by 0.791 as needed. It may be necessary to recall this dual approach when comparing various decompression computational procedures, especially the older ones; it has led to considerable confusion for some decompression researchers.

3. Ascent limits

When pressure is reduced after some gas uptake has taken place, the partial pressure or tension of inert gas dissolved in the tissue compartments may now be greater than the ambient pressure on the diver's body. The result is a theoretical **supersaturation.** A certain amount of supersaturation is usually tolerable without bubble formation, but the presence of a theoretical supersaturation today is generally considered by some decompression researchers to be an indication that bubble formation has probably begun. The impact of supersaturation depends on many things, including exercise, temperature, etc., and especially the duration of time it is maintained; longer exposures entail a higher risk that supersaturated gas will become bubbles. This issue is clouded by the presumption that there are tissue gas micronuclei present in most living tissue.

The next element of the Haldane method is a means of interrupting (or slowing down) the ascent of the diver. The method assumes that a given differential partial pressure or supersaturation can be "tolerated" in each compartment. As ambient pressure is reduced the differential between the gas loading in each compartment and ambient pressure increases. At some point one or more of the compartments reaches its limit—empirically determined—of tolerable differential pressure over ambient, and at that point (depth) the diver should stop or slow down the ascent. This is essentially what is done in computing a table. The diver remains at a stop (or uses a sufficiently slow continuous ascent) until all compartments have gas loadings below the ascent limit, and ascent can then proceed to the next stopping point. As a reminder, the values of the ascent limits are empirically determined.

Haldane expressed this limit as a ratio of partial pressures (he used air and not just the inert gas). His value for a tolerable pressure ratio between the gas loading in the limiting compartment and ambient pressure was observed to be 2, a figure that was the same for each compartment. Later studies showed that a single set of ratios does not work well for any but short, shallow dives, nor does it work for a wide range of dives, and in time the ratios were changed to reconcile results with more recent data. The current air tables of the U.S. Navy were done with ratios (Dwyer, 1955; 1956; Workman, 1957). Ratios are used successfully for decompression to low pressures in aviation and space work (but with ratios much less than 2; Conkin et al, 1990).

The concept of setting the limit based on differential pressure was introduced by Workman (1965). This amounts to about the same thing as ratios but is easier to use over a broad range of depths and times. It consists of selecting (again, empirically) a set of differential pressures which represent the maximum tolerable gas loading in a compartment at each depth. These are called M-values (M for maximum). They are inert gas partial pressures, and for computational convenience they are usually expressed in depth units, here fsw.

It is important to keep in mind that although these ascent-limiting M-values are handled as specific "hard" numbers, the experience behind them is that they belong to a spectrum of gradually increasing risk. A given set of M-values clearly does not mark a hard edge beyond which DCS is sure to occur and below which it is guaranteed not to (regrettably, this idea does exist in the minds of many divers). The same thing applies to bubbles; a set of bubble-based limits may produce dives causing only a few Doppler-detectable bubbles and therefore be highly reliable, but it is not likely that a set of tables (or any sort of diving method) can be devised that will yield completely bubble-free dives and still be practical. A few bubbles appear to be both tolerable and unavoidable. Spencer (1976) proposed that a decompression would be acceptable if no more than 20% of dives cause bubbles (although this suggestion is without regard to Spencer's own grading method, which would have enabled a more quantitative assessment to be made had he used it).

This also shows clearly that the Haldane concept does not fall apart if some bubbles form. One might consider that the empirically determined ascent limits work to limit the bubble load to a tolerable level, and not just to limit supersaturation. While "tolerable supersaturation" is a basic tenet of classical Haldane theory, this is no longer regarded as a realistic term. Whether a given limit is (or is not) tolerable is not because of supersaturation, but rather because it yields (or does not yield) an acceptable empirical DCS incidence.

The primary use of ascent limits is for dives which require decompression stops; development of no-stop tables may follow different procedures.

C. Development of the USN air tables

Because it illustrates the process, we here outline the development of the USN Standard Air Decompression Tables. These steps are laid out in several reports from the U.S. Naval Experimental Diving Unit, which at the time was located in the Washington Navy Yard.

1. The USN Standard Air tables

Whereas Haldane had set a fixed ratio to all compartments (and found this method inadequate in longer dives in the deeper range, and too conservative in the shallow end), researchers of the U.S. Naval Experimental Diving Unit recognized the need for variable ratios for the different half times (Hawkins et al, 1935), and Yarborough recognized the important effect of exercise on gas uptake (1937). This led to an effective and highly regarded set of tables in the 1943 edition of the USN Diving Manual (some old timers still use them). The next major change was the recognition that ratios should also be depth dependent, a point developed by Van Der Aue and colleagues (1945; des Granges, 1956) and by Dwyer, who worked out formulas for doing this (1955; 1956); there was another reduction of allowable ratios, and in order to accommodate repetitive diving and longer, deeper staged dives an additional half time, 120 min, was added. As with Haldane, all these investigations treated air as if it were 100% nitrogen. The algorithm for preparing a repetitive dive table was worked out, which forced recognition of the no-stop or "no-decompression" dive as an entity, since repetitive procedures also had to include no-stop dives. Also developed in this period was the concept of surface decompression with oxygen.

Because of the development of scuba apparatus in WWII, the tables were now made to include more appropriate depth increments, and the rate of ascent had been changed from the earlier 25 fsw/min to 60 fsw/min, where it has remained. The ascent rate was a compromise; Navy scuba divers wanted a rate of 100 fsw/min, but it was difficult to winch a tethered diver up at this rate, and the same rate had to be used by all Navy divers (Lanphier, 1990). The choice was a figure somewhat in between, the easy-to-calculate 60 fsw/min or 1 fsw/sec. Decompression "theory" did not enter into this choice.

The "second half" of the standard air tables, those referred to as the "exceptional exposure" and "extreme exposure" tables, were worked out by Robert Workman (1957). These rather unreliable tables required further changes in the ratios. But the same compartment half times (5-120 min) were used, and it was here that Workman added the 160 and 240 min compartments. He found that even if he cut the ratio in the 120-min compartment this would not account for some severe exposures; he found it necessary to include even slower compartments. The USN tables as we know them were first issued to the fleet in 1959.

The final chapter in this remarkably productive period at the EDU was a set of tables prepared by Workman which also covered helium-oxygen diving (1965). Here a big step was taken in the continuing development of the basic Haldanian method with the introduction of M-values. Workman converted the ascent limits used for the earlier tables from ratios to differential pressures (by multiplying the sea level ratio by 33 fsw/atm). These M-values (M for maximum) were easier to use and more versatile, and in particular they made it easier to make new tables conform to empirical experience. The set of M-values for all compartments at all depths is called a "matrix"; a matrix provides an ascent limit for each compartment at each depth.

Workman also realized that M-values could be derived mathematically by a single linear equation for each compartment; this considered the starting value for each compartment (M_0, the "surfacing" M-value or the value at one atmosphere) and a slope which defined the change in M per unit change in depth. This made it easy to have the matrix "expand" with depth, allowing greater changes at increasing depth. He also recognized that in order to use these methods for different mixtures it was necessary to consider only the inert gas component of air; he multiplied pressures by 0.79 (the fraction of nitrogen in air) and adjusted the matrixes accordingly. The final Workman 8-compartment matrix is shown in Table I (this matrix will not quite duplicate the USN Standard Air Tables, which were done by ratios).

Several other workers have continued to build on this sturdy foundation. Schreiner (and Kelly, 1971) added a method of handling multiple inert gases in the same dive (sometimes called the Haldane-Workman-Schreiner algorithm), and Bühlmann devised a slightly different configuration for the ascent limit mechanism (1984). Numerous other decompression models use the basic Haldane gas loading concepts with bubble growth, "linear," and other methods of limiting ascent. U.S. Navy Diving Medical Officers get training in calculating tables (Flynn et al, 1981). A "cookbook" on calculating tables based on the Workman matrix was prepared by Braithwaite (1972). Short and Flahan have shown how it can be done using a computer spreadsheet (Short and Flahan, 1989).

Not all of this is immediately relevant to recreational no-stop diving. Only the "surfacing" values in a matrix (designated M_0) apply to dives without stops (without stage decompression), and there is no reason for concern here about inert different gases. Additionally, compartments with very long half times are of only limited significance in no-stop diving.

This report defines the modifications made by Rogers to the Haldane and USN methods in developing the RDP.

2. USN's approach to repetitive diving

One of the more significant contributions of the USN table development program in the 1950's was the concept of how to perform repetitive dives. The problem here is that when the diver begins the second (or subsequent) dive there is some gas loading from the first and/or other preceding dives, and this gas has to be accounted for in computing the second dive. Also, if the interval between dives is more than a few minutes some gas will be eliminated during the interval, and this too should be accounted for. One method to do a repetitive dive would be to begin the second dive as if it were a continuation of the first dive, but this is inefficient at best and in some cases might prohibit a second dive at all.

a. Basic assumption of gas loading

The basic Haldanian assumption for repetitive diving is that the gas loadings can be tracked during a surface interval, and the calculation of the next dive can begin with a gas loading that is a specific function of the **first dive** and the

Table I. Workman M-values. The half times chosen by Workman are shown with their respective surface M-values, and the "slope" or change in M per change in depth (fsw).

Half time (min)	M-value (fsw)	Slope (ΔM/fsw)
5	104	1.8
10	88	1.6
20	72	1.5
40	56	1.4
80	54	1.3
120	52	1.2
160	51	1.1
240	50	1.1

interval (see for example Bühlmann, 1984; 1993; Schreiner and Kelley, 1967; Huggins, 1987; Heinmiller, 1992). This concept has been applied by users of other models as well (Thalmann, 1985 Apr; Nishi and Lauchner, 1984). If the first dive is not known, loadings equal to the M-values are used for all compartments, assuming that to be the maximum value that any compartment will have following a proper decompression. Certain aspects of the gas loading concept have recently been questioned (Edmonds, 1993; Imbert et al, 1992; Hahn, 1994, in preparation), but in general experience indicates that it works quite well and is accepted more or less by default.

To plan for repetitive diving, USN first had to define it. The Navy investigators regarded a dive done after a 720 min interval, 12 hr, as a "single" or new dive (Dwyer, 1956; des Granges, 1957). For complex dive patterns this limit has been questioned, but for no-stop and short air dives it appears to be effective.

While it is possible to use gas loading to calculate a repetitive dive as a function of the earlier dive and the interval this was not feasible to do under water until the development of diver-carried dive computers. The Navy's approach to this was—in effect—to monitor the gas loading (nitrogen) in a single compartment, account for buildup during the first dive and outgassing during the surface interval, then determine the effect that this prevailing loading had on the second dive and modify it accordingly. The reason for basing repetitive diving on a single compartment is that this made it possible to put repetitive diving information into relatively simple tables; to display all possible combinations would have been too complex a task. The method also had to be able to take into account the gas loading that could develop during a no-stop dive.

b. The 120 min compartment and repetitive groups

The compartment chosen was the **longest one in use at the time**, which had a half time of 120 min. This compartment had been added to remedy periodical difficulties with the earlier 75 min compartment (Dwyer, 1955). The total gas loading allowed to be in the 120 min compartment at surfacing could be as high as the surfacing M-value for that compartment, which at the time was 64 fsw (if at any time during a dive the loading got beyond this the diver had to stop until it went down to the M-value for the current depth, so it would never exceed this value on a proper dive). To prepare these tables the possible combinations of excess gas loadings in the 120 min compartment at the end of the first dive, a maximum of 31 fsw (the maximum 64 fsw allowed less the ambient pressure at sea level, 33 fsw) This excess gas was divided into 16 arbitrary groups of 2 fsw each. These were designated A through O, with the last one Z. These values used the concept that air = 100% nitrogen.

It was then determined for each group, at the depth of the subsequent dive, the time (in minutes) that it would take for the loadings to equilibrate to the condition that would normally be present at the beginning of descent. This becomes the "penalty" time that is then added to the additional exposure time of the second dive to use in selecting the table for the repetitive dive, as if the diver had already been at depth for that entire period. These calculations were straightforward since they were all based on the single 120 min compartment.

These were displayed in three tables. First is a surface interval timetable which allows calculation of the decay of the gas loading during the surface interval, by groups. This decay (gas elimination on an exponential path) then places a diver into a new lower repetitive group which is used for the second dive. This new group designation is used in the residual nitrogen time table (calculated as mentioned), which gives a time penalty for the specific depth of the next dive. The diver starts that dive with this amount of "bottom time" already accumulated.

c. Repetitive no-stop dives

One thing remained, to deal with the residual nitrogen from a no-stop dive (next section). A chart in the Navy Diving Manual entitled "No decompression limits and repetitive group designation table for no-decompression air dives" allows the determination of a residual nitrogen group for submaximal no-stop dives.

d. Additional developments

One might notice that the M-value for the 120 min compartment as listed by Workman, Table I, is 52 fsw rather than the 64 mentioned above. This is due to the change from the concept of working with air assumed to be 100% nitrogen to the more "contemporary" perspective of using the actual inert gas fraction. Discrepancies exist in the records, which has led to some confusion in later years.

It might also be noted that the original approach studied by the Navy researchers divided the excess gas pressure into 31 groups; this was reduced to 16 for more efficient presentation. Had the 31 groups been retained, the breakdown of repetitive times might have been such that this whole project would never have been needed. It is worth pointing out another effect, a benefit or defect depending on your perspective, of using the larger groups. Larger groupings in any table situation has the effect of increasing overall conservatism. This happens because a smaller fraction of the total number of times the group is used approaches the limits for the group, whatever they are. As an example, consider the case of 20 fsw increments on tables. If tables were supplied for every 20 fsw, then a dive to 41 fsw would have to use the table for 60 fsw, a gross bit of excess conservatism. This effect tends to mask inadequate tables, as it has the longer, deeper USN air tables. The overall record on the USN tables is good (partly because very few dives are done to the limit), but dives to 160 fsw for 60 min, for example, done to the limit would have a very high rate of bends, probably 15 to 20% (Weathersby et al, 1986). Rounding times to the nearest 5 min also adds conservatism while decreasing flexibility.

Groups O and Z can only be reached with dives long enough to require stops, so these groups are not included in most recreational diving reproductions of the Navy procedures. It might be noted also that DCIEM took a different approach in displaying its repetitive procedures (Nishi and Lauchner, 1984). They performed a "brute force" review of all likely combinations of dives to arrive at a single worst case factor for each repetitive dive, which is implemented as a multiplier for the time of the repetitive dive. Most commercial decompression tables determine repetitive dives in large time blocks, such as 2, 4, and 8 hours, following any previous dive, preparing a whole set of tables for each time block. This is hardly efficient, but it meets a seldom-used need.

3. The USN no-stop ("no-decompression") tables

a. Terms: No-stop vs. no-decompression

This section covers the concept of "no-stop" or "no-decompression" tables. In their simplest form these are nothing more than an allowable dive time in minutes for each depth range covered in the table set. Each depth covers the range from just deeper than the next shallower depth to the depth in question (in the usual way), such that the 80 fsw table would cover the range from just deeper than 70 fsw to 80 fsw. The no-stop time is the time a diver can spend in the specified depth range and ascend directly to the surface. Usually no-stop tables also specify (or imply) the descent and ascent rates.

Traditionally no-stop tables have been called "no-decompression" tables, sometimes using the useful abbreviation "no-d." This term is universally understood, but in one way it sends the wrong message to the diver. **All** dives involve decompression, and the implication that some do and some do not is inaccurate at best, and it could have detrimental results.

b. Delineating the no-stop tables

The concept of no-stop or no-decompression tables was something of an afterthought to USN. Each table calculation resulted in a time for which the stops were zero, and by definition a listing of these is a set of no-stop tables. The actual no-stop limits of the USN tables do not exactly match the values that would be generated based on the chosen M-values. This is due to discontinuities introduced as a result of experiment, calculation methods in use at the time, and the consequences of rounding off calculated values. These have little consequence to the utility of the tables.

c. *Repetitive no-stop tables*

Finally, the repetitive rules had to be applied to the no-stop tables. This is explained in sections above. The nitrogen accumulation during a no-stop dive is listed in a table, which includes submaximal exposures as well as those going the full time.

4. Validation of the USN Standard Air Tables

At the time of their development only a perfunctory validation was performed, and the no-stop tables were not specifically tested at all (more recently they have been; Thalmann et al, 1989). Many trials were performed during development, but it appears that there was little specific understanding at that time of the statistical nature of the phenomenon of decompression. For example, in one case a trial had an outcome of 2/6, 2 bends in 6 dives. A minor modification of 2 or 3 min was made and the table run again, this time with no bends. That table was accepted! If one discounts the fact that this could have been statistical mischance, the fact remains that a table with a true incidence of 2/6 needs a great deal more than a minor correction.

Despite the limited testing before release, the USN no-stop limits have stood up reasonably well. They have been shortened by various developers, including RER in this project, but are generally regarded as reliable. New USN statistically-based tables not yet released will allow a little more time in the deeper depths (e.g., 27 min vs. 25 min at 100 fsw) but the times for shallower no-stop dives have been shortened (Survanshi et al, 1993); this acts as an assessment of how well they have been working. The tables themselves have been defended until very recently as meeting the needs of the Navy (Thalmann, 1989), but they are well known to be unreliable in the deeper range for any but very short dives (Thalmann, 1984). They have worked because diving supervisors learned to "jump" them using a table for a longer and/or deeper dive than the one actually prepared (Arntzen and Eidsvik, 1980). The overall score has been good because these tables are seldom dived to their limits. The DCIEM table development specifically addressed observed weaknesses in the USN tables (Nishi and Lauchner, 1984).

D. Development of the RDP model

The development of the RDP ultimately had the following objectives:

- Recreational no-stop diving tables.
- Repetitive procedures for no-stop dives.
- Procedures for multilevel dives.
- Presentation as standard tables and as "The Wheel."
- Validation of the model with human volunteers.
  - Dry chamber, daily dives
  - Open water, daily dives
  - Dry chamber, multiday dives
- Report of the results.

This report is the last stage in the above list. In addition to the dives listed, during the development process it was recommended that an additional phase of multiday diving be conducted in open water. This phase was not carried out; it is discussed in Chapter IX.

This section discusses how the RDP model is constructed and how it works; a brief story of the sequence of its development is given in Chapter IX.

As mentioned in section A, above, the primary limitation of the USN tables as originally confronted by RER was the coarse "grouping" of repetitive dive options in the 40 to 50 fsw range. Thus his primary objective was initially to "interpolate" the USN tables and hence to improve their utility to recreational divers. Investigation of the USN tables and the methods used to generate them led to a program to revamp the repetitive system at a fundamental level. Since the orientation was solely for recreational diving, the needs were limited to no-stop dives. It became obvious to RER that a closer look at the no-stop limits was warranted.

a. No-stop limits

The USN no-stop table has irregularities in it, due mainly to rounding to increments of 5 minutes (mentioned above). RER intuitively felt that the curve of allowable time vs depth should be smooth. He was able to make this curve a little smoother by inserting 30, 60, and 100 min half times using interpolated M-values, but it was necessary to "massage" the USN values to make it a smooth curve.

Another way to make a smooth no-stop curve is to use a simple relationship known as "P root t" developed by Hempleman (1975) which relates a depth with its no-stop time,

$$C = D\sqrt{t} \tag{3}$$

where D is depth in fsw, t is allowable time at that depth in min, and C is a constant with a value of about 500. This reproduces the USN no-stop tables quite accurately for times to about 100 min, but becomes more restrictive for longer no-stop times (or shallower no-stop depths). A more general form of the equation is $D = Ct^{-x}$. This plots as a straight line on a log-log graph.

RER applied values recommended by Spencer (1976) based on Doppler data to adjust the constant in this equation to give a level of conservatism, according to Spencer's rather limited data, such that about 15% of divers should have detectable bubbles after making a single dive. The constant C used for the RDP was 510, and the exponent -0.53 (essentially still a square root—but note that these are "curve fit" data and not to be taken too literally). Spencer had suggested that a level of 20% of divers with bubbles (but without reference to his grading system) should give acceptable recreational tables, so this is still a bit more conservative than that. Additionally, the resulting no-stop tables were checked against available data on no-stop diving. Table II compares the resulting stop times for the RDP with those of the British Navy and the U.S. Navy.

A further slight modification to the equation was made to deal with the shallow depths where no-stop times get rather long. The depth at

Table II. Comparison of no-stop times. Dive depth shown at left, with maximum allowable times by the USN, British Navy, and RDP.

Depth	US Navy	British Navy	RDP
30	None	232	---
40	200	137	140
50	100	72	80
60	60	46	55
70	50	38	40
80	40	27	30
90	30	23	25
100	25	18	20
110	20	16	17
120	15	12	14
130	10	11	12

which a diver could saturate and still make a direct, no-stop ascent to the surface without DCS had been empirically determined to be significantly shallower than 25.5 fsw, probably in the range of 22 fsw (Eckenhoff et al, 1986). To be conservative and consistent with the curve, RER set this at a lower value, 20.15 fsw. This "shallow asymptote," A, could thus be added to the equation. Constants are C = 803 and x = 0.7476.

$$D - A = C\,t^{-x} \tag{4}$$

A "deep asymptote" of 262 fsw was also calculated. This was the theoretical depth to which a dive could be made with zero bottom time; it is not a realistic point and is not at all relevant to recreational diving, but it was needed for completeness.

b. RDP half times

The classical USN half times were 5, 10, 20, 40, 80, and 120 min. In an effort to smooth the curve of no-stop times RER added times of 30 and 60 min (without much success in solving the "coarseness" problem at 45 fsw). Later as the project began to encompass repetitive diving some additional times were added to yield a final set of 14, shown as Ht in Table III. Compartment half times longer than 200 min are never controlling (never reach their limit) in recreational diving, but the times had to be in the algorithm in order to determine that this was indeed the case.

c. *RDP M-values*

Pure Haldanian "theory" would imply that each half-time compartment has a limiting or maximum allowable value of (calculated) inert gas supersaturation at surfacing, below which no bubbles will form, and above which they are sure to form. This is clearly an oversimplification; it is doubtful that even Haldane believed that this was actually a valid physiological model (yet some critics of the Haldane method cite this as a defect). A more reasonable approach to these limits is that they represent a tolerable degree of bubble formation. For each specific compartment there appears to be a given gas loading limit (call it supersaturation if that seems important) below which the probability of DCS is acceptably low. These limits are expressed as M-values; the set of M-values that apply to the initial, single ascent to one atmosphere and hence affect no-stop diving are referred to as M_0-values.

The RDP M_0-values were back-calculated from the no-stop curve. Given the curve based on Spencer's data and smoothed to eliminate discontinuities, the M_0-values were thus developed for the RDP. These are shown as the RDP column in Table III.

For the record, when M-values are calculated from the no-stop times the shape of the no-stop dive profile used for the calculation has an influence on the resulting M_0-value. For the RDP we calculated these assuming a descent to depth at 60 fsw/min beginning at the beginning of bottom time, with the bottom time ending at the end of the time on bottom; the timed descent was used, not an instantaneous one. Differences in the definition of bottom time account for some discrepancies during the RDP development process and are sometimes found between different investigators. For example, in an earlier report on Phase I of this project called the "Blue Book" (Powell et al, 1988) the

Table III. RDP M-values. Compartment half times are at left, with the ultimate RDP values based on timed descent, the values using a square descent, and those given in Powell et al, 1988 (sometimes called the Blue Book).

Ht	RDP	Square	Blue Book
5	99.08	103.1	102.9
10	82.63	84.2	84.1
20	66.89	67.3	67.2
30	59.74	59.9	59.8
40	55.73	55.8	55.7
60	51.44	51.5	51.4
80	49.21	49.2	49.1
100	47.85	47.9	
120	46.93	46.9	46.9
160	45.78	45.8	
200	45.07	45.1	
240	44.60	44.6	
360	43.81	43.8	
480	43.40	43.4	

profile used was a "square" one assuming an instantaneous descent; this is a greater exposure and it therefore assumes that a slightly greater gas loading is tolerable. The values in Table III labelled as "square" and "Blue Book" refer to these. The slight differences between the Blue Book and the values based on a "square" descent are due to rounding of the factor used for the inert gas ratio (0.79 vs 0.791). These are not important physiologically, but are included to set the record straight.

There is another point of confusion alluded to above. Early calculations (beginning with Haldane) considered that the nitrogen in air made up the total pressure. This practice was followed through the development of the USN Standard Air Tables and was used initially by RER. This only works, of course, if air is always used. More recently decompression investigators consider the inert gas component specifically, and have modified their M-value matrixes accordingly.

Table III shows the M-values in the modern perspective which considers the atmosphere to be made up of 79.1% nitrogen. This is the explanation for the comment in the blue report that the calculations were made "using an inert gas ratio of 0.791."

d. Repetitive dives

As mentioned above, the USN procedures for repetitive diving were constructed by assigning excess gas loadings at the end of the first dive to arbitrary categories or "repetitive groups" and calculating the decay of gas loading in each group during the surface interval (loadings ranged between the value when equilibrated at the surface and the maximum allowable in the limiting compartment). Again arbitrarily, the decay or unloading of the compartments (each according to its half time) was assumed to be limited by the then-longest compartment, a half time of 120 min. For the normal range of Navy air diving, much of it with decompression stops, this was an effective choice. The method of displaying this half time in table format was to calculate the decay in each group according to blocks of surface interval time, which would arrive at a new level of gas loading for the 120 min compartment at the end of the interval. This new loading was considered to be present at the start of the repetitive dive, and this was implemented as a "residual nitrogen time." This method is basically conservative; it is made more so by the several steps, each of which groups times, depths, and/or gas loadings and requires that the worst-case end of each group be used (the value is rounded up to the maximum for the group).

The RDP uses a similar scheme, with some important modifications. First, because the RDP is dedicated to recreational no-stop diving a shorter limiting half time was used for repetitive diving, 60 min. This was arrived at by iterative calculations (using the entire half-time set and the M-values discussed above) which checked all ranges of dives that reasonably might be encountered. The 40-min half time was an early choice, but it was not sufficiently limiting for a sequence of long, shallow dives.

Another modification is that the RDP uses a larger set of repetitive groups. USN divides all possible excess gas loadings into only 16 groups. The RDP divides possible excess gas loading evenly into 26 groups, using the entire alphabet. This makes it somewhat less "coarse" than the USN method. Further, RDP values are displayed to the nearest minute rather than being rounded to 5-min increments as the USN tables are.

e. RDP multilevel diving

The last stage in modification of the Haldane algorithm was providing for multi-level diving. This is a procedure whereby a diver can spend some time at an original dive depth, then ascend to and spend time at one or more shallower depths on the way to the surface. The total process for developing the RDP procedure was somewhat tedious but not mathematically complex or unique. It is based on the traditional practice of limiting dive exposures by empirically determined ascent constraints. The M-values derived from the no-stop limits were used to limit multilevel diving in a similar manner to that of repetitive diving. This was done using gas loadings as discussed for repetitive diving. The groups were defined by iterative calculations.

Table IV. Range limits on multilevel dives. Limits prevent second level from being impractically close to the first level.

Range of the first depths	Maximum depth of next level
140 - 120	80
110 - 95	70
90 - 80	60
75 - 65	50
60 - 50	40

This development process resulted in a few salient considerations in order to simplify the display by eliminating categories of limited usefulness (such as the second level of a multilevel dive being too close to the depth of the first). All depths after the first must be shallower than the previous depth, according to a set pattern (displayed in Table IV), and calculations provide for at least 5 minutes at any subsequent level. Ascent times are not included in the time spent at a given level.

RER performed calculations for all combinations of maximum allowable time at the first depth followed by a shallower second depth; this process was repeated for subsequent depths shallower than the second, again following the minimum step restriction of Table IV. The multi-level limits of this algorithm frequently add extra conservatism, being designed to generate gas loadings that may be equal to but are generally less than the relevant M-values.

Information on multilevel diving is provided only with The Wheel and not with the "flat" tables.

f. Flying after diving and diving at altitude

The RDP does not calculate for either flying after diving or diving at altitude. Instructions on the planner say that it is useable to an altitude of 1000 feet. RDP-specific corrections are available for those who plan to dive at altitudes greater than 1000 feet. Both The Wheel and the table have flying after diving procedures printed on them which are in a typical format; they include some consideration for the type of diving that has been done.

g. The Wheel

The final step in the RDP development process was the creation and completion of "The Wheel." The Wheel is a hand calculator similar to a circular slide rule. It includes methods of determining initial (Rogers, 1989) no-stop times and a continuous, linked, sequence of multilevel and repetitive dives. The terms RDP (Recreational Dive Planner) and "The Wheel" are often used interchangeably, but strictly speaking RDP refers to the computational method and The Wheel is a method of implementing it. A "flat" table also produces the same RDP results as The Wheel (or vice versa), but the flat table does not include specific means of calculating multilevel dives and is limited to 10 fsw depth increments and fixed times. A cue card supplied with The Wheel guides divers already trained to use it through the steps.

The circular format allows linear numerical scales to be used along with curves that deal with the non-linear aspects of the calculation. The Wheel has two sides. Side One calculates no-stop time (called "NDL," the no-decompression limit) and the "PG" or pressure group (repetitive group). The next level on a multilevel dive is calculated directly after the depth and time of the first level are known (subject to the limitation that the next level has to be sufficiently lower than the current level, Table IV).

For repetitive calculations the credit during the surface interval is obtained from Side Two, resulting in a new PG. This is then used to reenter the process on Side One. The Wheel does not do decompression stops. If stops are required, instructions are given for using a fixed stop pattern with both The Wheel and the flat RDP table. For exceeding the table bottom time by no more than 5 min a stop of 8 min at 15 fsw is required, and the diver must remain out of the water for 6 hr. If the no-stop limit is exceeded by more than 5 min a 15 min stop at 15 fsw is called for (gas supply permitting), and the diver is not to dive again for 24 hours. These are called "emergency" stops in an effort to emphasize that they are not to be done regularly, albeit an inappropriate term.

Required "safety stops" are called for when the diver is within 3 pressure groups of a no-stop limit, and for any dive to 100 fsw or greater. The "safety stop" is 3 min at 15 fsw. The fact that this is a "safety" stop does not make it optional. Such stops are good practice for all dives, and are encouraged (Lang and Egstrom, 1990).

Made of sturdy plastic, The Wheel is waterproof and can be carried on a dive. Reading the values requires some technique in order to ensure reproducible results, but it has been mastered by many thousands of divers. The slight differences that might result from different individual interpretations are well within the conservative limits of the RDP algorithm and normal physiological variability.

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IV. PHASE I TESTING OF REPETITIVE AND MULTILEVEL PROFILES

In order to confirm that profiles generated by the new algorithm were acceptable for use in recreational diving, we set up a test program to simulate their use in recreational diving with human volunteers. Both pressure chamber simulated dives and actual open water dives were performed. We verified the Recreational Dive Planner by two phases of testing. The first phase (covered in this chapter) examined repetitive and multilevel diving in both pressure chamber and open water, and the second phase assessed multiple dives over multiple days, "multiday diving," in the chamber. The primary thrust of the series was to examine schedules designed for recreational divers who perform this type of diving, typical users of the Recreational Dive Planner. Subjects were volunteer recreational divers. We evaluated the outcome of the test dives primarily by careful monitoring for DCS, and also by means of Doppler ultrasonic bubble detection of bubbles in the central blood veins and heart in each diver after diving. Principal investigator for all the tests was MRP; he organized the operations, supervised the dives, and performed the Doppler analyses.

A. Methods: General test plan for Phase I

The Phase I test program emphasized repetitive and multilevel dive schedules. The majority of testing was carried out as simulated dives in a hyperbaric chamber, but a number of actual open water dives were also conducted. Subjects were volunteers from the local recreational diving community; we feel they were representative of the recreational diving population. For the chamber "dives" the divers were pressurized in groups according to selected pressure profiles in the chamber at the Institute of Applied Physiology and Medicine, Seattle. The profiles performed in open water were also performed in the chamber.

1. Tables used and limits tested

The test series examined the new RDP M-value limits. The tested profiles were calculated by one of us, RER, specifically for these tests. In selecting the profiles to test the objective was to cover the range adequately, to minimize testing of profiles and profile combinations that were more conservative than the USN Standard Air Tables, and to stress dives that help demonstrate that no-stop profiles could be based with confidence on the 60 min compartment. Profiles shallower than 100 fsw that were increments of 10 fsw were already established as being more conservative than the USN no-stop tables (Table II) so these values were not emphasized and the levels used were the 5-fsw in-between steps.

A wide spectrum of depths were chosen in an effort to emulate active recreational diving. The surface intervals of the chamber dives were selected to produce the best comparison to U.S. Navy tables with respect to allowable bottom time on the repetitive dive. If surface intervals were sufficiently long they would make the individual dives look more like single dive no-stop limits. On the other hand, short times were preferred for logistical reasons in conducting the texts, and these were good tests because they tended to have high gas loadings.

RER calculated repetitive and multilevel profiles based on gas loading according to this pattern using the RDP model described in Chapter III; RDP M-values are shown in Table III. Where possible, combinations that stressed the 60 min compartment were used.

Every chamber exposure was at least to the "table limit" for that depth. "Table limit" refers here to the schedule that would be generated by The Wheel or selected from the RDP flat table; these are the limits based on the 60 min compartment. First dives, the non-repetitive ones, were to the published RDP limits. For the repetitive dives, in all cases the profiles calculated from the gas loadings were longer than the table profiles. For these we selected for the test dive an exposure time midway between the "table limit" as calculated by the RDP and the calculated limit based on gas loading (in some cases it was necessary to change an earlier step in the sequence to maintain this rule). Thus for these cases the dives actually tested had a slightly longer bottom time than would be permitted by the RDP, an average of about 4 min for the 25 different profiles tested. Stated another way, all of the repetitive dives in this series would have required a decompression ("emergency") stop had they been carried out by RDP rules.

For the open water dives, because of the cold two of the 3 profiles tested (51, 52) were a few minutes (defined as one pressure group) short of the maximum allowable time and did not necessarily meet the "midway" criterion just mentioned; the other (53) was at the limit but not beyond it. Dive 53 would have required a stop by RDP rules (so-called "emergency stop") and all three inwater dives would have required stops under USN rules

We defined for the testing a total of 22 multilevel, repetitive, and repetitive-multilevel profiles for the chamber tests (Profiles 1 to 22), and 3 additional ones (51, 52, and 53) used for both chamber and inwater exposures. A summary of the profiles tested is given in Appendix B1.

Plans were in place to "back off" and reduce the stress of the test dives (and possibly of the RDP) had DCS or too many bubbles developed early in the program. There was no rigid protocol, but it was agreed among the principals that too many bubbles would be a majority of dives with Grade II and higher, consistent bubbling at Grade III, or the occurrence of Grade IV or DCS.

We selected 14 profiles on which at least 15 subjects performed exercise in the chamber. These were Schedules 1-3, 5-9, 11, 12, 14, 18-20. The other remaining schedules were given lesser trials (< 15 subjects) as time and subject availability permitted. Only one profile, number 22, was done without any exercise, but this was only used for two individual dives. Of the 3 profiles used for inwater tests we were able to conduct 24, 25, and 27 dives in the water out of 48, 40, and 43 trials, respectively, with the remainder run in the chamber.

2. Phase I timing

For all exposures that began at surface pressure the "bottom time" is considered as the time from the beginning of pressurization or descent to the beginning of ascent. This is the conventional definition of bottom time.

All other exposures such as multilevel steps are counted as the time at the depth. They do not include ascent time. Ascent time was calculated but is not shown specifically on the profiles. Both descent and ascent rates were calculated as 60 fsw/min. Surface intervals are time at the surface and do not include ascent time. Thus the elapsed time (from leaving surface to returning to surface) for either a square or a multilevel dive, regardless of the number of steps, would be the sum of the time or times listed plus the time to ascend to the surface from bottom depth at 60 fsw/min.

3. Phase I subjects

A total of 234 individuals participated in these tests. Except for a few staff members the divers were recruited from the recreational diving community in the Pacific northwest area. They served as volunteers, and gave their informed consent. Pregnant or possibly pregnant divers were excluded. They were not paid nor reimbursed for expenses; the boat trip to the San Juan Islands was a small reward for those on the open water dives. Appendix A1 lists these divers individually by coded identifiers (not initials), and includes gender, age at the time of the tests, weight, height, calculated body fat percentage, years of diving experience, and profiles to which they were exposed.

Of the total 234, 73 were female, amounting to 31 percent. Although averages of this sort are not especially meaningful, the averages shown in Table V apply to this group.

Table V. Phase I subject descriptions, ± s.d. (range).

	Males	Females
Number 234	161	73
Age, yr	33.0 ± 8.2 (21-63)	32.1 ± 7.2 (23-56)
Weight, kg	80.6 ± 11.2 (57-114)	63.0 ± 10.0 (48-91)
% body fat	21.0 ± 4.0 (13-36)	27.9 ± 4.8 (22-47)

Generally age clustered in the 30 to 35 year range, with most subjects between 25 and 45. Body fat ranged for most of the group between 20 and 30%. Years of diving experience seemed the most diversified, with nearly half the group having two years or less; the remainder were fairly evenly distributed in the 5 to 20 year range.

From this data, it appears that the age distribution of test divers is older than the recreational diver population as a whole, which is about 28 years. The percent of female divers as test subjects was also higher than encountered among recreational divers in the United States, about 25%. More statistical summary information is given later in this chapter.

Percent body fat was calculated from the Body Mass Index (weight/height squared; see Appendix A1 for formulae). These values may be compared with values for a sample of 194 U.S. Navy divers as shown here (Dembert et al, 1984).

Age (years)	n	Weight (kg)	Body fat (%)
20 - 29	125	80.4 ± 9.5	17.0 ± 4.7
30 - 39	66	82.3 ± 10.4	20.4 ± 4.7
40 - 42	3	0.8 ± 17.3	22.7 ± 2.3

4. Exercise and the chamber environment

Exposures were performed as simulated dives under dry conditions in the double lock hyperbaric chamber at the Institute for Applied Physiology and Medicine, Seattle. The chamber is approximately 1.5 m in diameter and 5 m in length. The chamber temperature was maintained at between 75 and 77 degrees F during the bottom time except when the depths were being changed. This warm temperature helped promote perfusion to the extremities. Carbon dioxide levels in the chamber were monitored by a mass spectrometer (Perkin-Elmer MGA). Levels were maintained at less than 0.5 kPa (0.5% sea level equivalent) by means of chamber ventilation.

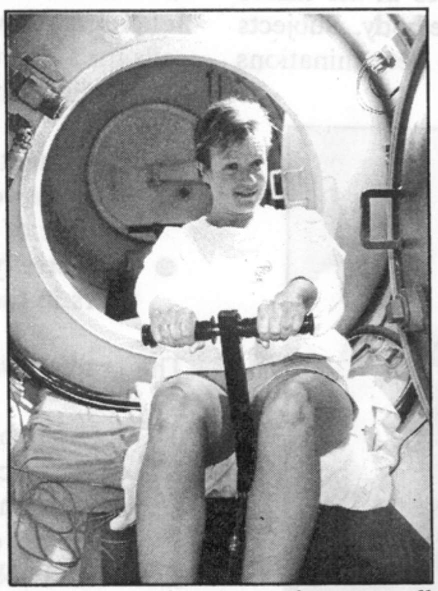

Figure 1. Diver operating a small rowing machine in the chamber.

The subjects exercised in the hyperbaric chamber on small rowing machines (Figure 1). The actual workload was determined at surface with five subjects by measuring the oxygen uptake. Expired air was collected, its volume measured in a spirometer, and analyzed by mass spectrometry. This method gave an average workload of 1.2 ± 0.09 liters O_2/min for this regime. This is equivalent to a moderately hard swim.

At bottom pressure on both single and repetitive dives the subject worked for 2 minutes with a 2-minute pause. This was repeated for up to 30 minutes. If the total time at depth exceeded 30 minutes, the exercise cycle was 2 minutes of exercise and 3 minutes of rest until decompression.

The divers were in a semi-reclining position in the chamber during the entire bottom time. This promoted perfusion to the extremities.

5. Doppler monitoring

Doppler ultrasound bubble detection was performed following each of the repetitive dives; Doppler methods detect only things that are moving relative to the probe. For monitoring we used an instrument made at IAPM, and recorded signals on tape. Pre-dive checks and magnetic tape recordings of each diver were made prior to every chamber pressure exposure (see additional comments on the IAPM Doppler in Chapter V).

We conducted precordial Doppler monitorings between the repetitive dives. In the "precordial" location the probe is placed on the front of the chest and the ultrasound beam is focussed on the pulmonary artery or the right atrium so that it detects bubbles in the mixed venous blood returning from the body. Subjects were standing (Figure 2), and determinations

Figure 2. Diver at rest being Doppler monitored in the precordial location.

were made at 15 minutes and 20-30 minutes after the divers returned to surface pressure. Following the final dive of a repetitive series, post-decompression precordial Doppler determinations were made at 15-20 minutes and 30-40 minutes. If the bubble load in the second reading was as high as the first one or higher then additional readings were made after this to ensure that the bubble count did not increase still further (there is no record that a further increase occurred, and it was not expected). A Combined Score is recorded as the higher one of the set of readings. For the assessment we combined all readings into one final "worst case" score for a given decompression.

Doppler flow signals for each diver were recorded on a separate cassette tape reserved for that specific individual to facilitate easy comparison of several dives made on different days. A reel-to-reel tape was also made for each dive series with voice annotation and with times recorded by a time code generator.

Two different individuals determined the bubble grade at the time of monitoring. The tapes were rechecked at the conclusion of the test series. Grading of the signal was in accord with the scheme developed originally by Spencer and Johanson at IAPM (1974). The Doppler signal calls for a degree of judgement by the observer; the grading scheme nonetheless is:

- Semiquantitative;
- Progressive in character with regard to the number of gas bubbles per cardiac cycle;
- Universally known and employed by researchers in the field of decompression.

The grading was as follows:

0 = no gas bubbles detected in at least 10 heart cycles.
I = occasional gas bubbles detected in 10 heart cycles.
II = few bubbles detectable; some cycles may have 2 to 4 bubbles/cycle.
III = several gas bubbles detectable/cycle
IV = gas bubbles present continuously (systole and diastole), gas bubble amplitude louder than flow sounds.

Roman numerals are used for the grades to call attention to the fact that these are non-parametric data and it is not proper to average them (Nishi, 1993).

After a reading had been taken with the diver at rest, each diver then exercised in a "motion sequence" or "flex" (Figure 3). This motion consisted of two deep knee bends. The Doppler flow signal was monitored for six consecutive cardiac cycles immediately upon standing. The "flex" Doppler signal was graded in a similar fashion to the "at rest" signal. These two were recorded during each reading as two values, designated "R" and "F."

Usually there was time to repeat the readings after 15 or 20 min, with both R and F scores recorded each time. When this was done the higher of the readings were taken as a Combined Score of the various readings following a dive; the Combined Score includes Doppler readings at rest and after flexing, and is the score given in the listings in the appendix to this report.

The system that we employed was not intended to be unique or necessarily superior to others, but it represented a method of achieving internal consistency and gave data that could be related to other laboratories.

6. Open-water tests

The first initial open-water tests were performed in Edmonds, Washington, with the divers departing from the beach. This site was near the hyperbaric chamber in Seattle and was easily and readily accessible in the event of decompression sickness. These dives were not all to the maximum times allowed by the RDP.

The initial design employed three dive floats anchored in 100 feet of water with heavy concrete anchors for support. The descent lines were easy to see and hold. These lines were approximately 25 feet apart on the 100-foot contour with two horizontal "clotheslines" of the same 5/8" line clipped between the vertical lines. This moveable "clothesline" allowed us to set the line at any depth for diver comfort and maintenance of appropriate depth.

Divers were checked out at the beach; they then swam using a snorkel the approximately 150 feet to the floats, where they were checked in/out by a qualified divemaster prior to descent. Upon descent, the divers proceeded to their designated depth, where they spread out on one of the "clotheslines." The system was safe, controlled, and simple. This beach site was employed initially but was abandoned because it did not attract many volunteer subjects and was not deemed cost effective, and it required a surface swim back to the beach. This

Figure 3. Diver being Doppler monitored in the precordial mode while "flexing" with a deep knee bend.

exercise during the immediate post-decompression phase (decompression is still going on) could promote gas washout or bubble formation and might thus be an uncontrolled variable.

For the remaining open water dives the 56-foot dive boat *Starfire* was chartered. This is one of the most popular dive boats in Northwest waters serving the San Juan Islands, the most popular diving area for Northwest divers. In contrast to the beach site, the boat trips attracted many volunteers.

We averaged 20 divers per day. The open-water staff consisted of three PADI instructors, two additional support staff, and the monitoring staff from IAPM; thus we had 10 staff for 20+ divers.

Divers were divided into the three dive profile groups according to experience level. Experienced divers were mixed in with each group of approximately eight people. Each team was color coded (Red, Green, and Yellow teams) using tape on their snorkels for easy in-water identification. Team leaders were selected, and, in all dives there was an instructor or a divemaster; we had in proportion a large number of divemasters and instructors.

Teams were individually briefed on team support and staying on schedule. The teams were initially staged in 10-minute intervals, and thereafter their profiles dictated their schedules. We were able to keep to the schedules by using our staff in a "full-service" capacity. As soon as divers were back on board the boat, their tanks were removed, etc., and the crew exchanged them with full ones for the next dive. This allowed the divers to relax and be Doppler monitored. Since the teams were entering and exiting constantly, this large support staff was absolutely essential to keeping on schedule.

A "live boat" pickup was employed with the boat moving along the wall. Entries and exits were quick and efficient. Divers were allowed to take pictures, spear fish, and otherwise indulge in normal diving activities as long as they conformed to their designated time and depth constraints. Conditions were ideal on all four days of diving, 53-56 degrees F water temperature and clear weather; one day, however, had poor water visibility.

Some divers terminated their profiles as a result of surfacing with their buddies or equipment problems. The primary problem was diver fatigue from constant activity to maintain body temperature and inability to warm up between dives, a consequence of the harsh dive conditions of the Pacific Northwest. Divers who terminated the three-dive sequence for any reason were not counted in the open water series. Thus, those divers listed in the appendix successfully completed all three dives on one dive day. Divers wore either wet suits or dry suits, as was their preference. All divers were briefed to observe safe diving practices, to dive within their comfort zone, and to terminate the dive any time they became particularly uncomfortable. Considering the water temperature, the divers were to be congratulated for their persistence. Even divers using dry suits became wet and chilled toward the end of the day's sequences. These tests effectively stressed the tables being evaluated as well as the divers.

B. Results of Phase I tests

Results of all Phase I exposures are given in appendix B2. A total of 911 man-dives (decompressions) were made, of which 228 were done in the water.

1. Decompression sickness

Decompression sickness was the primary indication of insufficient decompression. There were no cases of decompression sickness in either chamber dives or those done in open water. Some chamber subjects reported skin itching, and there were two cases of migraine headache in one diving subject who has a long history of problems with migraine.

2. Doppler-detectable bubbles

Doppler-detectable bubbles were a secondary stress index. All subjects exposed in the chamber, both those exercising on rowing machines and those not exercising, produced only minimal Doppler-detectable bubbles. Of these most were Spencer Grades I and II, but there were a few Grade III (a total of 5; see Appendix B2). Most of the bubbles detected and most of the scores higher than Grade I were following flexing. Because the cases of detectable bubbles were so scattered and relatively scarce a useful way of analyzing them is by incidence under various circumstances. A summary of these is given in Table VI. A distribution of the Spencer bubble grades among the various profiles is given in Table VII.

The objective of the tests was to evaluate the RDP and the algorithm that generated it. The test dives consisted of a wide variety of exposures, but most had the same degree of stress against that algorithm. Thus it seems more relevant to judge the overall incidences as if all exposures were from the same population rather than to try to pick them apart according to categories with uncertain meanings. The distribution of bubble occurrences among males and females is almost exactly the same as the gender distribution; there was no statistical difference between men and women by a chi-square test. Likewise, the distribution of bubble occurrences appears quite even over the entire age range of 25 to 50.

Within the limits of the method, we did not see much difference in the chamber between the exercising and the non-exercising divers with regard to Doppler bubbles.

Table VI shows some interesting observations. First, a review of the Doppler data on the Phase I exposures in Appendix B2 indicates that the incidences of Doppler bubbles are scattered rather evenly over the entire set of dives. Table VII shows that with almost equal numbers of repetitive and "first" dives the cases of bubbles being detected are divided in exactly the same proportions. Thus there does not seem to be any bias for or against repetitive dives. There seem to be more bubbles in the first dozen dives than in the later ones. A look at the dives in the 50 series shows that there seems to be no higher incidence of bubbles in the water than in the chamber, but chamber dives seem to have higher grades; there are entirely too few data points in this comparison to draw conclusions.

In the Phase I study, some divers exercised on rowing machines while others were at rest. The number of divers with Doppler-detectable bubbles in the two groups was not statistically different by the chi-square test.

Table VI. Summary of incidences of Phase I Doppler scores. A multilevel dive is one decompression so is one dive. A repetitive pair, two dives in one day, is two dives or two decompressions, but one dive set. Dives or readings with a Doppler score of "9" were not included in the totals.

Total number of individual dives (decompressions)	911
Number of dives with exercise	806
Number of dives without exercise	105
Number of dive sets (diver days)	437
Number of dive sets with exercise	377
Number of dive sets without exercise	60
Total number of decompressions with bubbles	70
Total number of dive sets with bubbles	58
Percentage of dives with bubbles (70/911)	7.7%
Percentage of dive sets with bubbles (58/437)	13.3%
Percentage of dives with exercise & bubbles (64/806)	7.9%
Percentage of dives w/o exercise, with bubbles (6/105)	5.7%
% of dives w/ bubbles, readings at rest (16/911)	1.8%
% of dives with bubbles, after flexing (68/911)	7.5%
Number of inwater dives	228
Percentage of inwater dive sets with bubbles (10/228)	4.4%
Number of male dive sets	318
Percentage of dive sets by male divers (318/437)	72.8%
Percentage of male divers with bubbles (43/318)	9.8%
Number of female divers	119
Percentage of dive sets by female divers (119/437)	27.2%
Percentage of female divers with bubbles (15/119)	12.6%
Number of dives by male divers with bubbles	52
% of dives with bubbles, by male divers (52/670)	7.8%
Number of dives by female divers with bubbles	18
% of dives with bubbles, by female divers (18/241)	7.5%

The Doppler results from the Phase I studies in which both wet and dry exposures were made were not significantly different. This can be rationalized by noting that of the three wet dives, only the third was at the table limits. Exposure times were limited because of the cold water of Puget Sound.

Table VII. Bubble grades in Phase I tests. A summary of the different Spencer bubble grades recorded in the Phase I dives. Profile numbers include as decimals the readings from the individual repetitive dives in the set; repetitive dives are shown in boldface type. The higher score of both rest and flex readings is used. No Grade IV scores were observed.

	Profile number	Number dive sets	Doppler bubble grades I	II	III	All
	1.1	25	0	0	0	0
	1.2	25	1	1	0	2
	2.1	18	4	0	0	4
	2.2	18	5	0	0	5
	3.1	20	0	0	0	0
	3.2	20	0	0	0	0
	4.1	5	0	0	0	0
	4.2	5	0	0	0	0
	5	32	4	0	0	4
	6	18	2	0	0	2
	7	15	4	0	0	4
	8	24	3	0	3	6
	9.1	27	1	1	0	2
	9.2	27	2	1	0	3
	10.1	6	1	0	0	1
	10.2	6	2	0	0	2
	11.1	15	0	0	0	0
	11.2	15	1	0	0	1
	12	19	2	0	0	2
	13.1	2	0	0	0	0
	13.2	2	0	0	0	0
	13.3	2	0	0	0	0
	14	15	0	0	0	0
	15.1	5	1	0	0	1
	15.2	5	1	0	0	1
	15.3	5	1	0	0	1
	15.4	5	1	0	0	1
	16.1	2	1	0	0	1
	16.2	2	1	0	0	1
	17.1	4	0	0	0	0
	17.2	4	0	0	0	0
	18.1	15	0	0	0	0
	18.2	15	0	0	0	0
	19.1	17	1	0	0	1
	19.2	17	0	0	0	0
	19.3	17	1	0	0	1
	20.1	17	0	1	0	1
	20.2	17	3	0	0	3
	21.1	3	0	0	0	0
	21.2	3	0	0	0	0
	22.1	2	0	0	0	0
	22.2	2	0	0	0	0
In chamber	51.1	24	2	0	0	2
	51.2	24	0	1	2	3
	51.3	24	1	1	0	2
	52.1	15	0	0	0	0
	52.2	15	1	0	0	1
	52.3	15	0	0	0	0
	53.1	16	0	1	0	1
	53.2	16	1	0	0	1
	53.3	16	0	0	0	0
In water	51.1	24	0	0	0	0
	51.2	24	1	0	0	1
	51.3	24	4	0	0	4
	52.1	25	0	0	0	0
	52.2	25	1	0	0	1
	52.3	25	1	0	0	1
	53.1	27	0	0	0	0
	53.2	27	0	0	0	0
	53.3	27	3	0	0	3
Totals for all dives:		911	58	7	6	70
Totals for initial (first) dives:		437	26	3	3	32
Totals for repetitive dives:		474	32	4	2	38
Totals for chamber dives 51-53:		165	5	3	2	10
Totals for in-water dives 51-53:		228	10	0	0	10

V.
PHASE II TESTING OF MULTIDAY EXPOSURES

A. Introduction

Somewhat coincident with the development and introduction of the DSAT Recreational Dive Planner the practice of "multiday" diving by recreational divers began to be noticed. Resort programs and "liveaboard" diving boats made it possible for divers to enjoy, for example, a full week of diving with several dives every day.

As discussed in Chapter III, the design premise of the RDP is to base repetitive no-stop dives on gas loading in the compartment with a 60-min half time. The USN tables use the 120 min compartment for the same purpose in about the same way, and although there are some known trouble spots in the USN tables, they are regarded as the *de facto* standard (Thalmann 1984 Mar; Weathersby et al, 1986). Since the longer 120 min compartment is better able to deal with longer dives and those requiring more decompression, it was a natural reaction to question whether the repetitive tables based on the 60 min compartment would provide adequate decompressions for dives repeated frequently over an extended time period of several days. It was conceded by the RDP's developers that longer, deeper dives requiring decompression stops would very likely not be handled adequately with procedures based on the 60-min half time compartment, but it was pointed out that this type of diving is firmly outside the domain of the RDP, which is intended only for no-stop diving.

It follows, however, that any decompression plan that allows undissolved gas to form in the body might become less reliable if the exposures are repeated not only several times per day, but over several consecutive days. Thus the question remained as to whether the RDP as the only decompression device being used would adequately handle multiday dives. The basic RDP development had been successful in large part because the Phase I test program was carried out to validate its effectiveness; in conventional repetitive no-stop dives and in the newer multilevel diving practices the RDP provided adequate decompression. It seemed reasonable that a multiday test program might accomplish the same purpose. Thus a multiday test program designated Phase II was devised to follow up on the original (Phase I) series covered in the last chapter. Principal investigator of this operation was MRP.

The Phase II program is in two parts, designated Phase IIa and Phase IIb. Both had the same objective of evaluating the efficacy of the RDP for dives conducted intensively over a period of several days. Decompression sickness occurred early in the first set of multiday exposures; for administrative reasons this caused the first series (now Phase IIa) to be stopped. That series was to be 6 dives per day for 6 consecutive days. After a regrouping the project was resumed as Phase IIb, which was for 4 dives per day over 6 days, and which was completed satisfactorily as planned.

B. Phase IIa, methods and results

1. Methods

a. Phase IIa conditions; same as IIb

The two Phase II studies were done with the same protocol, with the exception of the profiles. Aspects about the protocol are presumed to be the same as Phase IIb and should conform to the IIb descriptions. The series was planned to consist of 6 dives per day for 6 consecutive days. All exposures in this series were dry chamber dives, and the subjects did not follow a specific exercise regime. A total of four subjects participated in this series.

b. Phase IIa profiles

The test series assumed that the RDP had been adequately validated for single days of repetitive and multilevel diving, and the purpose of this series was to demonstrate that it could be used successfully for a greater number of dives per day for an extended number of days.

Profiles were calculated with the RDP Wheel, chosen so that each of the theoretical tissue compartments of the model would repeatedly be titrated to its theoretical maximum, especially in the slower compartments; this calls for long dives and short surface intervals where possible, but this was sometimes restricted by "rules." Every exposure would be to the time limit for that depth whenever possible, but safeguards for use of the Wheel would be observed, including the safety stop and rules for multiple dives or the long surface interval rule (discussed in Chapter 7). A number of tradeoffs had to be made to maintain a stressful dive series. All days ended with the diver in Pressure Group Z, indicating a maximal exposure.

The profiles were selected to represent a variety of dive patterns; some effort was spent in mixing up the possible combinations of depths and of single and multilevel dives. The depth of 130 feet would not be tested, on the rationale that it was tested for 12 minutes in Phase I, and if used it would be conservative because it would require the safety stop. The RDP only allows 10 min at 130 fsw.

The Phase IIa profiles are given in Appendix C1. These were planned as a full 6 days of dives, but only the first two days and a brief part of a third were completed. The plan called for 6 dives per day, run over the period 0800 to 2100. Overall the 6-day period would have included 18 single dives and 18 multilevel dives; on 5 of the six days the dives done early in the day were square and the multilevel dives—with increasingly shallower stops—were later. Of the two days actually done the pattern was as described, with the last dive of the day a 4-step multilevel dive.

c. Phase IIa subjects

Practice at IAPM was to run a preliminary trial of a new project using in-house, usually IAPM, employees to look for untoward and unexpected outcomes. The subjects were an aggregate of PADI employees. They were volunteers for the experiment, and received their usual wages. Their living expenses were reimbursed.

2. Phase IIa results

a. Doppler monitoring

The Spencer Doppler scores following each segment of this study are given in detail in Appendix C1. The scores from Phase IIa had a high level of grades greater than 1. This and the distribution of bubbles are shown in Table VIII.

b. Decompression sickness

This was the only series to experience decompression sickness; this occurred in subject GAR the night after the second dive day. He had no symptoms at the end of the day other than being tired, and he had slight skin itching. He awoke during the night at 0330 with joint pain in the right knee, just under 7 hours postdive. Before the treatment, which followed a few minutes later, the diver was found to have Grade I Doppler signals at rest and Grade III after flexing. There were no findings on a neurological exam. He was treated on U.S. Navy Table 5. He experienced some relief on reaching 1.2 atm ("40 fsw") and was free of pain after 10 min on oxygen at 2.8 atm.

Table VIII. Distribution of Phase IIa bubbles. The subject with decompression sickness was GAR. He showed the lowest level of bubbling, while MOM, who had no symptoms, had more than half of all the bubbles detected in this group.

	Runs with bubbles	% of runs with bubbles	% of total	Runs with bubbles >1	% of runs with bubbles	% of total
GAR	5 of 40	12.5	11.4	3 of 40	7.5	10.3
KEJ	6 of 47	12.8	13.6	4 of 47	8.5	13.8
MOM	25 of 47	53.2	56.8	18 of 47	38.3	62.1
SHK	8 of 45	17.8	17.8	4 of 45	8.9	13.8
Totals:	44 of 179	24.6	100.0	29 of 179	16.2	100.0

This subject was later found to have sustained bilateral knee injuries in a motorcycle accident three years prior to our dive series. After the treatment no bubbles were detected.

The third day was started without the treated diver, but the project was terminated after the first dive. The agreed-upon protocols had called for termination in the event of decompression sickness (which are discussed in Chapter VII), and this was done.

Counting the one dive with 3 subjects on the third day, Phase IIa had a total of 51 man compressions.

C. Phase IIb

1. Methods

a. Phase IIb dive profiles

After the cancellation of Phase IIa a new approach was needed. The test was recalculated, changing from six dives per day to four dives per day, for the same six days. The chosen format called for two morning dives, an afternoon dive, and a night dive. This distribution would be typical for many divers and because of the night dive would also serve to minimize the overnight surface interval, which might leave less time for outgassing of the slow compartments and thus improve the test of the multiday concept. Further, it left a couple of hours in the middle of the day for the hyperbaric medical facility to treat patients in the chamber.

An additional modification was to change the final dive from a complex multilevel dive to a simple square dive. The original rationale for ending with multilevel dive was that this was the best way to sustain high pressure in slow compartments. But another viewpoint was that the multilevel set was a sort of decompression that would remove the most stressful part of the gas load. Further, since the last dive was to simulate a night dive, a single square dive seemed to be more typical of actual diving practices. The dive times of the test program followed this daily schedule.

Some compromises had to be made in attempting to maximize the stress, and this was both complicated and helped by the longer surface intervals. The optimum depth range to stress the 60 min compartment would call for very long dives. The last dive would follow a long dinner surface interval, and the permitted dive time would probably exceed both endurance and air supply of most divers. For this reason on three of the days (1st, 3rd, and 4th) the final dive was shortened to 90 min; on the other days the final dive was a "full time" dive.

Dive schedules were calculated with The Wheel, as in Phase IIa. For any given depth, all dives were to the maximum time permitted. All rules for use which are in the printed instructions were followed. These are:

- A "safety" stop at 15 fsw for 3 minutes is required;
- All pressure changes were made at the rate of 1 fsw/second or 60 fsw/min (0.3 msw/sec);

and if there are to be more than 3 dives in a day:

- After any dive ending in Group W or X the minimum surface interval for all subsequent dives is one hour;
- After any dive ending in Group Y or Z the minimum surface interval for all subsequent dives is 3 hours.

The schedules were repeated 5 times to collect data for the twenty divers. The profiles are given in Appendix C2 and the results in C3.

b. Subjects

Twenty volunteer recreational scuba divers participated in these Phase IIb studies. They were paid $70 per day, and were told that once they started they would receive the entire amount of $420, and that it was not contingent on their completing the series; all subjects remained. Their individual physical characteristics are given in Appendix A3. There were 12 males and 8 females. The averages ± the standard deviations (and group ranges) are given in Table IX. None were pregnant.

Written, informed consent was obtained from all subjects. Each was free to withdraw at any point in the series. Divers ate their customary foods. They were instructed to retire not later than 11 PM and not to consume more than two glasses of wine or two bottles of beer at night.

Table IX. Description of Phase IIb subjects, ± s.d. (range).

	Males	Females
Number 20	12	8
Age, yr	39.08±11.62 (21-61)	36.38±7.76 (24-45)
Weight, kg	87.30±14.76 (59.1-111)	61.50±7.96 (50-75)
% body fat	20.54±5.90 (15.5-36.0)	26.74±5.28 (21.6-35.3)

For reasons of monitoring and safety, all subjects were housed together in double rooms, at no cost to them; lunches were provided. Travel was not reimbursed, but all were local residents.

c. *Exposures and exercise*

All Phase IIa and IIb exposures were performed under dry conditions in the IAPM chamber under the same conditions of Phase I, mentioned in Chapter IV. Ambient temperature was maintained between 25 and 26° C (75 and 77° F). The chamber was vented as needed to maintain the carbon dioxide at less than 0.8 kPa (or percent sea level equivalent); it was monitored by means of a Perkin-Elmer MGA mass spectrometer gas analyzer.

There was no planned exercise regime in Phase II, and the subjects were generally partially recumbent. However, the divers exercised *ad libitum* on the rowing machine, to avoid boredom. The level of exercise was not recorded, but it is felt that these divers generally exercised at least as much as those in Phase I. MRP observed during Phase I that many subjects found the prescribed exercise to be a rigorous effort, and concluded that it was not appropriate to attempt to expose these recreational subjects to levels based on U.S. Navy exercise tests.

In the series only 5 dives were missed; 1 subject, a substitute for a missing test subject, missed 4 of them.

d. *Doppler monitoring*

Doppler ultrasound monitoring was performed on each diving subject after each dive segment using a 5 mHz, continuous wave instrument made at the IAPM. The audio output was filtered to pass frequencies above 900 Hz and thus removed much of the cardiac wall motion noise. The probe used a transducer made by Carolina Medical Electronics that is unfocussed and has a cylindrical beam 9.5 mm in diameter; normally the probes made for bubble detection use two crystals focussed at about 5 cm. The unfocussed probe allows the bubble signal to be isolated from the majority of background heart valve noise.

The Doppler monitoring was done in two determinations at 20-25 minutes after surfacing, and again 45-50 minutes post surfacing. The reading was taken in the precordial location, with the subject standing. Two readings were taken at each determination, first with the subject standing at rest, and then after two deep knee-bend ("flex") maneuvers.

Monitoring was performed by several individuals, but one of us (MRP) did all the grading to ensure consistency over the entire course of the series Phase I and Phase II. Recordings on magnetic tape were made for post dive analysis if desired. All the Phase II readings were scored again by an additional investigator skilled in Doppler monitoring (RD). We used the grading scheme of Spencer, described in Chapter IV.

2. Phase IIb results

a. *Phase IIb Doppler monitoring results*

The scores for all Phase IIb exposures are given in Appendix C3. Each diver in each profile has as many as 8 scores. These are for the first and second determination, at rest or after flexing for each (R1 and F1, and R2 and F2). The score given by the second investigator is shown along with the score of the first, separated by a diagonal mark (see next section).

By subject, 3 subjects had no bubbles detected, two had only one instance, and two had only two instances. Grades I and II were detected in 5, and 7 subjects accounted for all the Grade III scores.

In order to have a better idea of the distribution of the bubble incidences we plotted the time course of Doppler scores for each subject throughout each 6-day series. These are shown in Figures 4a and 4b, which follow, with 10 subjects in each figure. A profile of the 6-day exposure is shown in the center of each figure, which provides a graphical look at the overall exposure series. The horizontal axis shows time in days, and the vertical axis shows Spencer grades (in arabic numerals) for the individual subjects and depth in fsw (pressure, increasing downward) for the profiles. Vertical bars show the Doppler grades, the highest score for as many as 8 values determined from each dive; these are readings at rest and after flexing, on the first and second determinations, with each score judged by the two investigators. A very small bar, essentially a dot, shows where a reading was taken with a score of zero. A careful look at the graph shows the Doppler score at the very beginning of each surface interval (for consistency), but it was done as stated, beginning about 15 min after the diver reached surface pressure.

b. *Problems related to the second Doppler investigator*

Some aspects of the conduct of the experiment are contained in a report prepared by RD as an after-the-fact confirmation or "second opinion" on the Doppler scores in both parts of Phase II (Dunford, 1990). The report is critical of some of the methods, and the scores given by RD make it a bit more difficult to understand and analyze the Doppler results. RD's scores are given for each Doppler reading in Appendixes B2 and B3, after the diagonal.

Two points about the Doppler monitoring need to be made. First that the Doppler monitoring was done essentially for research purposes. We did not know what to expect from the repetitive dive situations and felt this monitoring would provide a foundation for assessing them. Second, that the tapes were recorded by MRP for his own use and were never intended to be suitable for use by others. They were a type of notebook entry, and served as a record of each exposure and its monitoring. The Doppler grades were scored at the time of measurement by MRP and another IAPM technician who was present at the time (usually Mark McDaniel).

RD performed his analysis entirely from the tape recordings prepared during the initial Doppler monitoring. RD's report contains detailed explanations of Doppler monitoring technique and specific comments on many of the readings. Because of signal quality he had reduced confidence in some of the readings, some of which were given a score of "9," which means that a Doppler grade could not be assigned at all. The use of the 9 for unreadable signals is an innovation of RD. It is especially important because it prevents poor signals from being recorded as zero by default; if a definite positive score cannot be assigned but it is also not clear that the reading was free of bubbles then it is best to assign no score at all rather than a zero which may be inappropriate. There are two issues here, one of getting a valid reading, the other of what grade to assign.

According to his report RD used a different philosophy from the IAPM investigators (generally MRP). While the IAPM investigators tended to record only those signals that were unquestioned (their "monitoring philosophy" was not documented), RD tended to accept signals as positive if they were highly plausible. Differences were in both directions, but the predominant trend is that RD gave more positive scores and higher grades than did the IAPM team. Of the dives with a positive score, in 25% the two investigators agreed. In 50% the difference was within one grade (they varied in both directions, but in about 3/4ths of these RD gave the higher score), but in the other 25% of the differences RD gave a score 2 or 3 grades higher (Table 6, Dunford 1990). Doppler technicians often disagree, but usually by a difference of about one grade.

According to RD the unfocussed probe showed two special characteristics. First, it often received extremely clear flow signals with no bubble sounds (being able to hear the sound of flowing blood is a critical part of Doppler technique), but when it recorded signals with high background noise they often contained sounds that were apparently—but not clearly—bubbles.

We took an approach in this analysis different from RD regarding 9's. In many cases (15 in IIa, 60 in IIb) he scored a 9 when the problem was that there was no tape recording available or it was inadequately labelled. We do not consider these as 9's in this analysis because the problem was not an unreadable signal, it was no signal at all. Further, we have a score by another investigator. Therefore these grades are listed in Appendix C3 as dashes, indicating that RD was unable to grade the reading. RD's report says readings graded with a 9 constitute 6.8% of the total readings graded, but when the 9's due to no tape recording are removed the percentage is 3.3%. We can assume that in many of these cases MRP was able to make an assessment confidently, but the resulting recording was of poor quality. In establishing the totals, both in tables in the appendix and on Figures 4a and 4b, we used only scores that were documented.

Zeroes need a good signal also; a bad or unclear signal in which no bubbles are heard is best scored as no reading at all. This was our philosophy. On the other hand, if an unquestioned positive score was recorded in any of the 8 scores recorded for a dive, then that dive is decisively listed as having a positive Doppler score.

We arbitrarily defined an algorithm for determining a zero score in the presence of 9's. If in any reading the first investigator recorded a zero and the second a 9, then this would not be counted as a valid zero reading because the quality of the signal was questionable. We got very few positive scores in the first determination that did not also get a positive score in the second, therefore we could say that if there are two good 0 pairs in the second determination (R2 and F2) then we score a 0 with moderate confidence even if R1 and R2 are incomplete. Also, as a special case so as not to bias the analysis excessively toward high scores as a result of missing data, if there is only one 9 in all the readings after a dive with all the rest of them zero, we record this dive as having zero bubbles. As mentioned, the score of the first investigator is taken in cases in which no signal was available to the second investigator.

There were several problems with both the experiment and the results, according to RD. One was that the tape was running continuously from the subject identification until the probe was removed, with one channel recording the signal and the other an open microphone for investigator comments; the signal channel was recorded at a fairly low gain. This setup made a problem for RD, because when the probe was removed it made a loud crashing sound that was very disconcerting if not damaging to a listener trying to pay attention to subtle sounds.

According to RD the recordings do not seem to follow a strict recording regime (discussed earlier in this section). Most recording periods vary between 5 and 30 sec, some are even shorter. Sometimes the signal to flex was not heard; in many cases it was difficult for RD to tell from the recording when the flex began, but often he could deduce this from the signals. After flexing the recording period was supposed to be based on the bubbles detected in 10 heartbeats, but frequently fewer heart cycles than this were recorded.

These observations by RD are correct and consistent with the original purpose of the tapes, as solely a documentation of the event. They were not taken as a replication of data.

c. *Decompression sickness*

There were no cases of frank decompression sickness in any of the twenty divers during the Phase IIb series. At the end of the six day study some subjects expressed that they felt a greater degree of lethargy than might be expected for the activities of the week. One diver spoke of soreness in an upper extremity but this was not of sufficient intensity to report, and she was not sure that it was related to the diving. It was revealed several weeks after the close of the study in the course of another conversation, so a test of pressure was thus not possible.

d. *Bubbles according to gender*

In the Phase IIb study, in which the same individuals performed the numerous dives of the multiday series, the number of dives in which men had detectable bubbles was greater than that of women. This was significant at the $p < 0.05$ level by the chi-square test. The small number of separate individuals must not be discounted in assessing the significance of this result. In Phase I there was no discernable difference between the genders.

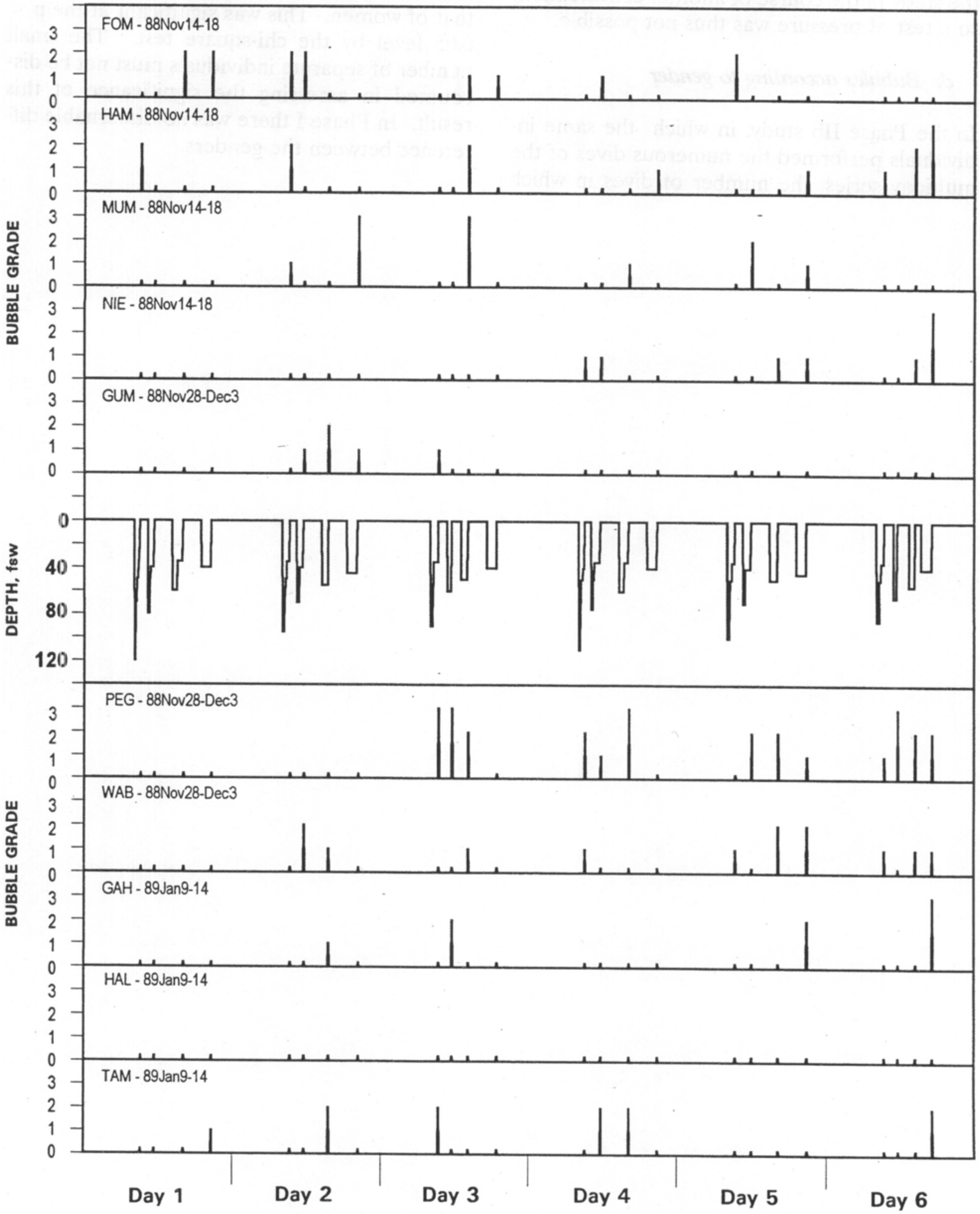

Figure 4a. Doppler scores in Phase IIb multiday series. Center of figure shows profile as depth in fsw for the 6 days. Doppler scores are Grades 0, I, II and III, shown as height of bars; see arabic numbers on y-axis. Small marks are Grade 0, showing a doppler reading with no bubbles detected; other grades are proportional.

FIG4A.XLS Chart 1

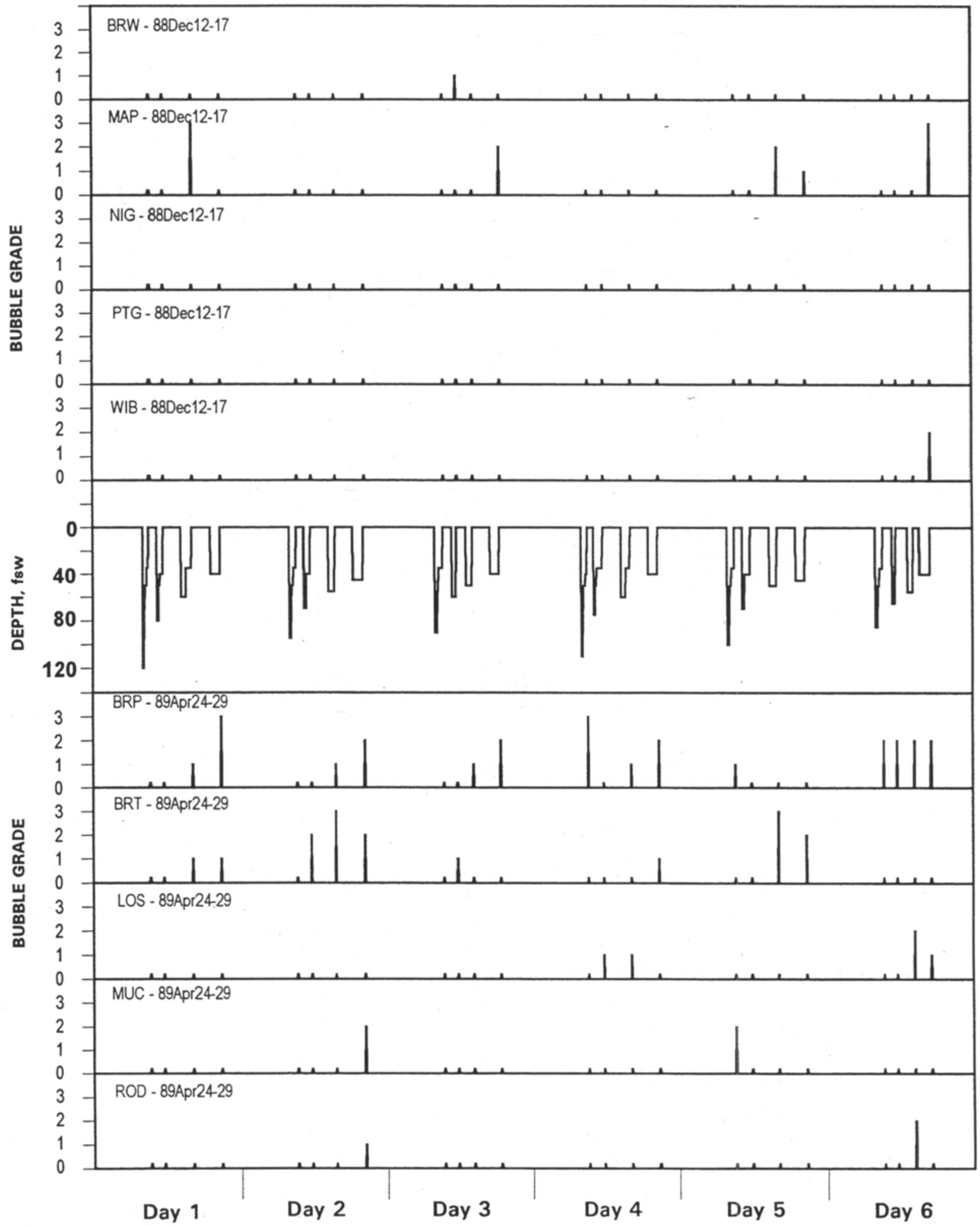

Figure 4b. Doppler scores in Phase IIb multiday series. Center of figure shows profile as depth in fsw for the 6 days. Doppler scores are Grades 0, I, II and III, shown as height of bars; see arabic numbers on y-axis. Small marks are Grade 0, showing a doppler reading with no bubbles detected; other grades are proportional.

FIG4B.XLS Chart 1

VI. ANALYSIS OF RESULTS

This chapter provides an overview analysis of the project, covering the testing done, the results with regard to the RDP, and some peripheral findings.

A. Aspects of the testing

1. Data points

It might be helpful to review some definitions. One source of possible confusion in this type of study is in the definition of a "unit data point." We are considering that a "dive" is an exposure to pressure followed by a decompression (a no-stop or "no-decompression" exposure is indeed followed by a decompression, albeit without stops). The individual "dives" in a repetitive sequence are considered as dives. The repetitive "set" of dives or days of diving may also provide an additional data point in another sense, the outcome of a repetitive sequence. The same interpretation could also apply to each complete Phase IIb 6-day exposure by each diver; the final outcome of this multiday exposure is itself a single data point.

The definition of a dive is further complicated by the Doppler monitoring. After a dive there may have been only one "reading," or "Doppler run" (such as after the Phase I dives), during which recordings were taken at rest (R) and after flexing (F). This is two distinct measurements, (R and F) but in this analysis we have lumped these into a single combined ("worst case") score. After the Phase II dives there were two such readings, giving 4 scores, which can be combined to determine whether that dive caused any bubbles. In Phase II two scores are shown because of the second investigator's grading.

Thus Phase IIb had 475 individual dives (480 less 5 that were incomplete), 117 all-day sequences (120 less 3 incomplete days), and 20 week-long exposures (ignoring the 5 missed dives).

The words "profile" and "exposure" are used in a general sense, and can refer to a dive or a dive sequence; they are defined by their context.

2. Selection of profiles for testing

There are two main considerations about the profiles used for the testing. The first asks whether they tested the RDP sufficiently against its own limits, and the second considers how the tests related to other limits such as those of the USN tables.

During Phase I all repetitive dives tested were calculated to be at a point of theoretical gas loading midway between the level produced by The Wheel and the theoretical maximum (e.g., the M-value) for that point (except profiles 51 and 52). The full model limit was not tested; some critics have suggested that this should have been done. However it is the RDP, not the algorithm, that would be used in the field, so it was felt that it was the RDP that should be tested. Another good argument is that if the tested profile exceeds the "table" profile by a large amount and the results show an unsatisfactory outcome (in this case, too many bubbles or too much DCS) then one could not say for sure whether the bad outcome was due to the table profile or to the excess. Under the circumstances the risk of failure by taking this approach was felt to be too high, but it is clear that the experiment might have been tidier had the whole algorithm been tested.

For Phase I the dives were calculated to be just beyond the maximum time allowed so pressure groups are atypical. In Phase IIb a measure of the extent of the test series is the pressure group reached at the end of dive; of the 24 different dives there was one that reached U, 3 that reached V, and the rest were W or beyond, with 9 Z's. This is summarized in Appendix D.

The tests as they were carried out do not necessarily show the difficulty of conducting tests that specifically stress the 60 min compartment in no-stop diving. This was what we wanted to do, of course, because this is the fundamentally new thing about the RDP model, that it uses the 60 min compartment for repetitive dives. Many profile pairs controlled by the 60 min compartment are less than those the USN limits allow. The no-stop depths controlled by the 60 min compartment are 35 and 40 fsw, so deeper dives do not meet the criterion (they are not controlled by the 60 min compartment) but are more typical of what should be tested. The only suitable way to test the 60 min compartment is to work around the zone where the 60 min compartment controls and do as many replications as possible. This is ultimately what was done.

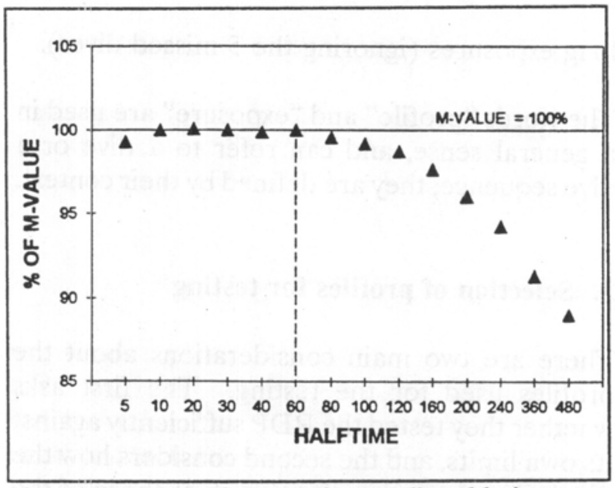

Figure 5. Approach to maximum allowable inert gas pressure. The degree to which each compartment approached its M-value limit at some time over the entire experiment is shown on the vertical axis. The 5-min compartment does not become limiting in dives no deeper than these. Note that compartments 10 through 80 min were essentially saturated at some time in the series.

Thus the testing consistently exceeded the RDP limits, but the underlying algorithm was **not** tested to its complete theoretical limits in this project. Because of this it is relevant to apprise others who might want to use the RDP algorithm itself for other applications, such as, for example, a dive computer, about this aspect of the testing.

3. Approach to M-values

One way to determine if limits were tested is to look at the theoretical gas loadings attained in the exposures. Figure 5 shows the approach to the allowable gas loading according to M-values over the three phases (I, IIa, IIb). It shows that all compartments through 80 minutes were essentially saturated at some time in the series. It also shows that even an **intensive** dive series with dives consistently to or beyond the limits, still does not fill the longer compartments. These longer compartments are those that would be expected to load up in multiday dives. The 5-min compartment is not limiting for dives as shallow as these; it only becomes limiting in short, deep dives with rapid ascent.

We took a more specific look at the approach to limits in Phase IIb. Phase II was carried out to see if using the 60 min compartment to control repetitive dives would hold up in multiday use. Figure 6 shows the approach to the M-value in the 40, 60, 120, and 480 min compartments throughout the Phase IIb exposure. It can be seen that the shorter of these compartments do get limiting (the peaks touch the M-value line), but the slow or long compartments stabilize at levels well below the limit. The primary reason for this is the limited decompression stress of no-stop diving.

4. Relevance to USN limits

Earlier reports on Phase I of the RDP test project (Powell et al, 1988) have compared calculated inert gas loadings from these exposures with the U.S. Navy M-values (shown in Table I). For the record we include the essence of this analysis in Table X. This table shows the Phase I profile number, the maximum percentage of USN M-values, and the compartment having that maximum. The meaning of this analysis is that these exposures, even though most are beyond what would be allowed with the RDP, are almost universally less than the maximum

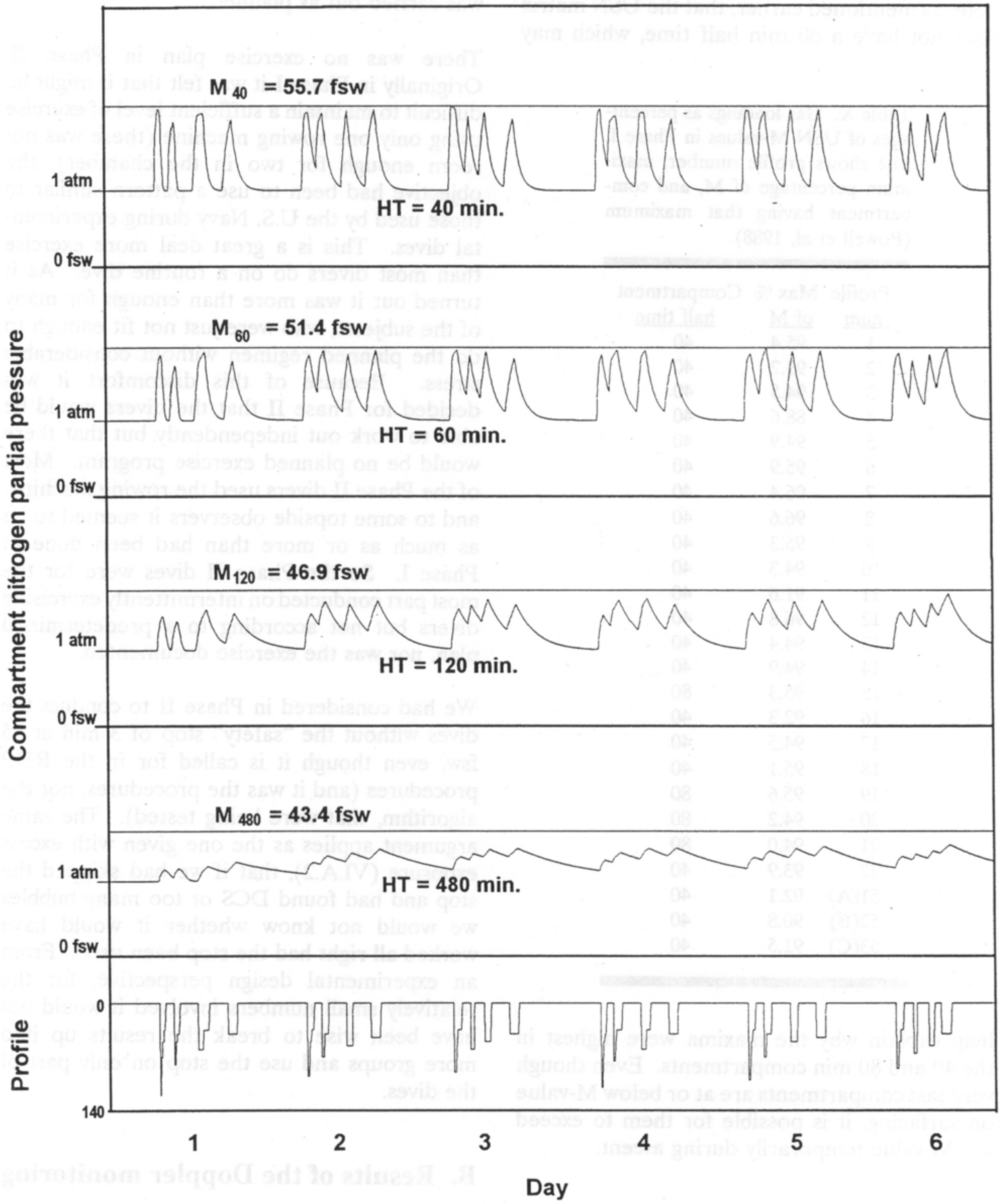

Figure 6. Buildup of gas loadings in Phase IIb multiday dives. Calculated nitrogen partial pressures in compartments with half times of 40, 60, 120 and 480 minutes. This shows that short half time compartments approach their M-values, but for long compartments, even after several days of diving, the peak partial pressures are still well below the theoretical allowable maximum.

FIG6.XLS Chart 1

allowed values of the USN air model. Please note, as mentioned earlier, that the USN matrix does not have a 60 min half time, which may help explain why the maxima were highest in the 40 and 80 min compartments. Even though very fast compartments are at or below M-value on surfacing, it is possible for them to exceed the M-value temporarily during ascent.

Table X. Gas loadings as percentages of USN M-values in Phase I. List shows profile number, maximum percentage of M, and compartment having that maximum (Powell et al, 1988).

Profile num	Max % of M	Compartment half time
1	95.4	40
2	93.2	40
3	94.5	40
4	88.6	40
5	94.9	40
6	95.9	40
7	96.4	40
8	96.6	40
9	95.3	40
10	94.3	40
11	91.6	40
12	96.8	40
13	94.4	40
14	94.9	40
15	95.3	80
16	92.3	40
17	94.5	40
18	95.1	40
19	95.6	80
20	94.2	80
21	94.0	80
22	93.9	40
51(A)	92.1	40
52(B)	90.8	40
53(C)	91.5	40

5. Execution of dives

There were the usual delays for ear clearing and similar minor deviations from the profiles, but the overwhelming part of the entire study was carried out as planned.

There was no exercise plan in Phase II. Originally in Phase I it was felt that it might be difficult to maintain a sufficient level of exercise using only one rowing machine (there was not room enough for two in the chamber); the objective had been to use a pattern similar to those used by the U.S. Navy during experimental dives. This is a great deal more exercise than most divers do on a routine dive. As it turned out it was more than enough for many of the subjects, who were just not fit enough to do the planned regimen without considerable stress. Because of this discomfort it was decided for Phase II that the divers would be able to work out independently but that there would be no planned exercise program. Most of the Phase II divers used the rowing machine, and to some topside observers it seemed to be as much as or more than had been done in Phase I. So the Phase II dives were for the most part conducted on intermittently exercising divers but not according to a predetermined plan, nor was the exercise documented.

We had considered in Phase II to conduct the dives without the "safety" stop of 3 min at 15 fsw, even though it is called for in the RDP procedures (and it was the procedures, not the algorithm, that were being tested). The same argument applies as the one given with excess exposure (VI.A.2), that if we had skipped the stop and had found DCS or too many bubbles we would not know whether it would have worked all right had the stop been used. From an experimental design perspective, for the relatively small numbers involved it would not have been wise to break the results up into more groups and use the stop on only part of the dives.

B. Results of the Doppler monitoring

Since there were no clear cases of decompression sickness in Phase IIb (and none in Phase I), the evaluation of the risk in multiday diving was examined with respect to the quantity of Doppler-detectable bubbles using the Spencer scale.

1. Subtle grades

In general, the Spencer Doppler grades were low (less than Grade II for subjects monitored in the stationary or resting mode) for all test phases. It was first advanced by Powell (1974, 1977) that the probability of decompression sickness could be predicted better by correlation with a Doppler bubble grade rather than simply the presence or absence of Doppler-detectable bubbles. This has been further refined more recently with further indications that the incidence of decompression sickness is low when Doppler grades of II and lower are found. It has been shown that grades of III or more tend to be associated with DCS, but that scores of II or less are not (Vann, 1982; Sawatzky and Nishi, 1990; Sawatzky, 1991; Nishi, 1993). That is in accordance with the experience of these studies with their low incidence of DCS problems. Interestingly, in Phase I there were far more Grade I than II and III, of which there are about the same number of each (Table VII), but in Phase II Grades I and II were more nearly the same and there were fewer Grade III.

Except for this observation, because bubbles were so scattered and there were so few high bubble scores we did not attempt to make much more of the grades. According to this analysis, then, the RDP did quite well in both completed phases of this test program. The statistical methods which have revolutionized decompression research in the last few years (Weathersby et al, 1984; Weathersby et al, 1986) work best when there are bends cases to be assessed.

In a sense the "combined score" approach we used effectively ignored any information from the resting Doppler readings, since the reading after flexing was virtually always at least as high a score as the score at rest (all but 2 times in Phase IIb, every time in I); most often it was higher. The lack of bubbles at rest has on occasion been taken as an indicator of a tolerable decompression despite any bubbles shaken loose by the flex.

Another way to look at data of this sort is with binomial statistics; these are useful for yes-no type data. The binomial distribution can be used to estimate the DCS risk of these trials. Grouping the exposures of Phases I and IIb together (0 DCS in 1386 man-dives), the 95% binomial confidence limits on DCS risk are about 0-0.3%. Similar limits for Phase IIa (1 DCS incident in 51 man-dives) are 0.05-10.07%.

As descent on a repetitive dive (i.e., recompression) might prevent an incipient DCS incident, this treatment of the data is not appropriate. A better approach to binomial confidence limits for repetitive diving uses "man-profiles" or repetitive dive sets rather than "man-dives." With this definition and assuming each of the six dive days of Phase IIb to be independent, the 95% confidence limits for the 517 man-dive profiles of Phases I and IIb are about 0-0.7%.

The effects of multi-day diving on DCS risk, however, are somewhat ambiguous. Recreational diving accident data from the Divers Alert Network suggest increased risk (Vann et al., 1989) while data from tunnel workers suggest decreased risk (Walder, 1975), but these are variable profiles and not controlled laboratory studies. The six days of diving in Phase IIb, therefore, should be considered a single profile. With the 457 man-dive profiles of Phases I and IIb (see Table 2), the 95% binomial confidence limits are 0-0.8%.

Even this restricted treatment has shortcomings as it assumes all profiles to be of equal DCS risk, an assumption which is frequently inconsistent with experience. In the strictest sense, binomial statistics are applicable only to multiple trials of the same profile. The largest number of trials per profile was 48 (Profile A, Phase I), for which the 95% confidence interval is 0-7.4%.

In summary the degree of gas phase formation as measured with the Doppler ultrasonic flowmeter was well within the desired criteria.

2. Comparison with DAN data

Another way to evaluate the bubbles seen in the DSAT study is to compare them with the level of bubble formation seen in "ordinary" recreational diving. To this end the Divers Alert Network (DAN) has sponsored studies in which experienced Doppler investigators monitor divers in their customary diving activities.

The data labelled "DAN" in Tables XI and XII were taken from work by Dunford and colleagues (1988; 1991; 1992) in research conducted by DAN on the habits of recreational divers on live-aboard dive boats. These authors used the Kisman-Masurel bubble grading method (Nishi and Eatock, 1980) which employs flexing (hand squeeze and knee bend) and is reducible to a 0-IV scale as in the Spencer (1976) grading system. In one DAN study there were 106 divers, each of whom made an average of 2 dives per day with a mean total of 5 dives. The mean depth was 70 fsw, and computers were used on half the dives.

In Phases I and IIb, bubbles were detected after 7.4 and 10% of all dives while there were bubbles after 33% of the Phase IIa dives. For comparison, 19% of the DAN divers had bubbles.

A chi-square test indicates that the difference in total bubble incidence between Phases I and IIb was not statistically significant, but the differences between Phases I and IIa and Phases IIa and IIb were highly significant ($p<0.00001$). Phases I (7.4%) and IIb (10%) had significantly fewer bubbles than the DAN divers ($p<0.00001$) while Phase IIa (33%) had significantly more bubbles ($p<0.01$).

All four divers in Phase IIa had bubbles several times during the dive series. Their individual bubble incidences (divers with bubbles/total dives) were 25, 30, 38, and 77%. The diver who developed knee pain had Grade III bubbles after the dive day which resulted in bends, but his individual incidence was only 25%. In Phase IIb, most of the 20 divers had bubbles after at least one dive, but three divers never had bubbles and two had only one single occurrence. The individual bubble incidences for all Phase IIb divers ranged from 0-38%.

Table XI. Comparison of RDP bubble scores with DAN data. Percentage of man-dives with bubbles in DSAT tests and in DAN studies of recreational divers.

Phase	I	IIa	IIb	DAN
Man-dives with bubbles	76	17	45	94
Total number of dives	911	51	475	508
% dives with bubbles	7.4%	33%	10%	19%
99% confidence interval	6-10	18-52	6-14	14-23

Table XII shows the number of divers with bubbles in each grading category and the corresponding bubble percentage. No diver had Grade IV bubbles and Grade III bubbles were rare in Phases I and IIb. Comparing the different bubble grading categories gives similar results as for Table XI except that the difference between Grade II bubbles in Phases I and IIb was statistically significant ($p<0.00001$), and there was no significant

Table XII. Comparison of maximum Doppler bubble scores. Number and percentage of individual dives in each category. Doppler score after flexing.

	Divers with indicated bubble grade and (%)				
Phase	0	I	II	III	IV
I	844 (97)	58 (6)	7 (1)	2 (0)	0 (0)
IIa	34 (67)	9 (18)	3 (6)	5 (10)	0 (0)
IIb	426 (90)	22 (5)	9 (4)	4 (1)	0 (0)
DAN	414 (81)	34 (7)	37 (7)	23 (5)	0 (0)

difference between Grade II bubbles in Phases IIa and IIb. Ranking the bubble incidence from greatest to least gives: IIa, DAN, IIb, and I. Thus, four dives per day for six days (Phase IIb) produced only slightly more bubbles than a single day of diving (Phase I) while six dives per day (Phase IIa) produced three times as many bubbles. All these differences are statistically significant. In another DAN study (Dunford et al, 1992) a total for 74.5% of divers (199/267) had bubbles of Grade I or higher. None of these bubbles is desirable, but it is relevant that what has been seen in these maximal RDP exposures is less than has been seen in recreational diving in the field.

3. Recording procedure and independent review

The review of the Doppler data in Phase II by RD provided another look at Doppler scores by an investigator whose "Doppler philosophy" was biased more in favor of scoring uncertain bubbles than was that of the principal investigator, MRP. MRP scored bubbles in 11.7% of Phase II dives, whereas RD scored 21.6%. Looking at the degree of difference, about 25% of the scores were the same, about 50% differed by 1 grade, and 25% differed by 2 or 3 grades. Even so, on over 80% of the dives with a positive score and on over 95% of all dives there was agreement. This clearly demonstrates that interpreting Doppler signals has a strong subjective element to it (Sawatzky and Nishi, 1991).

Because of the "worst case" approach we used for analyzing the Doppler scores the philosophy used by RD tends to dominate the Phase II analysis, but this leaves open the question about whether Phase I might have been "under-scored." We feel that in this case any such difference in monitoring is more than compensated by the philosophy used at the time of analysis, to consider only the worst case bubble score. If bubbles were detected at any time in the monitoring following a dive then this dive was scored as having bubbles; in Phase II, any one positive score out of 8 recorded readings gets listed as a "positive" exposure.

RD performed his analysis on tape recordings of the signals; he was understandably critical of the recording procedure and how it was carried out since it had been neither recorded nor documented for third party review. This criticism is valid, but it affected his task of scoring from recordings more than it did that of MRP, who had the enormous advantage of being able to score the "live" signals (Sawatzky and Nishi, 1991). It is unlikely that any Grade III or even many Grade II were missed or mis-scored, and the conclusions are not in doubt.

Another aspect of the worst case approach is that it virtually ignores the cases of bubbles in resting divers before flexing. A good indicator of decompression stress is the Doppler score in divers at rest; when that is high there is more risk of DCS. Since the flex score is nearly always higher and often the only one with a score at all, just looking at the flex scores biases the analysis in favor of bubbles.

4. Bubble susceptibility of subjects

We looked at the distribution of bubbles among the subjects; an overview looks random. There seems to be no relationship between number of dives performed and occurrence of bubbles. However, those with bubble scores greater than Grade I and who were exposed to more than one profile seemed to do more than their share of bubbling. Only 8 Phase I subjects had grades of 2 or 3, and of these 6 made more than one dive. Of these 6, 5 had bubbles on more than one dive. Two bubbled in all dives (2 and 4). This agrees with what has been known about Doppler bubble detection, that some people are more susceptible to Doppler bubbles, and they have a lot more bubbles than the average.

In Phase II, one subject (MUC) missed 4 dives, another (MUM) missed one. MUC did not bubble in the dives she completed, MUM had Grade I bubbles. This could be interpreted that the effect on the total score of these missed dives was negligible.

5. Doppler methodology

It is important to insert a cautionary note at this point concerning the physiological and/or prognostic meaning of low Doppler bubble grades. In actual practice, a fine line separates a Spencer grade of "0" from a grade of "1" for several reasons:

- It is very often a matter of diligence on the part of the operator to expend the time (which is virtually unbounded on the upper limit of what may be required) to find a "Doppler bubble."

- It is often a matter of judgment as to whether an "event" is a "Doppler bubble" or an extraneous valve leaflet sound. The interpretive ability of the operator is an important factor not to be minimized. Because of cleaner signals some authorities (but not all) feel that monitoring of peripheral veins (usually the subclavian) may detect bubbles not heard in the central veins; this method was not used in this study.

- The type of detector (i.e., does it filter out the heart wall motion noise) and the size of the probe crystal and its associated ultrasound field play a role in fine discrimination. Thus, instrument sensitivity is a factor in determining what is "Doppler detectable." (The instruments used in this study were of high quality in this regard.)

- The Spencer Doppler grading scale as a whole is grossly nonlinear, and nonparametric in the sense that it is not proper to average scores (this is explained in Sawatzky and Nishi, 1991).

When comparing the Doppler ultrasound results of a dive series in one laboratory with that in another, these points must be considered (Sawatzky and Nishi, 1991). The Doppler technique does not yet possess the requisite standardization of technique or interpretation needed for optimal inter-laboratory usage. The physiological basis for Doppler shift ultrasound for the interpretation of dive tables is also weak (Powell, 1972 Feb; 1972 Nov; Powell, 1977; Powell, Spencer and von Ramm, 1982; Nishi, 1993). Thalmann used Doppler in an extensive series of USN tests, but used only the occurrence of DCS to assess the profiles, as was essentially done for the RDP; he felt that the Doppler results were disappointing (1989). Nishi makes a good case for using the slightly less subjective Kisman-Masurel code (1990).

Another point that should be made is that there are some variations on the "Spencer" code. In the method used here Grade II is defined as "a few bubbles detectable; some heart cycles may have 2-4 bubbles/cycle" and Grade III is "several bubbles per cycle." Another version (Nishi, 1990) says for Grade II, "Many, but less than half, of the cardiac periods contain bubble signals, singly or in groups," and Grade III says, "All the cardiac periods contain showers of single-bubble signals, but not dominating or overriding the cardiac motion signals." There is a discrepancy in the second description, in that there is no category for more than half of cycles to contain bubbles, but not all of them. It would seem, also, that if one disregards training and experience (not a good idea with Doppler grading) and uses only the descriptions, it would be a great deal easier to get to Grade III with the former description than the latter. This problem in a nutshell was the incentive for the development of the Kisman-Masurel method.

6. Outcome of the multiday exposure

Using the definition in VI.B.1, above, we can take a look at the outcome of the Phase IIb multiday study. Table XIII shows bubble grades as percentages of the different exposures. Nishi defines a "stressful" profile as one causing Grade II bubbles in more than 50% of cases

Table XIII. Overall incidences in multiday study. Percentages are based on number of exposures from 3 perspectives: Single dive (475 exposures), whole-day sequences (117 exposures), and week-long (20 exposures).

	Grade			
Exposure	**0**	**I**	**II**	**III**
Single dive	90.5	4.6	4.0	0.8
All-day (4 dives)	70.9	12.8	12.8	3.4
Week-long(24 dives)	25.0	20.0	40.0	15.0

(Nishi, 1993). By this definition the 4x6 week-long exposure is stressful. From another perspective the dividing line is between Grades II and III, in which case the whole week study is minimally stressful (in 15% of cases). We have always regarded the week-long exposure as stressful!

7. Relevance to Spencer's recommendation

The numerical value of the maximum compartment loadings (M-values) utilized in this model are based upon the earlier work of Spencer (1976), which defines the no-stop limits (NDL's) in terms of the percent of divers with detectable precordial gas bubbles. From Table VI we see that 7.7% of the dives induced bubbles (70/911). and 13.3% of repetitive dive sets had bubbles (58/437). These fall below the 20% level suggested by Spencer of a satisfactory decompression (which is independent of Spencer grades). At first glance this could be read as a verification that a bubble level of 20% is consistent with no decompression sickness, and that it has borne out Dr. Spencer's forecast quite well. However, the RDP results are considerably below Spencer's limit, so it is not entirely relevant to use the RDP results to support Spencer's hypothesis.

C. Dive conditions

1. Effect of repetitive diving

Phase IIb shows an effect of repetitive diving, found in Appendix C2 or Figures 4a and 4b. We see a strong trend that for the first two dives of each day the number of divers with detectable bubbles is lower than for the third and fourth dives of the day. For the first two dives the number of Doppler runs with bubbles is 27 and 23 out of 187 total. For the remaining two dives, this increases to 67 and 70 out of 187.

The multiday effect as seen in Appendix C2 and Figure 4 is present but not as strong as we expected it might be. The number of Doppler runs with bubbles for the six days is, in order, 17, 33, 31, 22, 35, and 49 (total 187). This appears to be a clear trend. Figure 4 shows grades as well as numbers, and an inspection of the density of the lines shows a slight but by no means a strong trend toward more scores (number and size of the bars) toward the right side of the graph. (One could just as well conclude that the Doppler scores are distributed in a rather random way both within and over days.) There seems to be a clear but not linear tendency for dives with bubbles to increase both with successive dives during the day and with successive days.

A second dive of the same depth and duration as the first would be considered the "worst case" in repetitive terms; we made no special effort to test these pairs, but several were in the test series.

2. Effect of Pressure Group (Repetitive Dive Group)

The Pressure Group (PG) in RDP terminology, sometimes called the Repetitive Dive Group (RDG), is a measure of theoretical tissue nitrogen loading; it is usually of interest at the end of a dive or surface interval. The Pressure Group might be expected to correlate with precordial Doppler Bubble scores. The Pressure Groups are listed in Appendix D by profile, along with limited bubble information, the number of dives with bubbles. Table XIV summarizes the number of dives with bubbles in each PG (after surfacing) for Phases I, IIa, and IIb. Looking at the totals in the table we see that the incidence of bubbles is loosely correlated with increasing gas loading as indicated by the PG. If we group these it is found that there is a significant difference ($p<0.0000001$) between PG's K-W and X-Z.

Similar results are found for the individual Phases I, IIb, and IIa. We found statistically significant differences between PG's K-W and X-Z for Phase I ($p<0.00001$) and Phase IIb ($p<0.001$) but not for Phase II. Comparing the bubble incidence in K-W of Phase IIa with that of Phases I and IIb together, there were significantly more bubbles in Phase IIa ($p=0.023$). Phase IIa also had significantly more bubbles than Phases I and IIb in PG's X-Z ($p<0.00001$). Thus, the higher PG's ofPhases I and IIb had more precordial bubbles than the lower PG's, but there were

Table XIV. The number of incidents of bubbles (all grades) and the number of dives for each Pressure Group (or Repetitive Dive Group, RDG) in Phases I, IIa, and IIb. The PG "Past Z" occurred only in Phase I and does not appear in the Recreational Dive Planner (Appendix D). Bub = dives with bubbles; %Bub = % of dives with bubbles.

	Phase I			Phase IIa			Phase IIb			Total		
PG	Bub	Dives	%Bub	Bub	Dives	%Bub	Bub	Dives	%Bub	Bub	Dives	%Bub
K	0	40	0.0	-	-	-	-	-	-	θ	40	0.0
L	1	30	3.3	-	-	-	-	-	-	1	30	3.3
M	4	75	5.3	2	3	66.7	-	-	-	6	78	7.7
N	0	2	0.0	-	-	-	-	-	-	0	2	0.0
O	0	15	0.0	-	-	-	-	-	-	0	15	0.0
P	1	45	2.2	0	4	0.0	-	-	-	1	49	2.0
Q	0	20	0.0	-	-	-	-	-	-	0	20	0.0
R	-	-	-	-	-	-	-	-	-	-	-	-
S	3	28	10.7	-	-	-	-	-	-	3	28	10.7
T	-	-	-	-	-	-	-	-	-	-	-	-
U	6	91	6.6	0	4	0.0	0	20	0.0	6	115	5.2
V	1	58	1.7	1	4	25.0	2	58	3.4	4	118	3.4
W	5	79	6.3	-	-	-	2	20	10.0	7	99	7.1
X	6	57	10.5	11	28	39.3	10	137	7.3	27	222	12.2
Y	19	142	13.4	-	-	-	11	60	18.3	30	202	14.9
Z	17	149	11.4	3	8	37.5	20	176	11.4	40	333	12.0
Past Z	5	80	6.3	-	-	-	-	-	-	5	80	6.3
Total	68	911	7.6	17	51	33.3	45	471	9.6	130	1433	9.1

significantly more bubbles at both high and low PG's in Phase IIa than in Phases I and IIb. This suggests that the RDP will produce about the same number of bubbles with up to four dives per day (as done in Phase IIb) but significantly more bubbles with six dives per day.

3. Single level *vs.* multilevel dives

In Phase I it was seen that Doppler-detectable bubbles were found in smaller numbers following multilevel dives, significant at the $p < 0.005$ level by a chi-square test. Compartment gas loads were equivalent at the termination of the single and multilevel compressions. Perhaps the deeper multilevel dives functioned to eliminate gas micronuclei, or perhaps more gas was eliminated in the shallow phases of the multilevel dives.

4. "Reverse" profiles

It is widely believed from anecdotal evidence that sequential profiles in which a deep dive follows a shallower one have a higher risk of decompression sickness than the profiles themselves would seem to justify (Lang and Hamilton, 1989; Weinke, 1990). For the record it should be pointed out that the profiles during the first two days of Phase IIa involved significant "reverse" profiles. These were of the type that were not at the time and are not now permitted by RDP procedures. Had the tests progressed with no DCS we could suggest that perhaps reverse profiles have less consequence than what is generally believed. As it turned out, however, we have no basis to draw any conclusion whatsoever about this phenomenon.

5. Exercise

Within the limits of the method, we have not seen much difference in the chamber between the exercising and the non-exercising divers with regard to detectable gas phase formation. This is probably a consequence of the fact that the tables were conservatively calculated from their inception.

It appears that exercise did not play an important role in bubble grades with these profiles, and we consider that this indicates that the compartment loadings are not marginal; had they been marginal then exercise would be likely to incite bubble formation which would be revealed as a difference in bubble grades. When tissue loadings are in a marginal state, the effects of environmental conditions on the divers can be seen (Spencer and Powell, 1981) in their post-decompression Doppler grades.

6. Cold

The open water dives were in such cold water (normal conditions for Puget Sound) that the times were selected to be a little less than maximal. The role of cold in decompression is not clear because of many factors. Divers in hot water suits have been found to have higher incidences of DCS than divers in wet suits (Long, 1981; Shields and Lee, 1986), and Dunford and Hayward (1981) found a lower incidence of Doppler bubbles in divers who were chilled during the bottom time of dives similar to these. The popular conception is that cold is detrimental to decompression, but it makes a substantial difference in whether the cold is during the uptake or outgassing portion of a dive. Since the Phase I dives with divers diving in cold water were no-stop dives, it could be possible that the cold had a slight protective effect.

In any case, these divers did not show a strong susceptibility to cold. In the inwater dives 51, 52, and 53 there were 10 individual dives with bubbles out of 165 in the chamber dives, and 10 with bubbles out of 228 in the inwater dives, suggesting a lower susceptibility to bubbles as a result of diving in cold water, but this difference is not significant by a chi-square test. It is possible that there were fewer bubbles as a result of the cold, but there is no way to verify that this was the case.

D. Subject characteristics

1. Data available for analysis

Although not a primary project objective, some assessment of different aspects of the subjects, both individual and environmental, might be possible according to the available data. We have performed a casual analysis of these factors at best, but have tried to present the data in sufficient detail so that others can extend these analyses.

2. Role of gender

A quick look at the effect of gender on bubble susceptibility reveals a striking similarity. Using data from Phase I, some of which is summarized in Table VI, we see that 43 male divers out of 318 males in the study were in a dive set that had bubbles. For females, 15 of 119 divers had bubbles. A look at this with chi square shows an extremely low value, giving a P between 0.75 and 0.9. This is strong acceptance of the null hypothesis that there is no difference. If we look instead at individual dives with bubbles, of the 70 dives with bubbles 52 were male and 15 were female. Using the ratio of the sexes performing the 911 dives we find an expected number of males to be 51.8 and females 18.2. One cannot expect to be any closer to equal ratios than this. Again chi square shows about the same expectation, that there is no difference due to gender.

In the Phase IIb study, in which the same individuals performed the numerous dives of the multiday series, the number of dive sets (days) in which men had detectable bubbles was greater than that of women. There were 80 sets in which males had bubbles and 25 in which females did. This was significantly different from the proportions of the sexes in the dive

(12 males and 8 females) at the $p < 0.001$ level by the chi-square test. The small number of separate individuals must not be discounted in assessing the meaning of this result.

VII. DISCUSSION

This chapter discusses the RDP and its implementation, to some extent beyond the specific test program covered in preceding chapters. The objective of this report is to document the results of the program carried out to test the RDP. It is not our intent to address the RDP itself as a marketed commodity, but to the extent that critique of it relates to the test program we attempt to address some of it here. Some comments and critique about the RDP are collected in Appendix E.

A. Additional RDP limits and procedures

1. Additional limits, the W-X and Y-Z groups

One of the devices used to make the RDP algorithm produce reliable decompressions for recreational diving is a set of additional "limits" over and above the Haldane algorithm that forms its computational basis. Some of these are printed on the RDP itself or included in its manual; these are considered just as much a part of the RDP as The Wheel and the numbers on the RDP flat table. These include limitations on ascent rates (≤60 fsw/min or ≤18 msw/min), the sequence of dives (progressively shallower), repetitive dives deeper than 100 fsw or 30 msw (prohibited), a mandatory "safety" stop (when within 3 pressure groups of a limit), and limitations on multiple (more than 3 dives/day) repetitive dives that reach certain gas loading limits based on pressure groups (the "W-X" and "Y-Z" groups; see section V.C.1). A number of general diving rules are also mentioned on the RDP and in RDP training materials, such as an admonition to avoid approaching the prescribed limits, use the next deeper depth or longer time, allow for cold water (assume 10 fsw or 3 msw deeper), and avoid intensive multiday diving. The RDP is not designed for decompression diving, but provides conservative stops in the event that no-stop limits are exceeded.

These rules are to a large extent based on anecdotal experience and expert opinion more than hard data, but they are widely accepted and taught (Lang and Hamilton, 1989; Lang and Egstrom, 1990; Richardson and Shreeves, 1992). The limit on 3 or more dives in a repetitive sequence is theoretical, based on gas loading calculations; one cannot load the 60 min compartment with only one or two no-stop dives except by shallow dives with very long bottom times that are essentially impossible with scuba air resources, or with several dives per day.

There has been concern that long shallow dives with short surface intervals or multiday dives could violate (exceed the allowable gas loadings and thus be limited by) the 60 min compartment. The only way this pattern could violate the 60 min compartment while being inside RDP limits would require dives not possible with scuba air resources. Even so, this is covered by the special limits for W-X and Y-Z which require longer surface intervals (1 and 3 hr) for such dives. This is the functional equivalent of a slow compartment. Multiday diving about as intensive as it can be within RDP limits was tested in Phase IIb, with the expected daily buildup and gradual multiday buildup of Doppler bubbles, but no DCS.

After successful testing of all depths, it was decided for reasons of conservatism to arbitrarily reduce the no-stop times for depths over 100 feet by one minute, except for 130 feet where the reduction was for two minutes. Therefore, this no-stop time is the most conservative on the Wheel, when compared to testing.

2. The "safety" stop and the "emergency" stops

The boundaries of recreational diving create an awkward situation with regard to the name of the shallow stop called for by the RDP when the stress of the exposure exceeds certain conditions. Theoretical modelling, physiology, and experience all afford a firm basis for the benefit of a short stop near the surface after any but the most benign dives (Pilmanis, 1976; Lang and Hamilton, 1989; Lang and Egstrom, 1990; Rogers, 1990 4th qtr.). But recreational diving is supposed to be "no-stop" or "no-decompression" diving, and some purists consider that to **require** a stop violates some basic principle. The stop prescribed when diving with the RDP was named the "safety stop." As the expertise of the attendees who formed the consensus in the workshops just cited would indicate, there is nothing wrong with this stop; it is strongly advocated for any stressful dive, and many experts even recommend it for all dives. The problem here is one of terminology. One fault of the term "safety stop" is that it suggests that it is "recommended" or "encouraged," but by implication, not required. This is not the case with the RDP; for some situations (just mentioned) the stop is **required.** Perhaps it should have been called a "required" stop; in any case it should be thought of as that.

Another distinction should be made. The main difference between a "required safety stop" and a "decompression stop" is that the required safety stop is required by **procedures** as added conservatism and not by the **model**, whereas a decompression stop is needed to unload gas before continuing ascent. Both may be required of the diver, but the definitions spring from where the requirement for each stop originated.

Another RDP stop with an attention-getting name is the "emergency" stop. This is the stop needed if the diver exceeds the limits of the RDP and needs a stop. It is hardly a true "emergency" when this occurs, but the same set of constraints that apply to the term "safety stop" apply here as well; the terminology, although some have criticized it, certainly signals the diver that this is not the preferred thing to do. A dive that exceeds no-stop limits is one that has strayed from the plan to a degree that new conditions have emerged (hence the word "emergency") requiring an unplanned (but not necessarily unprepared for or even unanticipated) model-required stop. It would be acceptable to call this a "contingency" stop, but "emergency" conveys the best message.

3. Diving at altitude

The RDP is considered to be valid from sea level to an altitude of 1000 feet. If a diver wants to dive in water with the surface at an elevation higher than 1000 feet then special "diving at altitude" procedures should be used. The RDP does not deal directly with diving at altitude, but procedures have been developed to allow this. Assuming that the diver has a means of measuring depth accurately, these depths can be converted to "theoretical depths" as a function of the altitude of the surface. A chart giving the conversions to theoretical depths and other procedures necessary to dive at altitude has been published in The Undersea Journal (Rogers, 1989 2nd qtr).

B. Relevance of the testing of the RDP

First, it is important to keep the objective in mind. The RDP is intended for the recreational diver making repetitive and multilevel no-stop dives, possibly over several days. Its uniqueness is that it uses conservative no-stop times, but it allows more efficient repetitive dives by taking into account that only no-stop dives are done. Further, the RDP provides for multilevel dives as a primary intent, not as an arithmetical afterthought.

1. Loading long compartments

Increasing surface intervals will increase dive times, but at the price of not sustaining high pressures in the slow compartments. In planning the Phase II program we faced a kind of dilemma resulting from the effect of the RDP special rules mentioned above. The rules were designed to prevent elevating pressures in the compartments slower than 60 min half time, but we wanted to let them get up to a level of stress. Selecting profiles that elevate the slow compartment pressures to high levels, i.e., those falling in Pressure Groups W-Z, would require long surface intervals (in order to get long dives) and this would prevent these pressures from being sustained (they would decay). Conversely, if short surface intervals were desired so that the slow compartment tensions may be sustained, that would be possible only if Groups W-Z are avoided, i.e., diving profiles that do not elevate these tensions in the first place, and these would not be as stressful as we would like for the tests.

Furthermore, increasing the surface intervals to allow dives with more bottom time causes the intervals to go past 1 hour, thus rendering the W-X Rule irrelevant (since that is what this rule calls for anyway). It was possible to ignore the W-X Rule here and continue to avoid Groups Y and Z except for the final daily dive. This would require surface intervals of 1 hour or more, but that was already being done. Using Y and Z would gain on allowable dive time, by permitting selection of profiles that are two groups greater, allowing more gas buildup.

In summary, it was not easy to stress the slow compartments. Tables designed to be conservative and modified to enhance conservatism complicated a search for high risk profiles for the tests.

2. Bubble formation and DCS

The results of the Phase I experiments in particular indicate there was a 0% incidence of decompression sickness in divers making dives:

- With the chosen M-values and no-stop limits,
- On a repetitive basis in non-acclimatized divers (one day of diving),
- Controlled by a compartment with a half time of 60 minutes or less.

Further, a minimal to modest gas phase formation occurs following decompression from these profiles. A low degree of tissue gas phase separation is important because the computation of decompression tables by the Haldane method considers that tissue nitrogen uptake and elimination occur with the body's gas load in the dissolved state. This is necessary for a continuity of the transport equations during uptake and elimination, since when gas phase separation occurs, the inert gas in "bubbles" is at ambient (tissue) pressure, and it causes other disturbances. Its resolution is governed by Fick's Second law (as is all diffusional gas transport), but now the geometry differs substantially in the elimination phase from the uptake phase.

In addition, it is important that during decompression, a gas phase not form such that it can occlude the tissue capillaries. Should this occur, the perfusion rate would be reduced and gas washout would be hindered. With respect to the algorithms for the calculation of decompression tables, this would be rendered as a change in the half times, especially during gas elimination, with a shift toward increasingly longer half times as the perfusion rate was diminished.

Hempleman (1975) has attributed many problems associated with decompression to a "tissue-bubble complex" in which gas washout was reduced secondary to gas-phase formation in capillaries, and Thalmann has built a new algorithm around this (1984). Because of the short time interval between repetitive dives that is common in recreational diving (particularly on "liveaboard" boats), were a gas phase to form, it could substantially alter the mathematical model that was used to calculate safe ascent criteria. Further, the gas phase would serve to produce increased numbers of gas micronuclei that would serve as "seeds" for further growth of the gas phase in the subsequent dives.

While both of these events are a possibility, the results suggest that this is not a problem of sufficient magnitude to warrant the change of the half times in the calculations for repetitive diving. Additionally, the performance of repetitive dives with high tissue gas partial pressure in the 40- to 60-minute compartments can be done on a repetitive and multilevel repetitive basis with reliable outcome.

Supporting conclusions that the outcome was acceptable for recreational diving is the extreme "worst case" method of Doppler scoring we used during the analysis. Another factor supporting the idea that the bubbles were generally innocuous is the fact that they were generally quite evenly distributed over the entire experiment.

During Phase I some divers in the chamber noted skin itching. This is common in chamber exposures. It was not documented, and not regarded as of any consequence. Some laboratories keep score of skin itching, and in some cases when severe it is considered a warning sign (Hamilton, 1991), but we had none of that type or degree.

Another point worth making about the levels of bubbling seen in the DSAT subjects is a comparison with bubbling observed in other recreational dives. Dunford and colleagues (Dunford et al, 1988; Dunford, 1990; Dunford et al, 1992) have seen bubble formation in recreational divers at levels greater than those observed in these experiments. The dives in Dunford's observations do not fit any specific category. His objective was to find out if recreational diving as normally practiced would cause bubbles; it clearly does.

This project makes use of an important addition to the practice of Doppler monitoring. This is the concept introduced by RD, of the score of "9." A 9 is a Doppler monitoring recording (or session) which is not of good enough quality to make a confident decision of whether bubbles are present, or of the grade if they are. Far better, of course, is to be able to get a good "live" signal and take the time necessary to determine a reliable score.

3. What is a dive?

For our purposes here we defined a "dive" as it is done in data analysis. A "dive" is an exposure to pressure followed by a decompression. This does not include each element of a multilevel dive (the whole multilevel exposure is a "dive"), but it does allow consideration of each repetitive dive in a group as a discrete dive. The several separate dives in a day of repetitive diving are considered discrete dives, even though the total day is regarded as a specific "exposure" or "set" of dives as well. The same applies to the multiday exposures of Phase II. Here each day includes several dives but is itself an exposure entity, and the entire week of diving is likewise regarded as a single overall decompression exposure.

In a way repet dives served double duty; if the surface interval was long enough and if the diver had no bubbles as a result of the first dive, then the first dive of a repetitive pair could be regarded as a complete dive; we considered that surface intervals of 40 min and over met this criterion (this choice was somewhat arbitrary). If the second dive were bubble free after a long interval it could also be regarded as representing a "worst-case" single dive. Short surface intervals, on the other hand, were considered to be more risky in terms of decompression, so testing them was worthwhile as well, and they were favored because they were easier to do and they made the day shorter for both subjects and staff.

The question comes up about how to evaluate the Phase IIb dives. Looking at the whole exposure as a single data point we have only 20 exposures. Of these a few subjects had no or only a few bubble incidences (Figures 4a and 4b), a few subjects had a few bubbles, and some had many. This becomes, in a sense, a study of individual susceptibility. The multiday exposures were clearly stressful, and their results showed a higher level of bubbles than were found in the single-day dive sequences. As mentioned earlier, this is to be expected. The buildup toward the end of the exposure that some predicted was slight if it was present at all, but again, this would be expected. An overall look at the results suggests that this regime is a tolerable exposure, but not one to be encouraged. It further suggests that for normal recreational diving, which involves substantially less exposure than this as a general rule, the RDP is at about the right level.

4. "Square" dives

To make a point, some individuals questioned why the dives tested did not include a greater proportion of "square" dives, such as divers on a deep (in the 100 fsw range) wreck or reef might do. In terms of single or isolated deep, no-stop square dives, our objective was not to retread USN's no-stop tables, but rather to do an algorithm that dealt efficiently with repetitive and multilevel dives, and the testing was focussed on these procedures. The RDP program did not target sequential square dives as a primary objective, mainly because those dives do not stress the unique parts of the RDP algorithm, and to do so would have taken effort away from the more relevant multilevel and longer, shallower repetitive dives which were our design effort. Phase II, however, included a full-time repetitive square dive as the last one every day.

C. Problems with Phase IIa

1. On the case of decompression sickness in Phase IIa

The initial start of Phase II was abruptly terminated. This was due to a case of decompression sickness in Diver GAR. That this caused the abrupt termination of the project at that time was an administrative issue. In Phase I a plan had been in place to adjust the profiles and carry on in the event of DCS or too many bubbles. The plan for Phase II did not include such a provision, and in fact just the opposite was the case. There was a provision in the agreement between IAPM and DSAT that if DCS occurred the project was to be terminated. In summary, this might be explained as an aspect of an experimental plan designed by lawyers, not scientists. There was a rationale to it, but its impact was overlooked by the scientists. By way of rationale, this phase of the testing was intended to show what works, not what does not work, and there would be no point in completing a set of tests that could not be recommended for use. The termination itself was a bit chaotic, since the provision had been forgotten until the case occurred and diving had already been resumed on Day 3.

It is tempting to make an excuse in this case of DCS that the diver had an old motorcycle injury (usually they are old football injuries). There is no way of knowing if this was a contributing factor to the DCS. It is generally believed that injuries or surgery to a joint may predispose an individual to DCS in that joint, and that certain types of injury appear to provide a most probable site for it to occur.

However, a substantial fraction of people or divers have old injuries of this sort. An unusually susceptible person usually finds this out early (often with some inconvenience), and is usually self-screened out of the practice. But many others, divers with a benign or even forgotten joint injury from the past, still participate in recreational diving. In general, the tables should provide for these people and afford them decompressions with a reasonable degree of risk. The risk may be higher or even much higher than the general diving population, but a responsible table should provide decompression with a reasonably low risk. Tables that afford the low level of risk associated with recreational diving usually accommodate people with old injuries without special effort, except occasional advice to dive more conservatively. It is not normal for people with injuries to be used as subjects intentionally, and it is not likely that studying this effect would be of any value because of the impossible task of predicting the DCS potential of each old injury. In any case, it would likewise be inappropriate to screen out divers with old injuries from this type of study. Nor, for that matter, should divers with a history of DCS be eliminated as subjects.

DCS forming in an injured joint is usually easy to treat and is not likely to be serious.

2. On six dives per day

Should a single data point from a diver with an old injury be the basis for a limit on the capabilities of the RDP? The reaction to the "hit" was unstructured, but the end result was probably appropriate. Doppler data for this 2-day experiment showed more and higher scores (Appendix C1). It could be argued with conviction that this rate of bubbling alone should discourage 6 dives/day. The vast majority of recreational divers can get along quite well without doing 6 dives per day over several days.

Those who intend to do so are engaging in a high stress activity beyond the intended scope of the RDP. In fact, electronic dive computers are under serious scrutiny with regard to whether they can adequately deal with such exposures (Lang and Hamilton, 1989; Hamilton, 1993 workshop, in preparation, 1994).

D. The DAN Recreational Diving Advisory Board

1. DRAB or DAB

In 1989 the Divers Alert Network organized an advisory board to address decompression issues in recreational diving. This might well be the DAN Recreational Advisory Board (DRAB) or several other names that have been used, but DAN Advisory Board (DAB) will suffice. Appointed to the Board by DAN director Peter B. Bennett, who also acts as the DAB chairman, were the following, alphabetically:

- Alfred A Bove
- R.W. Hamilton (RWH)
- Karl Huggins
- Ronald Y. Nishi
- Andrew A. Pilmanis
- Edward D. Thalmann
- Richard D. Vann

The DAB met twice, in May and December of 1989. The first meeting was to ascertain the status of the RDP. Drs. Pilmanis and Thalmann were not at the first meeting, but Dr. Thalmann sent comments. Also attending were Michael R. Powell (MRP) and Raymond E. Rogers (RER) to discuss the development and testing of the RDP, and Drew Richardson (DR) representing PADI/DSAT. Members were sent the "Blue Book" report by Powell et al (1988) and notes covering the unreported results of Phase IIa and IIb. Comments from the meeting were distributed to the Board. Salient points from the work of the DAB are addressed here (Bennett, 1989).

A uniform request from the Board was for a complete report covering the entire experiment. It was agreed by the Board that Phase I provided reasonable assurance that the repetitive and multilevel procedures tested are reliable for up to 3 dives in one day of diving. Phase IIb provided some confidence that the repetitive no-stop times can be extended beyond those of USN, and noted that the trials of 4 dives per day for 6 days "does not suggest high DCS risk."

The Board called for an independent evaluation of the Doppler tapes, which was accomplished as related in Chapter V.

A prevailing sentiment was the need for open water trials as a followup of Phase II. What seems not to have been appreciated by the Board is that at that time the RDP had been in use for at least a year and seems to have been quite successful (it still seems so, but that is outside the scope of this report). A list from the DAN data base of DCS cases related to the RDP up to May 1989 was presented to the Board. Of the 11 cases 3 were beyond the "legal" limits of the RDP. Another 6 were within the USN limits so can be discounted in assessing the increased capability of the RDP. This leaves one valid DCS case within RDP limits. We as well as DAN lament that no denominator exists for this data, but it is surely many thousands of exposures, and the incidences do not loom as excessive; some DCS is expected. The Board recommended continued efforts to collect time-pressure logs and data on recreational dives.

Several of the Board felt that performing the safety stop during the Phase II trials was not appropriate, since the model does not include it. In the sense of testing the RDP model maximally this is a valid point, but in terms of testing the RDP itself it must be acknowledged that this stop was required for those dives; it is a part of the decompression. (See section VII.A.2.)

2. Nishi

Nishi did a comparison of Phase II exposures with the DCIEM model. Since the DCIEM model is substantially more conservative than the USN, it is no surprise that many of the second and later dives would have called for stops had they been done against that set of constraints. Nishi found that Bühlmann's model did not show many violations.

3. Hamilton

Analyses by Hamilton using DCAP Model Tonawanda IIa with Matrix MF11F6 likewise showed few violations. Although conservative in longer, deeper dives (even more than DCIEM) the 11F6 algorithm is equivalent to USN in the no-stop range, so would not be expected to show much, and it did not. Hamilton offered the opinion that the meeting convened by the DAN Board to assess the RDP did not constitute its "Decompression Monitoring Board" (now called the "Decompression Decision Board" because of this very issue) under the guidelines of the UHMS Validation Workshop, (Schreiner and Hamilton, 1989). The DDB is an **internal** board responsible for making the decisions during table development, whereas the DAN Board was constituted to provide external monitoring or oversight of recreational diving decompression, including the DSAT development. As seen below, the Board made recommendations for all recreational diving as well as that of the DSAT development program.

4. Bove

Bove with a colleague did an analysis similar to that reported in Table X, with similar results (Bookspan and Bove, 1989). Quite predictably, some repetitive RDP dives had higher loadings than the USN repetitive dives used for comparison, since more time was allowed by the RDP; loadings were still well below the M-values. Despite this, Bove was still critical of the RDP validation. Bove felt the bubbles were of concern, but perhaps did not appreciate at that time that recreational divers have been found to have bubbles in routine dives, substantially more than were seen in Phase I (Tables XI and XII, and Dunford et al, 1988; 1992).

5. Huggins

Huggins performed a gas loading analysis, with results essentially the same as our Table X. He also did some incidence calculations. In a count of 320 dives in Phase IIb he found an incidence of 10% bubbles. Our count was 475 dives, and we got 10% bubbles as well (187/1853). Huggins also noted, as we did, the increasing bubble incidence with successive dives during the day in Phase IIb, and the lack of a strong trend over days (Figure 4). He feels the safety stop should be required in all dives, and he recommends a provision for "backing off" when conditions do not permit the stop—an excellent idea.

6. Vann

Vann calculated predicted DCS incidences using maximum likelihood calibrated with USN air dives. These showed in Phase I that a few of the profiles had predicted DCS incidences of 2% or slightly greater, but that most of them were about 1% or less. For Phase IIa the predicted incidences are greater than 5% for several of the dive sets. Phase IIb predictions taken at the end of the day were about 2-3%, except for the last day which was about 4%. The predictions are not totally inconsistent with the bubble scores, but if the true incidence of DCS had been this high it is likely that DCS would have been seen. He also commented that the model did not predict the extra stress in the multiday exposure. (This need for limitations to such extra stress is not well covered by Haldane algorithms in most cases, so the RDP covers these with other non-model restrictions.) Vann feels that the type of exposure seen in Phase IIa of 6 dives per day is not acceptable, and he encouraged open water tests of the Phase IIb type exposures.

7. Thalmann

Thalmann felt that the number of dive sets without DCS was impressive but not sufficient to consider testing complete. This opinion was based on an early count of 90 dive sets (a dive set is a diver day in our analysis). Phase I actually included 437 such DCS-free sets, a number substantially higher than the 300 to 400 he recommends as sufficient. We could likewise consider Phase II as being another 117 (120 less 3 incomplete) diver-days, for a total of 557, which should more than exceed his criterion. He questions the validity of making the assumption that low bubble scores necessarily mean a low incidence of DCS, and like everyone else, awaits a good report on the results of the RDP in extensive field use. Further, he suggests that the model should predict DCS on the occasions when it does occur. This wish is commendable but unrealistic for the RDP environment, because the tests do not operate in the domain where DCS is expected, and the RDP does not include DCS prediction in a direct way.

8. Followup

Throughout this study we have compared the RDP with the USN tables and allowable limits. The RDP is uniformly more conservative, except that it "interpolates" and thus allows repetitive exposures to be done that would not be possible using USN rules. It is a matter of interpretation as to whether this really makes the RDP less conservative. In Phase I all repetitive exposures (and a few first dives) would have required a decompression stop by USN rules. No stops were used in the trials, and the dives were "clean".

Since DCIEM is more conservative than USN, we presume without making formal calculations that the DCIEM tables would not allow the Phase I exposures without stops (nor does the RDP, for that matter). Historically, DCIEM's no-stop calculations made with the model were so conservative that it was necessary to go back to values near to the old USN ones in order to satisfy Canadian Forces divers who knew what would work.

9. Second meeting of the Board and Phase III

At the second meeting in 1989 December the focus was on plans to conduct open water tests of the type of profiles used in Phase IIb, which were then designated as Phase III. This addressed a myriad of considerations, from the fact that one really cannot do the IIb pattern in the water because of scuba tank size limits—not to mention cold—to economics and the matter of securing subjects.

At this meeting the Board—inspired by the RDP work—made some recommendations that apply to recreational divers in general no matter what decompression system is used. They recommended that dives be limited to 130 fsw, preferably less than 100 fsw. Six dives per day for 6 days is felt to entail unacceptable risk, so a maximum of 4 dives per day for no more than 6 days is suggested, but preferably with a day off on the 3rd or 4th day, and preferably no more than 3 dives per day. The safety stop (3 min at 15 fsw) is recommended for **all** recreational dives, and ascents should be no greater than 60 fsw/min. Divers should be warned that DCS is a possibility on all dives, and that diving within the tables reduces risk but does not guarantee against getting DCS.

VIII. CONCLUSIONS

This project resulted in the development of a new approach to decompression management in recreational diving, the DSAT Recreational Dive Planner. The RDP was developed by adapting a familiar algorithm, the method developed by the U.S. Navy for their decompression calculations, to the special needs of recreational divers. This method is based on the Haldane model; this considers the body to be made up of a series of hypothetical "compartments" which take up and eliminate inert gas according to an exponential pattern. This means that the rate of change of inert gas in the compartment is proportional to the difference in inert gas partial pressure between the inspired gas and the compartment. Partial pressure of inert gas is used to account for gas loading in the compartments. Ascent or decompression is constrained by a series of empirically determined limits on the differential partial pressure which is allowed to develop in a given compartment.

The RDP model differs from the classical U.S. Navy version in significant ways. First, the no-stop limits were derived from empirical data based on bubble development in divers; this was done by basing the exposure limits on bubbles detected using Doppler ultrasonics. Using this data, developed primarily by Spencer (1976), as a basis we calculated a uniform set of allowable no-stop times for the recreational range of 40 to 130 fsw. This calculation was done by selecting the times so they would fall on a smooth curve based essentially on a square root relationship between depth and allowable exposure time. The resulting no-stop dive times are uniformly less than those of the U.S. Navy.

Since recreational no-stop divers often want to make repetitive dives, the RDP took a fresh approach to providing this capability. Instead of using the 120 min compartment for repetitive diving as done by the U.S. Navy tables, the RDP uses the 60 min compartment. The Navy's approach is designed for repetitive dives following dives with decompression stops, but because the RDP user will be making only no-stop dives a shorter half time for repetitive dives seems more appropriate. The shorter half time would not work well for dives with extensive decompressions, but for the no-stop diver it would provide more efficiency. Other than using the shorter half time, the RDP follows familiar techniques of using "pressure groups" and the decay of residual nitrogen during the surface interval to select a new pressure group for the next dive in the repetitive sequence.

Another desire of the recreational diver is the ability to do multilevel diving. This is also provided by the RDP, and in fact the RDP is the first decompression system to include multilevel diving in its inherent capabilities. As its set of ascent-limiting M-values (tolerable nitrogen partial pressure levels) the RDP uses values "back calculated" from the mathematically smoothed, empirically determined no-stop limits. Multilevel dives are allowed within the constraints of these M-values.

The most obvious innovation of the RDP is its presentation in The Wheel, a circular, non-electronic calculator which allows the user to determine no-stop, repetitive, and multilevel dive profiles. This provides an infinite number of ascent options in a device that can be carried along on a dive (but requiring no batteries). It allows interpolation between table categories, giving the diver an efficient access to no-stop decompression procedures, including repetitive and multilevel options.

Because some aspects of the RDP were new and not easily evaluated with documented existing decompression experience, it was necessary to validate it in controlled laboratory and open water dives. For this a program was set up at the IAPM in Seattle, using both the pressure chamber and the cold waters of Puget Sound for the exposures. Dives were carried out in the IAPM dry hyperbaric chamber and in the water, by 234 divers from the local sport diving community; 119 were female.

Considering an exposure to pressure followed by a decompression to be a "dive" and a repetitive sequence a "set," some 1437 dives were made in the validation series. Not all these were independent dives, however, since many were parts of repetitive sequences. The first phase tested repetitive and multilevel dive profiles, based on a single day of diving. A total of 911 individual dives were run, some of these multilevel, in 437 daily sequences (sets); 228 dives were in the water. Divers performed prescribed exercise on 806 of the Phase I dives.

After each dive we monitored the divers using Doppler ultrasonic bubble detectors; we scored these in a "worst case" way by taking the highest score seen after each dive or during each sequence. This revealed bubbles, mostly low grade (less than Grade II on the Spencer scale) on many of the dives. Of the total 911 dives, 70 dives had some bubbles for an incidence percentage of 7.7%; 58 of the 437 dive sets had bubbles at at least one point for an incidence of 13.3%. Dives in cold water seemed to have fewer bubbles than those in the chamber.

We conclude with reasonable confidence that this testing shows the RDP algorithm to be quite reliable and appropriate for recreational dive use, for the single-day, repetitive and multilevel dive pattern.

As just mentioned, the use of the 60 min compartment to limit repetitive dives invokes some concern among students of the Haldane method. Speaking as if the model reflected physiological reality, we can be sure that if one did enough dives limited only by the 60 minute compartment we would expect this to "load" the slow compartments excessively, and the diver would be at risk. Put another way, the 60 min compartment is likely not to be adequate to deal with multiple dives over multiple days. Calculations show, however, that this is not the case because no-stop dives are too short, especially when repetitive dives are limited by the 60-min compartment, to allow the slow compartments to build up (Figure 4). Nevertheless, there was concern both within the RDP team and from outside critics, particularly the DAN Advisory Board, that multiday diving should be examined, and another set of experiments was carried out. These were to test multiple dives over multiple days, and were Phases IIa and IIb of the project.

The first test was to be 6 to-the-limit dives per day for 6 days (Phase IIa). The exposure of the first group of 4 divers was stopped on the third day because one of the divers got joint-pain DCS; there was a provision in the plan that the exposures would stop if DCS occurred. The DCS happened at the site of an old injury—a common occurrence—and was easily treated. Significant, however was that the other 3 divers had just as many or more Doppler bubbles as the one with DCS. Although any conclusion on such a small data set is questionable, this abrupt test cast doubt about the suitability of any decompression system (including computers) that would allow six such extreme, near-the-limit dives with reverse profiles over the course of two or more days. There is general agreement that this sort of exposure is ill advised no matter what the decompression plan.

A second series of 4 dives per day for 6 days was concluded successfully without DCS (Phase IIb). The profiles were designed to be as stressful as possible within the constraints of the RDP, and used the required "safety" stop because it was called for by the RDP for these dives. The Doppler scores from the multiday exposure were clearly higher than those of the single-day dives in Phase I. Bubbles increased with successive dives during the day, and there was a slight tendency for them to increase over the course of the 6 days; this was actually less prominent than expected. The bubbles seen in Phase IIb were also substantially fewer than found in studies sponsored by DAN of recreational divers performing actual recreational dives.

It is fair to conclude that the number of bubbles seen in Phase IIb makes this exposure "marginal" with respect to what can be judged with Doppler scores. The risk of doing this kind of exposure is reasonable, but it may be higher than for single isolated days of diving. The DAN Advisory Board recommended that the Phase IIb type of tests be repeated in the water and public funding was requested but not obtained; open water multiday tests were not done. The recommendation of PADI is not to exceed 4 dives per day (Richardson, 1989 3rd qtr). This is probably a good recommendation for recreational divers no matter what their decompression plan.

Overall we conclude that this program succeeded in developing and validating a new mode of decompression management for recreational diving. The Recreational Dive Planner was designed with repetitive and multilevel diving as its main features; as such it is the first decompression planner to do this. Further, no other recreational decompression device, either tables or computer, has had this level of validation testing for the specific implementation (twice as many individual dives were used to validate the RDP as were used for the DCIEM tables). We know of no prior laboratory testing of multilevel procedures. The validation programs support the conclusion that the special repetitive and multilevel diving procedures developed for the RDP are reliable and offer no more risk than customary recreational diving practice. From the test results we further conclude that performing multiple dives over multiple days with the RDP is acceptable, and can be done with no greater risk than is encountered in the common practice of recreational divers. Even so, based in part on this evidence and the suggestions of other experts, we recommend limiting the number of dives per day to 3 or at most 4, and suggest a day with a reduced level of diving (or none) every 2 or three days.

IX. HISTORY

In 1983 RER began his investigations because the underwater topography of South Florida exposed a defect in the USN tables as they are used in recreational diving. This was that large differences in dive time result when repetitive dives exceed 40 fsw, even momentarily, using a literal interpretation of USN repetitive tables. When he was able to get no information from his instructors, he began to work on the tables, and before digging very deep saw that they were less than appropriate for recreational diving. They were coarse, from large depth increments and excessive round-offs. The work of Dr. Merrill Spencer (1976) suggested that it may be good to lower single dive no-stop limits. RER attempted to adapt the USN tables by introducing new depth columns, increasing the number of steps in the surface credit table, and reducing no-stop limits. His early numbers were not calculated, only interpolated, and although they did not solve all problems, they encouraged further efforts.

RER spoke to PADI International. PADI encouraged continued development but insisted that any new tables would have to be calculated by established methods. RER began to find in US Navy Experimental Diving Unit reports the basis of the tables, and he learned to reproduce the Navy's numbers and to work with the Navy's mathematical model. He also learned that the Navy's main purpose was stage decompression tables, a practice rejected by recreational diving.

After many calculations (by hand calculator at first, then a TI994a; then a TRS-80), RER concluded that the problem was more than round-off and over-large increments. He recognized that a problem was the Navy's dependence on the 120 min compartment for repetitive dives. This compartment does not reach its limit in no-stop diving. He noticed that most no-stop dives were controlled by a compartment with a half time of 40 min or less. There seemed to be no reason why recreational tables could not be based on a faster compartment. RER felt the USN 6-compartment model had too few compartments; adding more compartments (with interpolated M-values) eliminated some irregularity, but the M-value curve for no-stop limits still was not smooth. He felt intuitively that these curves should be perfectly smooth, so he adjusted no-stop limits and M-values to achieve complete internal consistency, using variations on Hempleman's "p root t" concept (1975), later modified to $D = Ct^{-x}$ but always with an empirical basis. Based on these changes, RER began to devise new tables that would respond to the unique nature of recreational diving, but retaining the Navy's concept of residual nitrogen. Modifications used 5 fsw depth increments instead of 10 and calculated time to the nearest minute. He used more repetitive groups to eliminate the large time discontinuities (26 instead of the 16 used by USN). He calculated M-values from these empirically-determined, mathematically-smoothed, conservative no-stop limits.

Initially, RER intended only to modify the familiar "flat" tables; the concept of a rotary calculator did not occur until the tabular evolution had been largely completed. The idea for The Wheel sprang from graphing, on paper and by computer. The early version of The Wheel was still based on the 40 minute compartment. After consulting aggressive divers who might "push" limits, RER felt that a 60 minute compartment may be a better basis for repetitive dives, and he generated all subsequent tables on that basis.

In 1984 September RER visited PADI in California. PADI saw the circular calculator demonstrated, but wondered about introducing a new and untested product. RER suggested testing, but noted that suitable government research funds had all but dried up. PADI suggested private funding for the tests. Discussions were held with different research facilities about a research program. By July of 1985 an understanding was reached with IAPM; two years passed before suitable arrangements were completed.

Profile selection was to stress the computational algorithm to the maximum; a secondary goal was to evaluate many combinations of repetitive, multilevel, and repetitive-multilevel profiles. After each test profile was selected its bottom time was increased to make the tests more rigorous, splitting the difference between the dive times specified by the table and those determined by gas loadings of the theoretical model. Testing was therefore of the algorithm itself, so none of the operational rules (safety stops, long surface intervals) were used.

The RDP test program was not to be considered as basic research (although the Doppler studies were), but rather as a demonstration that modifications to established procedures would be acceptable. If an adequate exposure tested well it would be defined as the new no-stop limit, even though the true physiological limit might be higher. It may be possible to test higher limits successfully, but there was no plan to do so. Maximum times allowed by the tables would not be increased because of favorable outcomes, but would be reduced in the event of unfavorable outcomes.

Phase I testing began in 1987 April and continued through September. Most of the dives were conducted in the IAPM chamber in Seattle, the others in Puget Sound. No profiles required modification because of test results. At this point, there were no plans for further testing and an introduction of the RDP was planned for the 1988 January Diving Equipment Manufacturers Association show. There was controversy at the DEMA show. Words had appeared on prototypes of the RDP that were well intentioned but misunderstood. They warned against making too many dives in a day, but seemed to suggest that it is acceptable to make up to 8 dives per day. Although this wording never appeared on any version of the RDP made available to the public, the Divers Alert Network expressed concern that the warning was inappropriate. This wording was changed on the RDP before it was released to the public.

It was also agreed that PADI, DSAT, and DAN would cooperate in additional research into the rapidly developing practice of multiday diving. A meeting at Duke University in 1988 April discussed "Phase II." DAN asked RER to prepare profiles and protocols for both chamber and open water trials for 6 dives a day for 6 days. Profile selection was similar to Phase I, except that while Phase I tested the algorithm, Phase II would evaluate the RDP, and would use operational rules (safety stops, long surface intervals). Along with Phase II preparations, procedures were developed for diving at altitude with the RDP, including altitude equivalents and methods of compensating for arrival from lower elevations. (No testing of altitude procedures was done.) Phase IIa testing began on 1988 October 31 but ended on the third day. DCS had occurred and the IAPM procedures contained a clause that required termination in that event. This test, in terms of what tests are for, was highly successful, but it cast doubt on the suitability of making 6 extreme, near-limit dives per day with reverse profiles, and thus required a regrouping.

The program was resumed, this time with 4 dives per day; Phase IIb ran from 1988 November through 1989 April. Phase IIb proceeded successfully to its conclusion. In the meantime DAN had appointed a committee to consider broad issues of decompression in recreational diving. Since the program represented the sum of RDP research at the time, the committee addressed the suitability of the DSAT studies. The consensus (not unanimous) was that the series should be repeated in open water, and preparations began. For various reasons, the "Phase III" study met repeated delays, and by mid-1991, three years had passed since the RDP had been introduced; it had been used extensively, and evidence—albeit limited and without a "denominator"—indicated that field use had been highly successful. DSAT determined that further laboratory studies would be of marginal benefit, but remains interested in improving the acquisition of field data and in maximizing what can be learned.

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APPENDIX

Appendix A. Subject descriptions

This appendix provides a brief description of the diver-subjects who participated in the project. It includes essentially all information on each subject that was recorded.

Appendix A1. Description of subjects in Phase I

A total of 234 subjects participated in Phase I. They are listed here alphabetically by diver identifiers. Descriptive information follows in columns, as noted.

Subject. Unique coded identifier for each diver; these are not initials.

Gender. Two possible choices.

Age in years at beginning of test program

Weight in both pounds and kilograms.

Height in both inches and centimeters.

Fat % based on height and weight. This is a calculated value which is a gross estimate, so we are stretching things to report 2 significant figures. The formulas for this are different for males and females (Wormersley and Durnin, 1977).

Males: $1.34*((\text{wt in kg})/(\text{ht in m})^2) - 12.47$

Females $1.37*((\text{wt in kg})/(\text{ht in m})^2) - 3.47$

Yrs exp is years of diving experience, shown with the first decimal place filled in for those with less than 3 yrs experience, if the information is available, and rounded to zero for the others to represent the nearest year. More precision is unwarranted.

Profiles participated in. The list of profile numbers in which this subject participated.

Comments begin with a parenthetical indication if the Phase I diver also participated in Phase II (we attach no special relevance to this). A few comments taken from the logbook relating to that particular profile follow.

Appendix A1. Page 1 of 4. Description of subjects in Phase I. This was single repetitive and multilevel dives. Profiles performed by each subject are shown. Divers also in Phase IIb are so marked.

Subject	Gender	Age	Weight lb	Weight kg	Height in	Height cm	Fat, %	Yrs. Exp.	Phase I profiles, this subject	
ALS	m	30	190	86.4	68.0	173	26	13.0	5,7,12,12,15	
AND	m	44	145	65.9	67.0	170	18	3.0	1,3,5,5,9,12,12,12,14,20,52	
ANM	m	29	200	90.9	74.5	189	21	0.5	5,14,52	
AZN	m	40	200	90.9	72.0	183	24	20.0	11	
BAD	m	21	175	79.5	70.0	178	21	1.5	53	
BAJ	m	28	180	81.8	72.0	183	20	3.0	51	
BAK	f	23	125	56.8	64.0	163	26	0.1	51	
BEJ	m	27	230	104.5	76.0	193	25	11.0	51	
BET	m	25	165	75.0	70.0	178	19	0.5	8	
BID	m	33	175	79.5	70.0	178	21	4.0	8,9,51,51,52,53,53,53	
BOB	m	27	175	79.5	66.0	168	25	2.0	1,7,8,10	
BOD	m	25	180	81.8	71.0	180	21	0.5	52	
BOJ	m	26	175	79.5	74.0	188	18	1.0	20	
BOL	f	27	139	63.2	65.0	165	28	1.0	1,7,8,10	
BOP	m	47	204	92.7	72.0	183	25	2.0	1,14	(also in IIb)
BRD	f	31	125	56.8	65.0	165	25	4.0	5,12	
BRP	m	25	160	72.7	70.0	178	18	0.5	52	
BRT	f	30	125	56.8	68.0	173	23	1.5	1,14	(also in IIb)
BRW	m	59	167	75.9	71.0	180	19	2.0	20	(also in IIb)
BSJ	m	28	165	75.0	68.0	173	21	4.0	14	
BUA	m	42	185	84.1	71.0	180	22	1.5	51	
BUJ	f	25	150	68.2	66.5	169	29	0.5	9,9	
BUL	f	39	140	63.6	66.0	168	28	0.5	53	
BUM	m	28	165	75.0	71.0	180	18	1.0	5	
BWP	m	27	150	68.2	68.0	173	18	4.0	51	
CAD	m	32	197	89.5	72.5	184	23	14.0	53	
CHJ	m	40	170	77.3	74.0	188	17	5.0	52	
CHM	m	24	140	63.6	67.0	170	17	2.0	19	
CHR	f	38	125	56.8	67.5	171	23	5.0	52	
COJ	m	31	160	72.7	70.5	179	18	1.5	20	
CRG	m	46	185	84.1	72.0	183	21	28.0	53	
CRJ	m	30	150	68.2	72.0	183	15	17.0	20,52	
CRM	f	43	145	65.9	62.0	157	33	20.0	53	
CRT	m	41	170	77.3	69.0	175	21	1.0	19	
CUT	m	21	175	79.5	72.0	183	19	1.0	51	
DAD	f	34	125	56.8	65.0	165	25	5.0	51,51	
DAJ	m	42	205	93.2	73.0	185	24	10.0	9,53	
DAP	m	44	170	77.3	74.0	188	17	25.0	8	
DEL	m	31	165	75.0	71.0	180	18	3.0	2	
DES	m	26	152	69.1	70.0	178	17	2.2	18	
DNS	f	46	147	66.8	69.0	175	26	0.4	2,2,5,8,51,52,53	
DOD	f	27	120	54.5	64.0	163	25	1.5	20	
DOJ	f	26	125	56.8	66.5	169	24	0.5	3	
DRJ	m	52	205	93.2	74.0	188	23	38.0	8	
DUC	f	35	117	53.2	64.0	163	24	4.0	18	
DUJ	f	33	150	68.2	67.0	170	29	1.0	18	
DYJ	m	40	168	76.4	67.0	170	23	1.0	53	
EAD	m	42	165	75.0	66.0	168	23	1.0	18,53	
EID	m	25	195	88.6	69.0	175	26	0.5	52,53	
EIL	f	26	133	60.5	63.0	160	29	1.0	2	
EKM	m	22	205	93.2	75.0	191	22	1.0	2	
ELS	f	37	145	65.9	67.0	170	28	3.0	5	
ERD	f	29	180	81.8	70.0	178	32	0.5	52	
FAD	m	35	195	88.6	69.0	175	26	3.0	9	
FAR	m	58	180	81.8	70.0	178	22	29.0	8,53	
FEW	m	29	164	74.5	68.8	175	20	14.0	18	
FIJ	m	39	195	88.6	73.0	185	22	31.0	5,6,7,12,12	
FIR	m	32	140	63.6	71.0	180	14	15.0	9	

Appendix A1. Page 2 of 4. Description of subjects in Phase I. This was single repetitive and multilevel dives. Profiles performed by each subject are shown. Divers also in Phase IIb are so marked.

Subject	Gender	Age	Weight lb	Weight kg	Height in	Height cm	Fat, %	Yrs. Exp.	Phase I profiles, this subject
FLD	m	42	145	65.9	69.0	175	16	1.0	53
FTR	m	22	150	68.2	68.0	173	18	1.5	1,14
GAB	m	38	170	77.3	66.0	168	24	8.0	20
GAH	f	23	155	70.5	62.0	157	35	2.0	3 (also in IIb)
GAK	f	26	110	50.0	64.0	163	22	1.5	7,12
GET	f	23	138	62.7	62.0	157	31	0.5	6
GID	f	33	175	79.5	60.0	152	43	1.0	52,52
GLD	m	31	145	65.9	69.0	175	16	1.0	51
GOC	m	29	220	100.0	78.0	198	22	1.0	53
GOG	m	39	170	77.3	70.0	178	20	10.0	51
GOK	m	25	140	63.6	68.0	173	16	0.5	3
GRB	m	50	190	86.4	73.0	185	21	3.0	20,51
GRG	m	41	200	90.9	74.0	188	22	3.0	5
GRN	f	37	160	72.7	63.0	160	35	9.0	18
GRW	m	34	185	84.1	72.0	183	21	1.0	18
GUP	m	27	185	84.1	74.0	188	19	0.5	18,52
HAF	f	29	117	53.2	64.0	163	24	0.4	8,9,9,53
HAJ	m	23	185	84.1	72.0	183	21	2.0	18
HAL	f	28	110	50.0	58.0	147	28	1.0	5,19
HAP	m	35	235	106.8	76.0	193	26	0.5	5
HAR	m	26	160	72.7	66.0	168	22	4.5	2
HAV	f	24	141	64.1	65.0	165	29	1.0	3,20,52
HED	f	29	139	63.2	66.0	168	27	0.3	3,51,53
HEJ	f	36	135	61.4	64.5	164	28	15.0	53
HEL	m	42	192	87.3	75.5	192	19	0.3	52
HML	m	37	215	97.7	75.0	191	24	1.0	1
HNL	f	30	130	59.1	65.0	165	26	10.0	8
HOR	m	38	207	94.1	76.0	193	21	16.0	5
HOS	m	40	230	104.5	70.0	178	32	2.0	51
HRJ	m	39	158	71.8	69.0	175	19	21.0	8
HRL	m	23	135	61.4	67.0	170	16	2.0	1,7,8,10
HUB	m	35	145	65.9	67.0	170	18	10.0	19
IRR	m	32	195	88.6	72.0	183	23	6.0	20,51
IVP	m	21	135	61.4	68.0	173	15	3.0	9,51
JAJ	f	32	147	66.8	66.0	168	29	2.0	3
JOS	m	33	135	61.4	67.0	170	16	16.0	9
KAA	f	56	145	65.9	66.5	169	28	11.0	53
KAJ	m	34	165	75.0	72.0	183	18	14.0	51
KAR	m	32	160	72.7	68.0	173	20	17.0	53
KED	m	30	159	72.3	69.5	177	19	10.0	5,7,12,12,14
KEE	m	41	170	77.3	72.0	183	18	4.0	8,9
KEW	m	35	185	84.1	68.5	174	25	9.0	19
KIG	m	37	150	68.2	72.0	183	15	15.0	1,3,5,6,9,9,12,51
KIN	m	43	238	108.2	70.0	178	33	11.0	8,15,51
KIV	f	34	155	70.5	71.0	180	26	1.0	6,7,8,15,20
KLJ	m	48	176	80.0	72.0	183	20	0.3	52,53
KNG	f	42	200	90.9	62.0	157	47	9.0	15
KOV	m	29	195	88.6	72.0	183	23	2.0	6
KPJ	f	38	122	55.5	66.0	168	24	0.8	9
KRL	f	27	125	56.8	64.0	163	26	0.5	1
KRM	m	26	185	84.1	72.0	183	21	0.5	1,51
KUD	m	43	155	70.5	71.0	180	17	16.0	52
LAD	f	26	135	61.4	64.0	163	28	5.0	5,6
LAL	m	41	178	80.9	70.0	178	22	3.0	51
LAM	m	36	175	79.5	70.0	178	21	24.0	11
LIC	f	27	200	90.9	66.0	168	41	3.0	52
LOD	f	27	130	59.1	67.5	171	24	2.5	2
LOJ	m	26	230	104.5	73.0	185	28	1.0	2
LOP	m	26	180	81.8	72.0	183	20	5.0	8,52

Appendix A1. Page 3 of 4. Description of subjects in Phase I. This was single repetitive and multilevel dives. Profiles performed by each subject are shown. Divers also in Phase IIb are so marked.

Subject	Gender	Age	Weight lb	Weight kg	Height in	Height cm	Fat, %	Yrs. Exp.	Phase I profiles, this subject
LUJ	m	22	150	68.2	68.0	173	18	2.0	14
MAB	m	37	153	69.5	70.0	178	17	4.0	51
MAC	f	27	113	51.4	62.0	157	25	6.0	6,8
MAD	m	22	175	79.5	74.0	188	18	1.0	1,14
MAF	f	34	140	63.6	66.0	168	28	16.0	53
MAG	f	36	125	56.8	61.0	155	29	1.0	53
MAJ	m	39	192	87.3	67.0	170	28	1.0	4,8,10
MAM	m	27	190	86.4	73.0	185	21	7.0	5,6,7
MAP	m	37	160	72.7	70.0	178	18	0.3	52,52,53
MAR	m	41	195	88.6	73.0	185	22	0.5	18
MCD	m	36	190	86.4	71.0	180	23	15.0	19
MCF	m	26	175	79.5	70.0	178	21	2.0	52,52
MCJ	m	33	155	70.5	70.0	178	17	1.3	20
MCM	f	25	145	65.9	63.0	160	32	1.0	3
MEC	f	37	175	79.5	64.5	164	37	0.3	1,2,51
MEM	m	30	198	90.0	67.0	170	29	10.0	4,18,19
MER	m	42	180	81.8	71.0	180	21	1.0	8,53
MES	f	23	165	75.0	72.0	183	27	4.0	51
MET	m	31	165	75.0	73.0	185	17	1.0	19
MID	m	27	210	95.5	75.0	191	23	1.0	7
MIL	m	35	150	68.2	68.0	173	18	0.5	1,5,9,14,52
MIN	f	34	165	75.0	69.0	175	30	12.0	9,52
MOG	m	28	180	81.8	72.0	183	20	0.5	9,9
MOM	f	29	135	61.4	69.0	175	24	1.0	6
MRM	f	26	105	47.7	62.0	157	23	7.0	9,12
MRM	f	26	105	47.7	62.0	157	23	7.0	9,12
MUM	m	32	160	72.7	71.0	180	17	8.0	6
MYC	m	26	180	81.8	72.0	183	20	2.0	5,11,19
NEC	m	22	150	68.2	68.0	173	18	1.0	2
NED	m	34	250	113.6	70.0	178	36	0.5	51,53,53
NEK	f	38	144	65.5	65.0	165	29	0.5	2,3,5,11,14,17,17,18,19,22
NIG	f	44	110	50.0	65.0	165	22	1.0	3,7 (also in IIb)
OLP	m	32	175	79.5	75.0	191	17	0.1	4
OLR	m	33	165	75.0	68.0	173	21	2.0	53
OLT	m	37	228	103.6	72.0	183	29	0.1	52
ORC	f	29	135	61.4	67.0	170	26	3.0	1,52
OWK	f	35	180	81.8	66.0	168	36	0.8	2,6
PAA	f	34	105	47.7	61.0	155	24	13.0	11
PAC	m	27	185	84.1	72.0	183	21	9.0	20
PAD	m	29	250	113.6	72.0	183	33	12.0	1,14,14,51
PAJ	m	34	225	102.3	77.0	196	23	4.0	1
PAP	m	42	173	78.6	69.0	175	22	20.0	5
PAR	m	29	210	95.5	69.0	175	29	2.5	11,52
PEB	f	26	165	75.0	66.0	168	33	1.0	1,2,5,5,5,6,8,51
PEC	m	38	125	56.8	68.0	173	13	0.6	51
PEJ	m	33	170	77.3	74.0	188	17	12.0	53
PEM	f	29	125	56.8	69.0	175	22	0.8	11
PEO	m	63	168	76.4	71.0	180	19	17.0	17
PIJ	m	44	185	84.1	69.0	175	24	2.0	2
PLA	m	40	170	77.3	70.0	178	20	2.0	11,11
POG	m	37	139	63.2	67.8	172	16	1.0	7,51
POH	m	31	180	81.8	72.0	183	20	1.0	3,53,53
POM	m	45	175	79.5	70.0	178	21	2.0	1,3,4,5,5,6,6,8,8,10,11,13,18,19,19,22,52,52
PRM	m	32	180	81.8	70.0	178	22	17.0	52
PUM	f	32	118	53.6	62.0	157	26	1.0	51
PYK	f	25	160	72.7	70.0	178	28	3.0	52
RAJ	m	39	185	84.1	73.0	185	20	0.5	7
RAR	m	31	190	86.4	68.0	173	26	15.0	3,52

Appendix A1. Page 4 of 4. Description of subjects in Phase I. This was single repetitive and multilevel dives. Profiles performed by each subject are shown. Divers also in Phase IIb are so marked.

Subject	Gender	Age	Weight lb	Weight kg	Height in	Height cm	Fat, %	Yrs. Exp.	Phase I profiles, this subject
RDD	f	42	134	60.9	67.0	170	25	1.0	51,53 (also in IIb)
RED	m	27	195	88.6	76.0	193	19	8.0	5,6,6,51
RER	m	29	155	70.5	73.0	185	15	3.0	53
RES	m	27	190	86.4	75.0	191	19	11.0	53
RHL	f	27	150	68.2	64.5	164	31	0.6	9
RHR	m	29	165	75.0	66.0	168	23	0.5	9,51
RIK	f	51	154	70.0	67.0	170	30	3.0	53
RIL	m	26	185	84.1	73.0	185	20	1.0	8,9,20
RIM	m	34	190	86.4	71.0	180	23	8.0	51
RIT	m	23	175	79.5	73.0	185	18	0.5	53
ROA	m	30	165	75.0	70.0	178	19	1.0	19
ROB	m	25	170	77.3	70.0	178	20	0.5	3
ROD	m	27	150	68.2	69.5	177	17	14.0	11
ROK	m	32	175	79.5	72.0	183	19	0.5	51
ROS	f	39	122	55.5	65.0	165	24	10.0	4
ROT	m	37	170	77.3	69.0	175	21	4.0	16
RTD	m	25	158	71.8	70.5	179	17	9.0	1,3,5,11,12,12,20
SAS	m	23	155	70.5	70.0	178	17	0.5	3
SCB	f	31	130	59.1	67.0	170	24	4.0	18
SCD	m	31	180	81.8	70.0	178	22	1.0	3,52
SCH	f	42	124	56.4	62.0	157	28	1.0	9
SCT	f	31	145	65.9	68.0	173	27	2.0	53
SEL	m	30	140	63.6	61.0	155	23	11.0	53
SEP	m	24	140	63.6	66.0	168	18	1.0	1,5,11
SHJ	m	29	150	68.2	68.0	173	18	6.0	1,2,19
SHR	m	29	145	65.9	68.0	173	17	1.0	52
SIB	f	28	120	54.5	62.0	157	27	0.5	51
SIT	m	29	190	86.4	71.0	180	23	0.5	9,9
SMB	m	28	160	72.7	72.0	183	17	1.0	2,51
SMD	f	27	178	80.9	72.0	183	30	0.7	20
SMK	m	45	194	88.2	72.0	183	23	17.0	16,21
SMR	m	25	175	79.5	65.5	166	26	1.0	52,53
SMS	f	24	185	84.1	70.0	178	33	4.0	52
SPD	f	39	115	52.3	62.0	157	25	0.8	14
SRJ	m	32	165	75.0	67.0	170	22	18.0	1
STC	m	23	170	77.3	72.0	183	18	6.0	1,2,5,9,10,12,15,17,18,19,19,21
STD	m	34	200	90.9	71.0	180	25	10.0	6
STG	m	36	190	86.4	76.0	193	19	2.5	3
STJ	m	25	170	77.3	70.5	179	20	3.0	7,12,12
STT	m	25	170	77.3	73.0	185	18	7.0	19
SUK	m	27	175	79.5	70.0	178	21	1.0	5,14
SWJ	m	33	160	72.7	68.0	173	20	4.0	6
TAJ	m	22	142	64.5	68.0	173	16	0.5	7
TAM	m	32	185	84.1	74.0	188	19	1.0	3
TEC	m	30	220	100.0	72.0	183	28	2.5	1,8,11,21,51
TSW	m	39	150	68.2	69.0	175	17	1.0	51
URD	f	37	118	53.6	62.0	157	26	0.5	51
VAJ	f	49	132	60.0	69.0	175	23	3.0	51,51,51,52,53
VIB	m	40	180	81.8	74.0	188	19	5.0	2
WAA	m	51	230	104.5	73.0	185	28	14.0	11
WAT	m	26	200	90.9	72.0	183	24	10.0	51
WEB	f	27	120	54.5	67.0	170	22	0.8	5
WEW	m	61	180	81.8	67.0	170	25	15.0	51,52
WHJ	f	23	120	54.5	63.0	160	26	1.5	20
WID	f	27	140	63.6	67.0	170	27	1.0	53
WOJ	f	36	125	56.8	62.0	157	28	0.5	51
WRR	m	32	170	77.3	70.0	178	20	4.0	12
WYK	m	27	240	109.1	70.0	178	34	13.0	13
YES	m	27	180	81.8	68.0	173	24	1.0	53

Appendix A2. Description of subjects in Phase IIa

There were 4 subjects in Phase IIa. The plan that had operated in Phase I was for the divers to fill out the information form after the dive when time was more readily available. When Phase IIa was abruptly halted the divers departed without filling out the forms, so description forms were not filled in for these divers. Some of the data on these divers is estimated from other sources; it is close enough to be useful.

The format for Phase IIa subjects is the same as for Phase I.

Appendix A3. Description of subjects in Phase IIb

Twenty divers participated in Phase IIb. Six of these had also participated in Phase I. Descriptions of these divers follows the same pattern as Phase I.

Appendix A2. Description of subjects in Phase IIa. Six dives per day, two days completed, repetitive and multilevel dives.

Subject	Gender	Age	Weight lb	Weight kg	Height in	Height cm	Fat, %
GAR	m	26	166	75.5	73	185	17
KEJ	m	38	180	81.8	73	185	19
MOM	m	26	170	77.3	71	180	19
SHK	m	31	165	75.0	73	185	17

The age, height and weight of KEJ and MOM were estimated.

Appendix A3. Description of subjects in Phase IIb. Four dives per day for six days, repetitive and multilevel dives.

Subject	Gender	Age	Weight lb	Weight kg	Height in	Height cm	Fat, %	
BOP	m	49	200	90.9	72	183	25	(also in I)
BRT	f	33	125	56.8	68	172	23	(also in I)
BRW	m	61	167	75.9	71	180	19	(also in I)
FOM	m	49	190	86.4	74	188	20	
GAH	f	24	155	70.5	62	157	35	(also in I)
GUM	m	28	160	72.7	69	175	19	
HAL	f	32	130	59.1	65	165	26	
HAM	m	33	155	70.5	71	180	17	
LOS	f	44	128	58.2	65	165	26	
MAP	m	38	160	72.7	70	178	18	
MUC	f	39	165	75.0	65	165	34	
MUM	f	30	130	59.1	70	178	22	
NIE	m	30	165	75.0	70	178	18	
NIG	f	45	110	50.0	65	165	22	(also in I)
PEG	m	39	124	56.4	68	173	13	
PTG	m	21	130	59.1	66	168	16	
RDD	f	44	140	63.6	67	170	27	(also in I)
TAM	m	48	245	111.4	69	175	35	
WAB	m	28	195	88.6	71	180	24	
WIB	m	45	175	79.5	69	175	22	

Appendix B. Data from Phase I single day exposures

Appendix B1. Profile summary for Phase I.

This is a list of the 25 different profiles used for Phase I. The following information is given for each profile.

- Profile number.
- Profile details by depth and time sequences.
- Descriptive summary or type of profile (in small type).
- Location of exposures (chamber, inwater beach, inwater boat).
- Summary of profile results; number of diver-days, exercise, Doppler summary.
- Some comments from the dive log are included.

All Phase I profiles except 51, 52, and 53 were done in the dry hyperbaric chamber. The 50 series were done both in the chamber and in the water. Each profile is displayed as a sequence of depth/time periods (fsw/min), with surface intervals shown in sequence in the same format. For example, Profile #1 is listed as 130/12 + 0/43 + 45/83 + 0/..., with a description as "Repetitive 2, square, square." This is a repetitive sequence of two dives. The first is a "square" dive to 130 fsw for 12 min, followed by a surface interval of 43 min, followed by another square dive to 45 fsw for 83 min. Profile #5 shows an example of a 2-step multilevel dive ("Multilevel 2") displayed as {120/14 + 55/27} + 0/---." French braces enclose the steps of each multilevel dive.

"Square" means that at the starting time the diver went straight to bottom pressure and remained there until the end of bottom time, at which time ascent (decompression) began. The time to get to pressure is part of the bottom time. Ascent time to the surface or to the next level in a multilevel dive is not shown; it is in addition to the times shown. Therefore each total dive time is longer than shown by the total ascent time, depth/60 fsw/min. The final surface period is indicated as "0/---," meaning an indefinite time at 0 depth or 1 atm pressure.

The total number of exposures on each profile sequence is listed in the first column at right as "Diver days." A single diver going through the entire daily sequence is considered as a "diver day." The second column gives the number of these exposures during which the diver performed exercise (all inwater dives were considered to be with exercise; see Chapter IV).

The last column to the right gives both a summary of Doppler results as the number of dives in which bubbles were found, and the total number of Doppler readings taken. These were taken during surface intervals between individual repetitive dives as well as at the end of the sequence. For multilevel dives the number of Doppler readings is the number of dives, regardless of the number of steps or levels in the dive. In this and the other appendixes we use Arabic numbers for the Doppler grades, to save space. Profiles 51, 52, and 53 have been called A, B, and C, respectively in other materials.

We have reproduced the comments as they were recorded in the dive log. We have no further interpretation of this information. In many cases it can be assumed that there was a delay in pressurization or descent of a few seconds to a minute or two, but details are not available.

Appendix B1. Profile summary for Phase I. Individual repetitive and multilevel dives. Profiles are shown as depth/time (fsw/min) for all phases, including intervals. Multilevel dive sequences are shown in braces { }.

Profile #	Profiles, as Depth/Time	Diver days	with exercise	Doppler runs with bubbles
1	130/12 + 0/43 + 45/83 + 0/— Repetitive 2: square, square	25	15	2 of 50
2	55/65 + 0/57 + 55/43 + 0/— Repetitive 2: square, square	18	18	9 of 36
3	85/27 + 0/43 + 45/72 + 0/— Repetitive 2: square, square	20	19	0 of 40
4	45/100 + 0/75 + 85/20 + 0/— Repetitive 2: square, square	5	5	0 of 10
5	{120/14 + 55/27} + 0/— SIngle: multilevel 2	32	20	4 of 32
6	{100/20 + 50/29} + 0/— SIngle: multilevel 2	18	15	2 of 18
7	{80/30 + 45/32} + 0/— SIngle: multilevel 2	15	15	4 of 15
8	{60/55 + 40/25} + 0/— SIngle: multilevel 2	24	16	6 of 24
9	120/14 + 0/40 + 55/49 + 0/— Repetitive 2: square, square	27	24	5 of 54
10	75/35 + 0/57 + 55/47 + 0/— Repetitive 2: square, square	6	3	3 of 12
11	100/ 20 + 0/77 + 75/29 + 0/— Repetitive 2: square, square	15	15	1 of 30
12	{130/12 + 70/13 + 45/29} + 0/— SIngle: multilevel 3	19	15	2 of 19
13	110/17 + 0/37 + 65/31 + 0/23 + 45/41 + 0/— Repetitive 3: square, square, square	2	2	0 of 6
14	{130/12 + 60/21 + 45/23 + 35/42} + 0/— SIngle: multilevel 4	15	15	0 of 15
15	130/12 + 0/43 + 90/16 + 0/37 + 0/21 + 40/71 + 0/— Repetitive 4: square, square, square, square	5	5	4 of 20
16	{90/25 + 45/34} + 0/49 + 60/39 + 0/— Repetitive 2: multilevel 2, square	2	2	2 of 4
17	55/65 + 0/24 + {55/27 + 40/20} + 0/— Repetitive 2: square, multilevel 2	4	4	0 of 8
18	{130/12 + 50/41} + 0/84 + {80/21 + 45/33} + 0/— Repetitive 2: multilevel 2, multilevel 2	15	15	0 of 30
19	{110/17 + 65/11} + 0/33 + {50/47 + 35/37} + 0/32 + {60/17 + 40/29} + 0/— Repetitive 3: multilevel 2, multilevel 2, multilevel 2	17	14	2 of 51
20	{120/14 + 60/19 + 45/22} + 0/23 + 40/67 + 0/— Repetitive 2: multilevel 3, square	17	15	4 of 34
21	65/45 + 0/37 + {65/17 + 45/26 + 35/36} + 0/— Repetitive 2: square, multilevel 3	3	3	0 of 6
22	95/22 + 0/39 + {55/35 + 40/34 + 35/17} + 0/— Repetitive 2: square, multilevel 3	2	0	0 of 4
51	100/18 + 0/33 + 65/26 + 0/30 + 50/39 + 0/— [24 / 48 in water] Repetitive 3: square, square, square	48	39	12 of 144
52	80/21 + 0/30 + 60/33 + 0/30 + 55/28 + 0/— [25 / 40 in water] Repetitive 3: square, square, square	40	40	3 of 120
53	65/35 + 0/28 + 55/32 + 0/28 + 50/33 + 0/— [27 / 43 in water] Repetitive 3: square, square, square	43	43	5 of 129
	Totals:	437	377	70 of 911

Appendix B2. Phase I exposures and Doppler results.

A comprehensive summary of the experimental data from Phase I of the validation testing is given here, listed by profile. The profiles are numbered consecutively from 1 to 22 for the dry chamber exposures, and 51 to 53 for the profiles which included open water exposures. The list shows details of the profiles performed along with the Doppler data. The profile summaries are given in Appendix B1, and the dive data in B2.

The following information is included for each profile:

- Profile number (see Appendix B1 for a condensed description of the profiles).
- Profile details by depth and time sequences (see Appendix B1 for explanation).
- Location of exposure (chamber, inwater beach, inwater boat).
- Descriptive summary (type of profile, same as B1).
- Exercise or no exercise, separated by a long horizontal line.
- Gender of divers; males are above the short horizontal line within each level of exercise, females below it. Groups with no line are all males.
- Open water dives, and whether inwater dives were from the beach or a boat. These are separated by dotted lines (Profiles 51, 52, 53).
- Diver/subject identification code for each diver-exposure.
- Date and time of start of each exposure.
- Doppler grades, resting (R#) and after flexing (F#) from each Doppler session.
- Summary of profile results; number of diver-days, diver-days with exercise, Doppler summary.

The explanation of the profile display is given in Appendix B1. Essentially they are a sequence of depth/time periods (fsw/min), with surface intervals shown in sequence in the same format. The profile steps are located so as to allow the surface intervals during which measurements were made to be over the columns of Doppler data.

Pairs of Doppler scores follow the starting time, in columns arranged under the R1 and F1 headers, where R=resting and F=after flexing. These are from readings taken during each surface interval; a "reading" is the bubble score taken with the diver at rest and again after flexing (see Chapter IV). The duration of the surface interval is shown at the top of each column. Using the first profile as an example, the first surface interval depth/time is "0/43" and the second interval is shown as "0/---." Only one column of pairs of Doppler scores are recorded following each multilevel dive, but more than one reading may have been taken.

The exposures with and without exercise are indicated on the left side. Where dives were done in the water, this is indicated in the same manner on the right side (profile #51, 52, 53 only). Inwater dives were considered to be with exercise. A summary line is at the bottom of each set of dives for a given profile.

Appendix B2, page 1 of 9. Data summary for Phase I. Profiles shown as depth/time (fsw/min) for all phases, including intervals. Doppler scores are in columns; R = rest and F = flex. Long line delineates exercise, (above the line), short line delineates males (above the line) from females.

Profile #1 130/12 + 0/43 +45/83 + 0/---

Repetitive 2
Square
Square
Chamber

Group	Subject	Date	Time	R1	F1	R2	F2	R3	F3	R4	F4	Notes
⇓ Exercise	AND	87Jul16	1652	0	0	0	0					
	BOB	87Jun16	1740	0	0	0	0					
	BOP	87May15	1241	0	0	0	2					
	FTR	87Aug25	1829	0	0	0	0					
	HRL	87Jun16	1740	0	0	0	0					
	MAD	87Aug25	1829	0	0	0	0					
	MIL	87Jul16	1652	0	0	0	0					
	PAJ	87May04	1252	0	0	0	0					
	POM	87May04	1252	0	0	0	0					
	RTD	87Jul16	1652	0	0	0	0					
	SRJ	87Jun16	1740	0	0	0	0					
	BOL	87Jun16	1740	0	0	0	1					
	BRT	87May15	1241	0	0	0	0					
	KRL	87Aug25	1829	0	0	0	0					
	ORC	87Sep18	0929	0	0	0	0					
⇓ No Exercise	HML	87May21	1806	0	0	0	0					
	KIG	87May21	1806	0	0	0	0					
	KRM	87Aug25	1829	0	0	0	0					
	PAD	87May16	1035	0	0	0	0					
	SEP	87May21	1806	0	0	0	0					
	SHJ	87May16	1035	0	0	0	0					
	STC	87May21	1806	0	0	0	0					
	TEC	87May15	1241	0	0	0	0					
	MEC	87Aug25	1829	0	0	0	0					
	PEB	87May16	1035	0	0	0	0					

Summary, Profile #1: Diver days - 25 w/ exercise - 15 Doppler runs w/ bubbles - 2 of 50

Profile #2 55/65 + 0/57 +55/43 + 0/---

Repetitive 2
Square
Square
Chamber

Group	Subject	Date	Time	R1	F1	R2	F2	R3	F3	R4	F4	Notes
⇓ Exercise	DEL	87Sep25	1459	0	0	0	0					
	EKM	87Sep21	1318	0	0	0	0					Ear problem, 9 min to 55 fsw.
	HAR	87Sep25	1459	0	0	0	0					
	LOJ	87Aug24	0950	1	1	0	1					
	NEC	87Jun09	1224	0	0	0	0					
	PIJ	87Sep21	1318	0	1	0	1					Ear problem, 9 min to 55 fsw.
	SHJ	87Jun13	1121	0	0	0	0					
	SMB	87Aug24	0950	0	0	0	0					
	STC	87Jun09	1224	0	0	0	0					
	VIB	87May01	1210	0	0	0	0					
	DNS	87Aug21	0926	0	0	0	1					
	DNS	87Sep29	1809	0	0	0	0					
	EIL	87Aug24	0950	0	1	0	0					
	LOD	87Aug21	0926	0	0	0	0					
	MEC	87Sep29	1809	0	0	0	0					Ears; first descent 12, second 7:30.
	NEK	87Aug21	0926	0	1	0	0					
	OWK	87Sep29	1809	0	0	0	1					Ears; first descent 12, second 7:30.
	PEB	87Jun13	1121	0	0	1	1					

Summary, Profile #2: Diver days - 18 w/ exercise - 18 Doppler runs w/ bubbles - 9 of 36

Profile #3 85/27 + 0/43 +45/72 + 0/---

Repetitive 2
Square
Square
Chamber

Group	Subject	Date	Time	R1	F1	R2	F2	R3	F3	R4	F4	Notes
⇓ Exercise	AND	87May13	1804	0	0	0	0					Time to depth 3:10 min
	KIG	87Sep28	1824	0	0	0	0					Ear clearing problems both dives.
	POH	87Aug26	1829	0	0	0	0					Ear clearing problem
	POM	87May05	1227	0	0	0	0					
	RAR	87Sep28	1824	0	0	0	0					Ear clearing problems both dives.
	ROB	87Sep30	1823	0	0	0	0					
	RTD	87May13	1804	0	0	0	0					Time to depth 3:10 min

Appendix B2, page 2 of 9. Data summary for Phase I. Profiles shown as depth/time (fsw/min) for all phases, including intervals. Doppler scores are in columns; R = rest and F = flex. Long line delineates exercise, (above the line), short line delineates males (above the line) from females.

	Subject	Date	Time	R1	F1	R2	F2		R3	F3	R4	F4
Exercise ⇓	SAS	87Aug26	1829	0	0	0	0	Ear clearing problem				
	SCD	87Sep30	1823	0	0	0	0					
	STG	87Aug12	0937	0	0	0	0					
	TAM	87Aug12	0937	0	0	0	0					
	DOJ	87May13	1804	0	0	0	0	Time to depth 3:10 min				
	GAH	87Sep30	1823	0	0	0	0					
	HAV	87Aug26	1829	0	0	0	0	Ear clearing problem				
	HED	87Sep30	1823	0	0	0	0					
	JAJ	87Sep30	1823	0	0	0	0					
	MCM	87Sep28	1824	0	0	0	0	Ear clearing problems both dives.				
	NEK	87May05	1227	0	0	0	0					
	NIG	87May13	1804	0	0	0	0	Time to depth 3:10 min				
No Ex	GOK	87Aug26	1829	0	0	0	0	Ear clearing problem				

Summary, Profile #3: Diver days - 20 w/ exercise - 19 Doppler runs w/ bubbles - 0 of 40

Profile #4

45/100 + 0/75 +85/20 + 0/---

Repetitive 2
Square
Square
Chamber

	Subject	Date	Time	R1	F1	R2	F2
Exercise	POM	87Apr28	??	0	0	0	0
	OLP	87Apr28	??	0	0	0	0
	MEM	87Apr28	??	0	0	0	0
	MAJ	87Jul20	1253	0	0	0	0
	ROS	87Jul20	1253	0	0	0	0

Summary, Profile #4: Diver days - 5 w/ exercise - 5 Doppler runs w/ bubbles - 0 of 10

Profile #5

{120/14 + 55/27} + 0/---

Multilevel 2
Chamber

	Subject	Date	Time	R1	F1
Exercise ⇓	ALS	87Apr14	1827	0	0
	BUM	87Aug17	1816	0	0
	FIJ	87Apr14	1827	0	1
	GRG	87Aug13	1829	0	1
	HAP	87Aug13	1829	0	1
	HOR	87Aug13	1829	0	0
	KIG	87Mar31	1850	0	0
	MAM	87Apr14	1827	0	0
	MYC	87Sep25	0922	0	1
	PAP	87Jun30	1820	0	0
	RED	87Apr10	1727	0	0
	SEP	87Apr10	1727	0	0
	STC	87Mar31	1850	0	0
	DNS	87Aug17	1816	0	0
	ELS	87Jun30	1820	0	0
	HAL	87Sep25	0922	0	0
	LAD	87Apr10	1727	0	0
	NEK	87Sep25	0922	0	0
	PEB	87Mar31	1850	0	0
	PEB	87Jun30	1820	0	0
No Exercise ⇓	AND	87Mar26	1745	0	0
	AND	87Jun04	18??	0	0
	ANM	87Jun04	18??	0	0
	KED	87May21	1807	0	0
	MIL	87Jun04	18??	0	0
	POM	87May21	1807	0	0
	POM	87Jun04	18??	0	0
	RTD	87Mar26	1745	0	0
	SUK	87May21	1807	0	0
	BRD	87May22	1821	0	0
	PEB	87May22	1821	0	0
	WEB	87May22	1821	0	0

Summary, Profile #5: Diver days - 32 w/ exercise - 20 Doppler runs w/ bubbles - 4 of 32

Appendix B2, page 3 of 9. Data summary for Phase I. Profiles shown as depth/time (fsw/min) for all including intervals. Doppler scores are in columns; R = rest and F = flex. Long line delineates exercise, (above the line), short line delineates males (above the line) from females.

Subject	Date	Time	R1	F1		R2	F2	R3	F3	R4	F4
Profile #6		{100/20 + 50/29} + 0/---									Multilevel 2 Chamber
⇓ Exercise FIJ	87Apr30	1834	1	1							
KOV	87Apr01	1840	0	0							
MAM	87Apr30	1834	0	0							
MUM	87Aug14	1813	0	0	Ear clearing problem						
POM	87Apr01	1840	0	0							
POM	87Apr03	1318	0	0							
RED	87Apr01	1840	0	0							
RED	87Apr28	1833	0	0							
STD	87Apr03	1318	0	0							
GET	87Aug14	1813	0	0	Ear clearing problem						
KIV	87Apr03	1318	0	0							
LAD	87Apr28	1833	0	0							
MAC	87Apr28	1833	0	0							
MOM	87Sep03	1832	0	0							
OWK	87Aug14	1813	0	0	Ear clearing problem						
KIG	87May15	1818	0	1							
No Ex SWJ	87May15	1818	0	0							
PEB	87May15	1818	0	0							
Summary, Profile #6:		Diver days - 18			w/ exercise - 15			Doppler runs w/ bubbles -	2	of	18
Profile #7		{80/30 + 45/32} + 0/---									Multilevel 2 Chamber
⇓ Exercise ALS	87Apr03	1836	0	0							
BOB	87May07	1800	0	0							
FIJ	87Apr03	1836	0	1							
HRL	87May07	1800	0	0							
KED	87May05	1808	0	0							
MAM	87Apr03	1836	0	1							
MID	87May14	1813	0	0							
POG	87Jul28	1830	0	0							
RAJ	87Aug04	1840	0	0							
STJ	87May05	1808	0	0							
TAJ	87Jul28	1830	0	0							
BOL	87May07	1800	0	1							
GAK	87May05	1808	0	0							
KIV	87May14	1813	0	1							
NIG	87May07	1800	0	0							
Summary, Profile #7:		Diver days - 15			w/ exercise - 15			Doppler runs w/ bubbles -	4	of	15
Profile #8		{60/55 + 40/25} + 0/---									Multilevel 2 Chamber
⇓ Exercise BET	87Aug18	1840	0	0							
BID	87Aug20	0930	0	0							
BOB	87Jul13	1630	0	0							
FAR	87Aug20	0930	0	0							
HRL	87Jul13	1630	0	0							
KEE	87Apr04	1321	0	1							
LOP	87Jun19	1824	0	0							
MAJ	87Jul29	1325	0	0	Ear clearing problem						
MER	87Jul29	1325	0	0	Ear clearing problem						
POM	87Apr04	1321	0	0							
RIL	87Sep30	0919	2	3							
BOL	87Jul13	1630	2	3							
DNS	87Sep30	0919	2	3							
HAF	87Jul29	1325	0	0	Ear clearing problem						
MAC	87Apr04	1321	0	0							
PEB	87Jun19	1824	0	1							

Appendix B2, page 4 of 9. Data summary for Phase I. Profiles shown as depth/time (fsw/min) for all phases, including intervals. Doppler scores are in columns; R = rest and F = flex. Long line delineates exercise, (above the line), short line delineates males (above the line) from females.

	Subject	Date	Time	R1	F1	R2	F2		R3	F3	R4	F4
⇓ No Exercise	DAP	87Apr02	0929	0	0							
	DRJ	87Apr02	0929	0	0							
	HRJ	87Apr02	0929	0	0							
	KIN	87Apr02	0929	0	0							
	POM	87May19	1225	0	1							
	TEC	87May19	1225	0	0							
	HNL	87Apr02	0929	0	0							
	KIV	87May19	1225	0	0							

Summary, Profile #8: Diver days - 24 w/ exercise - 16 Doppler runs w/ bubbles - 6 of 24

Profile #9

120/14 + 0/40 +55/49 + 0/---

Repetitive 2
Square
Square
Chamber

	Subject	Date	Time	R1	F1	R2	F2	Comment
⇓ Exercise	AND	87Jul09	1638	0	1	0	1	Compression 2:22 min
	DAJ	87Aug27	1816	1	2	0	2	DAJ poor night's sleep; slow descent
	FAD	87Jun23	1828	0	0	0	1	
	FIR	87Sep21	1823	0	0	0	0	
	IVP	87Aug20	1842	0	0	0	0	Ear trouble, 2nd compression 3 min.
	JOS	87Aug20	1842	0	0	0	0	Ear trouble, 2nd compression 3 min.
	KEE	87Apr07	1817	0	0	0	0	
	KIG	87Apr07	1817	0	0	0	0	
	KIG	87Aug24	1829	0	0	0	0	
	MIL	87Jul09	1638	0	0	0	0	Compression 2:22 min
	MOG	87Aug19	1841	0	0	0	0	
	MOG	87Sep23	1818	0	0	0	0	
	RHR	87Aug20	1842	0	0	0	0	Ear trouble, 2nd compression 3 min.
	RIL	87Sep21	1823	0	0	0	0	
	SIT	87Aug19	1841	0	0	0	0	
	SIT	87Sep23	1818	0	0	0	0	
	STC	87Apr07	1817	0	0	0	0	
	BUJ	87Aug19	1841	0	0	0	0	
	BUJ	87Sep23	1818	0	0	0	0	
	HAF	87Aug19	1841	0	0	0	0	
	KPJ	87Jun23	1828	0	0	0	0	
	MIN	87Aug27	1816	0	0	0	0	DAJ poor night's sleep; slow descent
	MRM	87Apr07	1817	0	0	0	0	
	SCH	87Jun23	1828	0	0	0	0	
No Ex	BID	87Sep21	1823	0	0	0	0	
	HAF	87Sep23	1818	0	0	0	0	
	RHL	87Aug20	1842	0	0	0	0	Ear trouble, 2nd compression 3 min.

Summary, Profile #9: Diver days - 27 w/ exercise - 24 Doppler runs w/ bubbles - 5 of 54

Profile #10

75/35 + 0/57 +55/47 + 0/---

Repetitive 2
Square
Square
Chamber

	Subject	Date	Time	R1	F1	R2	F2
Exercise	BOB	87Jun29	1607	0	1	0	0
	HRL	87Jun29	1607	0	0	0	0
	BOL	87Jun29	1607	0	0	0	1
No Ex	MAJ	87May18	1220	0	0	0	1
	POM	87May18	1220	0	0	0	0
	STC	87May18	1220	0	0	0	0

Summary, Profile #10: Diver days - 6 w/ exercise - 3 Doppler runs w/ bubbles - 3 of 12

Profile #11

100/20 + 0/77 +75/29 + 0/---

Repetitive 2
Square
Square
Chamber

	Subject	Date	Time	R1	F1	R2	F2	Comment
⇓ Exercise	AZN	87Jul15	1237	0	0	0	0	
	LAM	87Apr29	1839	0	0	0	0	
	MYC	87Sep09	1826	0	0	0	0	
	PAR	87Sep09	1826	0	0	0	0	
	PLA	87Jul15	1237	0	0	0	0	PLA tooth problem
	PLA	87Jun20	1139	0	0	0	0	

Appendix B2, page 5 of 9. Data summary for Phase I. Profiles shown as depth/time (fsw/min) for all including intervals. Doppler scores are in columns; R = rest and F = flex. Long line delineates exercise, (above the line), short line delineates males (above the line) from females.

	Subject	Date	Time	R1	F1	R2	F2	R3	F3	R4	F4
⇓ Exercise	POM	87Jun20	1139	0	0	0	1				
	ROD	87Sep17	1815	0	0	0	0				
	RTD	87Apr29	1839	0	0	0	0				
	SEP	87Apr29	1839	0	0	0	0				
	TEC	87May12	1206	0	0	0	0				
	WAA	87Jul15	1237	0	0	0	0				
	NEK	87May12	1206	0	0	0	0				
	PAA	87Jun20	1139	0	0	0	0				
	PEM	87Sep17	1815	0	0	0	0				

Summary, Profile #11: Diver days - 15 w/ exercise - 15 Doppler runs w/ bubbles - 1 of 30

Profile #12 {130/12+70/13+45/29} + 0/—

Multilevel 3
Chamber

	Subject	Date	Time	R1	F1	Notes
⇓ Exercise	ALS	87Apr23	1811	0	0	
	ALS	87May06	1759	0	0	
	AND	87Apr02	1317	0	0	
	AND	87Apr22	1805	0	0	
	AND	87May06	1759	0	1	
	FIJ	87Apr21	1823	0	0	
	FIJ	87Apr23	1811	0	1	
	KED	87Apr22	1805	0	0	
	KIG	87Apr21	1823	0	0	
	RTD	87Apr02	1317	0	0	
	RTD	87May06	1759	0	0	
	STC	87Apr02	1317	0	0	
	STJ	87Apr22	1805	0	0	
	WRR	87Apr23	1811	0	0	
	BRD	87Apr21	1823	0	0	
No Ex	KED	87May19	1808	0	0	
	STJ	87May19	1808	0	0	
	GAK	87May19	1808	0	0	
	MRM	87May19	1808	0	0	

Summary, Profile #12: Diver days - 19 w/ exercise - 15 Doppler runs w/ bubbles - 2 of 19

Profile #13 110/17 + 0/37 + 65/31 + 0/23 + 45/51 + 0/—

Chamber Repetitive 3
Square

	Subject	Date	Time	R1	F1	R2	F2	R3	F3	
Exer	POM	87May08	1309	0	0	0	0	0	0	Square
	WYK	87May08	1309	0	0	0	0	0	0	Square

Summary, Profile #13: Diver days - 2 w/ exercise - 2 Doppler runs w/ bubbles - 0 of 6

Profile #14 {130/12+60/21+45/23+35/42} + 0/—

Multilevel 4
Chamber

	Subject	Date	Time	R1	F1	Notes
⇓ Exercise	AND	87Jun17	1737	0	0	
	ANM	87Jun17	1737	0	0	
	BOP	87Jun26	1222	0	0	
	BSJ	87Aug22	1045	0	0	
	FTR	87Aug31	1836	0	0	
	KED	87May12	1822	0	0	
	LUJ	87Aug22	1045	0	0	
	MAD	87Aug31	1836	0	0	
	MIL	87Jun17	1737	0	0	
	PAD	87May07	1345	0	0	Slow descent; 130/3 actual
	PAD	87Aug22	1045	0	0	
	SUK	87May12	1822	0	0	
	BRT	87Jun26	1222	0	0	
	NEK	87Jun26	1222	0	0	
	SPD	87May07	1345	0	0	Slow descent; 130/3 actual

Summary, Profile #14: Diver days - 15 w/ exercise - 15 Doppler runs w/ bubbles - 0 of 15

Appendix B2, page 6 of 9. Data summary for Phase I. Profiles shown as depth/time (fsw/min) for all phases, including intervals. Doppler scores are in columns; R = rest and F = flex. Long line delineates exercise, (above the line), short line delineates males (above the line) from females.

Profile #15 130/12 + 0/43 + 90/16 + 0/37 + 60/32 + 0/21 + 40/71 + 0/---

Repetitive 4, Square, Square, Square, Square, Chamber

	Subject	Date	Time	R1	F1	R2	F2	R3	F3	R4	F4
Exercise	ALS	87Apr25	1020	0	0	0	0	0	0	0	0
Exercise	KIN	87Apr25	1020	0	0	0	0	0	1	0	0
Exercise	STC	87Apr23	1317	0	0	0	0	0	0	0	0
Exercise	KIV	87Apr23	1317	0	1	0	1	0	0	1	1
Exercise	KNG	87Apr25	1020	0	0	0	0	0	0	0	0

Summary, Profile #15: Diver days - 5 w/ exercise - 5 Doppler runs w/ bubbles - 4 of 20

Profile #16 {90/25+45/34} + 0/49 + 60/39 + 0/---

Repetitive 2, Multilevel 2, Square, Chamber

	Subject	Date	Time	R1	F1	R2	F2
Exer	ROT	87Jun16	1241	0	0	0	0
Exer	SMK	87Jun16	1241	0	1	0	1

Summary, Profile #16: Diver days - 2 w/ exercise - 2 Doppler runs w/ bubbles - 2 of 4

Profile #17 55/65 + 0/24+ {55/27+40/20}+ 0/---

Repetitive 2, Square, Multilevel 2, Chamber

	Subject	Date	Time	R1	F1	R2	F2
Exercise	PEO	87Jul01	1238	0	0	0	0
Exercise	STC	87Jul01	1238	0	0	0	0
Exercise	NEK	87Jul01	1238	0	0	0	0
Exercise	NEK	87Jun04	1212	0	0	0	0

Summary, Profile #17: Diver days - 4 w/ exercise - 4 Doppler runs w/ bubbles - 0 of 8

Profile #18 {130/12+50/41} + 0/84 + { 80/21+45/33 } + 0/---

Repetitive 2, Multilevel 2, Multilevel 2, Chamber

	Subject	Date	Time	R1	F1	R2	F2
⇐ Exercise	DES	87Aug25	0923	0	0	0	0
	EAD	87Aug19	0913	0	0	0	0
	FEW	87Aug19	0913	0	0	0	0
	GRW	87Aug25	0923	0	0	0	0
	GUP	87Aug25	0923	0	0	0	0
	HAJ	87Apr14	1307	0	0	0	0
	MAR	87Aug19	0913	0	0	0	0
	MEM	87Apr27	1226	0	0	0	0
	POM	87Apr14	1307	0	0	0	0
	STC	87Apr27	1226	0	0	0	0
	DUC	87May02	1132	0	0	0	0
	DUJ	87May02	1132	0	0	0	0
	GRN	87May02	1132	0	0	0	0
	NEK	87Apr27	1226	0	0	0	0
	SCB	87May02	1132	0	0	0	0

Summary, Profile #18: Diver days - 15 w/ exercise - 15 Doppler runs w/ bubbles - 0 of 30

Profile #19 {110/17+65/11}+0/33+{50/47+35/37}+0/32 +{60/17+40/29}+ 0/---

Repetitive 3, Multilevel 2, Multilevel 2, Multilevel 2, Chamber

	Subject	Date	Time	R1	F1	R2	F2	R3	F3	
⇐ Exercise	CHM	87Sep14	1321	0	0	0	0	0	0	
	HUB	87Jul07	1216	0	0	0	0	0	0	
	MEM	87Apr30	1239	0	0	0	0	0	0	
	MET	87Sep17	0908	0	0	0	0	0	0	
	MYC	87Sep22	1718	0	0	0	0	0	0	Ear problems.
	POM	87Apr20	1316	0	0	0	0	0	0	
	POM	87Apr30	1239	0	0	0	0	0	0	
	ROA	87Sep14	1321	0	0	0	0	0	1	
	SHJ	87Jul07	1216	0	0	0	0	0	0	
	STC	87Apr20	1316	0	0	0	0	0	0	
	STC	87Jul07	1216	0	0	0	0	0	0	
	STT	87Sep22	1718	0	0	0	0	0	0	Ear problems.
	HAL	87Sep22	1718	0	0	0	0	0	0	Ear problems.
	NEK	87Sep17	0908	0	0	0	0	0	0	

Appendix B2, page 7 of 9. Data summary for Phase I. Profiles shown as depth/time (fsw/min) for all including intervals. Doppler scores are in columns; R = rest and F = flex. Long line delineates exercise, (above the line), short line delineates males (above the line) from females.

	Subject	Date	Time	R1	F1	R2	F2	R3	F3
No Ex	CRT	87Jun06	1032	0	0	0	0	0	0
	KEW	87Jun06	1032	0	0	0	0	0	0
	MCD	87Apr20	1316	0	1	0	0	0	0

Summary, Profile #19: Diver days - 17 w/ exercise - 14 Doppler runs w/ bubbles - 2 of 51

Profile #20

{120/14+60/19+45/22} + 0/23 40/67 + 0/---

Repetitive 2
Multilevel 3
Square
Chamber

	Subject	Date	Time	R1	F1	R2	F2
⇓ Exercise	AND	87Apr10	1312	0	0	0	0
	BOJ	87Apr21	1331	0	0	0	0
	COJ	87Sep08	1834	0	0	0	0
	CRJ	87Sep10	1832	0	0	0	0
	GRB	87Sep08	1834	0	0	0	0
	IRR	87Apr21	1331	0	0	0	1
	MCJ	87Aug28	906	0	0	0	0
	PAC	87Apr21	1331	0	0	0	0
	RIL	87Sep23	0929	0	0	0	0
	RTD	87Apr10	1312	0	0	0	0
	DOD	87Sep08	1834	0	0	0	0
	HAV	87Sep10	1832	0	0	0	0
	KIV	87Apr10	1312	1	2	0	1
	SMD	87Sep10	1832	0	0	0	0
	WHJ	87Apr21	1331	0	0	0	0
No Ex	BRW	87Sep08	1834	0	0	0	0
	GAB	87Apr21	1331	0	0	0	1

Summary, Profile #20: Diver days - 17 w/ exercise - 15 Doppler runs w/ bubbles - 4 of 34

Profile #21

65/45 + 0/37 + {65/17+45/26+35/36} + 0/---

Repetitive 2
Square
Multilevel 3
Chamber

	Subject	Date	Time	R1	F1	R2	F2
Exer	SMK	87Jun18	1113	0	0	0	0
	STC	87Jun18	1113	0	0	0	0
	TEC	87Jun18	1113	0	0	0	0

Summary, Profile #21: Diver days - 3 w/ exercise - 3 Doppler runs w/ bubbles - 0 of 6

Profile #22

95/22 + 0/39 +{55/35+40/34+35/17} + 0/---

Repetitive 2
Square
Multilevel 3
Chamber

	Subject	Date	Time	R1	F1	R2	F2
No Ex	POM	87Jun08	1237	0	0	0	0
	NEK	87Jun08	1237	0	0	0	0

Summary, Profile #22: Diver days - 2 w/ exercise - 0 Doppler runs w/ bubbles - 0 of 4

Profile #51

100/18 + 0/33 + 65/26 + 0/30 +50/39 + 0/---

Repetitive 3
Square
Square
Square

⇓ Chamber

	Subject	Date	Time	R1	F1	R2	F2	R3	F3
⇓ Exercise	BID	87Aug06	1254	0	0	0	0	0	0
	IVP	87Aug05	1832	0	0	0	0	0	0
	KIG	87Jul29	1816	0	0	0	0	0	0
	KRM	87Aug06	1813	0	1	0	0	0	0
	LAL	87Aug06	1813	1	1	1	2	0	0
	NED	87Aug05	1310	0	0	2	3	0	1
	PEC	87Aug05	1310	0	0	0	0	0	0
	RED	87Jul29	1816	0	0	0	0	0	0
	RIM	87Aug06	1254	0	0	0	0	0	0
	TEC	87Aug06	1254	0	0	0	0	0	0
	BAK	87Jul29	1816	0	0	0	0	0	0
	DNS	87Aug06	1813	0	0	0	0	0	0
	MEC	87Aug05	1832	0	0	0	0	0	0
	PEB	87Aug05	1832	0	0	0	0	0	0
	WOJ	87Aug05	1310	0	0	0	0	0	0

Appendix B2, page 8 of 9. Data summary for Phase I. Profiles shown as depth/time (fsw/min) for all phases, phases, including intervals. Doppler scores are in columns; R = rest and F = flex. Long line delineates exercise, short line delineates males (above) from females. Dotted lines show inwater dive locations.

	Subject	Date	Time	R1	F1	R2	F2	R3	F3	
⇓ No Exercise	CUT	87Aug11	1825	0	0	0	0	0	0	⇓ Chamber
	GLD	87Aug11	1825	0	0	0	0	0	0	
	GOG	87Jul30	1832	0	0	2	3	1	2	
	POG	87Aug11	1825	0	0	0	0	0	0	
	RHR	87Jul30	1832	0	0	0	0	0	0	
	TSW	87Jul30	1832	0	0	0	0	0	0	
	PUM	87Jul30	1832	0	0	0	0	0	0	
	SIB	87Aug11	1825	0	0	0	0	0	0	
	URD	87Aug11	1825	0	0	0	0	0	0	
⇓ Exercise	BAJ	87Aug16		0	0	0	0	0	0	Inwater, beach
	BEJ	87Aug16		0	0	0	0	0	0	
	HOS	87Aug15		0	0	0	0	0	0	
	MAB	87Aug16		0	0	0	0	0	0	
	BID	87Sep2		0	0	0	0	0	0	⇓ Inwater, boat
	BUA	87Sep16		0	0	0	0	0	0	
	BWP	87Sep1		0	0	0	0	0	0	
	GRB	87Sep16		0	0	0	1	0	1	
	IRR	87Sep1		0	0	0	0	0	1	
	KAJ	87Sep16		0	0	0	0	0	0	
	KIN	87Sep15		0	0	0	0	0	0	
	PAD	87Sep1		0	0	0	0	0	0	
	ROK	87Sep16		0	0	0	0	0	0	
	SMB	87Sep16		0	0	0	0	1	1	
	WAT	87Sep1		0	0	0	0	0	0	
	WEW	87Sep15		0	0	0	0	0	0	
	DAD	87Sep1		0	0	0	0	0	1	
	DAD	87Sep2		0	0	0	0	0	0	
	HED	87Sep1		0	0	0	0	0	0	
	MES	87Sep1		0	0	0	0	0	0	
	RDD	87Sep15		0	0	0	0	0	0	
	VAJ	87Sep1		0	0	0	0	0	0	
	VAJ	87Sep2		0	0	0	0	0	0	
	VAJ	87Sep15		0	0	0	0	0	0	

Summary, Profile #51: Diver days - 48 w/ exercise - 39 Doppler runs w/ bubbles - 12 of 144

Profile #52

80/21 + 0/30 + 60/33 + 0/30 + 55/28 + 0/--

Repetitive 3
Square
Square
Square

	Subject	Date	Time	R1	F1	R2	F2	R3	F3	
⇓ Exercise	BOD	87Jul30	1244	0	0	0	0	0	0	⇓ Chamber
	BRP	87Aug03	1256	0	0	0	0	0	0	
	EID	87Aug03	1256	0	0	0	0	0	0	
	GUP	87Aug10	0940	0	0	0	0	0	0	
	HEL	87Aug10	0940	0	0	0	0	0	0	
	KLJ	87Aug03	1525	0	0	0	0	0	0	
	POM	87Jul30	1244	0	0	0	0	0	0	
	POM	87Jul31	1251	0	0	0	0	0	0	
	PRM	87Aug11	1306	0	0	0	0	0	0	
	SHR	87Aug11	1306	0	0	0	0	0	0	
	SMR	87Aug07	0920	0	0	0	1	0	0	
	DNS	87Aug07	0920	0	0	0	0	0	0	
	ERD	87Aug11	1306	0	0	0	0	0	0	
	PYK	87Jul31	1251	0	0	0	0	0	0	
	SMS	87Aug10	0940	0	0	0	0	0	0	
	LOP	87Aug15		0	0	0	0	0	0	Inwater, beach
	SCD	87Aug15		0	0	0	0	0	0	
	LIC	87Aug15		0	0	0	0	0	0	
	AND	87Sep15		0	0	0	0	0	0	⇓ Inwater, boat
	ANM	87Sep15		0	0	0	0	0	0	
	BID	87Sep16		0	0	0	0	0	0	
	CHJ	87Sep1		0	0	0	0	0	0	
	CHR	87Sep1		0	0	0	0	0	1	
	CRJ	87Sep1		0	0	0	0	0	0	
	GID	87Sep1		0	0	0	0	0	0	
	GID	87Sep2		0	0	0	0	0	0	
	HAV	87Sep16		0	0	0	0	0	0	
	KUD	87Sep15		0	0	0	0	0	0	

Appendix B2, page 9 of 9. Data summary for Phase I. Profiles shown as depth/time (fsw/min) for all phases, including intervals. Doppler scores are in columns; R = rest and F = flex. Long line delineates exercise, short line delineates males (above) from females. Dotted lines show inwater dive locations.

Subject	Date	Time	R1	F1	R2	F2	R3	F3	
MAP	87Sep15		0	0	0	0	0	0	⇓ Inwater, boat
MAP	87Sep16		0	0	0	0	0	0	
MCF	87Sep1		0	0	0	0	0	0	
MCF	87Sep2		0	0	0	0	0	0	
MIL	87Sep16		0	0	0	0	0	0	
MIN	87Sep15		0	0	0	0	0	0	
OLT	87Sep1		0	0	0	0	0	0	
ORC	87Sep15		0	0	0	0	0	0	
PAR	87Sep1		0	0	0	0	0	0	
RAR	87Sep1		0	0	0	0	0	0	
VAJ	87Sep16		0	0	0	1	0	0	
WEW	87Sep16		0	0	0	0	0	0	

Summary, Profile #52: Diver days - 40 w/ exercise - 40 Doppler runs w/ bubbles - 3 of 120

Profile #53

65/35 + 0/28 + 55/32 + 0/28 + 50/33 + 0/---

Repetitive 3
Square
Square
Square

	Subject	Date	Time	R1	F1	R2	F2	R3	F3	
⇓ Exercise	BID	87Aug13	0917	0	0	0	0	0	0	⇓ Chamber
	BID	87Aug27	0925	0	0	0	0	0	0	
	CRG	87Sep29	0948	0	0	0	0	0	0	
	DAJ	87Aug14	0922	1	2	0	0	0	0	
	FAR	87Aug27	0925	0	0	0	0	0	0	
	MAP	87Sep24	1758	0	0	0	0	0	0	
	NED	87Aug13	0917	0	0	0	0	0	0	
	NED	87Aug14	0922	0	0	0	1	0	0	
	SEL	87Sep24	1758	0	0	0	0	0	0	
	SMR	87Aug14	0922	0	0	0	0	0	0	
	YES	87Sep24	1758	0	0	0	0	0	0	
	CRM	87Sep29	0948	0	0	0	0	0	0	
	DNS	87Aug13	0917	0	0	0	0	0	0	
	MAG	87Sep24	1758	0	0	0	0	0	0	
	RDD	87Aug14	0922	0	0	0	0	0	0	
	VAJ	87Sep29	0948	0	0	0	0	0	0	
	EAD	87Aug16		0	0	0	0	0	0	Inwater, beach
	EID	87Aug16		0	0	0	0	0	0	
	RIT	87Aug15		0	0	0	0	0	0	
	HED	87Aug15		0	0	0	0	0	0	
	BAD	87Sep15		0	0	0	0	0	0	⇓ Inwater, boat
	BID	87Sep1		0	0	0	0	0	0	
	CAD	87Sep2		0	0	0	0	0	1	
	DYJ	87Sep16		0	0	0	0	0	1	
	FLD	87Sep15		0	0	0	0	0	0	
	GOC	87Sep16		0	0	0	0	0	0	
	KAR	87Sep15		0	0	0	0	0	0	
	KLJ	87Sep15		0	0	0	0	0	0	
	MER	87Sep16		0	0	0	0	0	0	
	OLR	87Sep16		0	0	0	0	0	0	
	PEJ	87Sep1		0	0	0	0	0	0	
	POH	87Sep15		0	0	0	0	0	0	
	POH	87Sep16		0	0	0	0	0	0	
	RER	87Sep2		0	0	0	0	0	0	
	RES	87Sep1		0	0	0	0	0	1	
	BUL	87Sep16		0	0	0	0	0	0	
	HAF	87Sep15		0	0	0	0	0	0	
	HEJ	87Sep1		0	0	0	0	0	0	
	KAA	87Sep15		0	0	0	0	0	0	
	MAF	87Sep2		0	0	0	0	0	0	
	RIK	87Sep15		0	0	0	0	0	0	
	SCT	87Sep2		0	0	0	0	0	0	
	WID	87Sep15		0	0	0	0	0	0	

Summary, Profile #53: Diver days - 43 w/ exercise - 43 Doppler runs w/ bubbles - 5 of 129

Appendix C. Data from Phase II multiday exposures

Appendix C1. Data from Phase IIa 6x6 study: Profiles and results

The Phase IIa exposures were for 6 dives per day, with 4 subjects, all in the dry chamber. The exposures were planned to carry on for 6 days, but they were actually conducted for only two full days and a brief part of a third day. All the data are shown in Appendix C1, on one page. The profile summary and two Doppler grades are shown for each dive during the day. Profiles are represented using the depth/time format given for Phase I data. An ellipsis (. . .) shows continuity (within the same day) and indicates that a specific dive profile is part of a more comprehensive sequential exposure. Braces enclose the steps in multilevel dives. Ascent time is in addition to the times shown. None of these dives are listed as "repetitive" since in a sense all but the first one of the series are repetitive.

For the Phase II exposures all of the RDP rules were followed, including the safety stop at 15 fsw for 3 min at the end of each dive, which is shown. The Phase II divers did not perform scheduled exercise, but most of them exercised voluntarily.

The display of Doppler scores is slightly different from Phase I. In both Phase IIa and IIb two investigators made independent assessments of the readings. Scores are shown as two digits separated by a diagonal, "0/0." The left score is that of the on-site investigator (MRP) assessing the "live" reading with a later tape check, while the right number is that of a second investigator (RD) who took the reading entirely from the tape recording. Columns for resting and after flexing (R and F) are as before (see Chapter V).

Appendix C1. Data and profiles from Phase IIa. 6 dives per day for 2+ days. Profiles are depth/time (fsw/min); ellipses show continuity and braces multilevel dives. All but the first dive of each day are repetitive. Doppler scores for rest R and after flexing F are by two investigators separated by a diagonal.

Doppler scores, by Observer 1 / 2

Day 1, Profile 1 — Square

95/22 + 15/3 + 0/60 ...

Subject	Date	Time	R1	F1	R2	F2
GAR	88Oct31	0800	0/0	0/0	0/0	0/0
KEJ	88Oct31	0800	0/0	0/0	0/0	0/0
MOM	88Oct31	0800	0/0	0/0	0/0	0/0
SHK	88Oct31	0800	0/0	0/0	0/0	0/0

Day 1, Profile 2 — Square

... 65/30 + 15/3 + 0/63 ...

Subject	Date	Time	R1	F1	R2	F2
GAR	88Oct31	0927	0/0	0/0	0/9	0/9
KEJ	88Oct31	0927	0/0	0/0	0/0	0/0
MOM	88Oct31	0927	0/0	0/0	0/9	0/9
SHK	88Oct31	0927	0/0	0/0	0/0	0/9

Day 1, Profile 3 — Square

... 45/61 + 15/3 + 0/130 ...

Subject	Date	Time	R1	F1	R2	F2
GAR	88Oct31	1104	0/0	1/0	0/0	0/0
KEJ	88Oct31	1104	0/0	1/0	0/0	0/0
MOM	88Oct31	1104	0/0	3/2	0/0	0/0
SHK	88Oct31	1104	0/0	1/0	0/2	0/9

Day 1, Profile 4 — Square

... 55/54 + 15/3 + 0/60 ...

Subject	Date	Time	R1	F1	R2	F2
GAR	88Oct31	1421	0/0	0/0	0/9	0/9
KEJ	88Oct31	1421	0/0	0/0	0/2	2/2
MOM	88Oct31	1421	0/3	3/3	0/2	2/3
SHK	88Oct31	1421	0/0	0/0	0/0	0/0

Day 1, Profile 5 — Multilevel 3

... { 90/10 + 60/9 + 35/57 } + 15/3 + 0/95 ...

Subject	Date	Time	R1	F1	R2	F2
GAR	88Oct31	1619	0/0	0/0	0/0	0/0
KEJ	88Oct31	1619	0/0	0/0	0/2	0/3
MOM	88Oct31	1619	2/2	3/3	0/3	2/3
SHK	88Oct31	1619	0/2	0/2	0/2	0/2

Day 1, Profile 6 — Multilevel 4

.. {120/6+80/8+50/17+35/42 } +15/3 + 0/690

Subject	Date	Time	R1	F1	R2	F2
GAR	88Oct31	1915	0/0	0/0	0/9	0/9
KEJ	88Oct31	1915	0/0	0/0	0/9	0/9
MOM	88Oct31	1915	0/1	3/3	0/9	0/9
SHK	88Oct31	1915	0/0	0/0	0/9	0/9

	Number of dives	Doppler runs with bubbles
Totals:	51	44 of 179

Doppler scores, by Observer 1 / 2

Day 2, Profile 1 — Square

60/55 + 15/3 + 0/76 ...

Subject	Date	Time	R1	F1	R2	F2
GAR	88Nov1	0800	0/0	0/0	0/0	0/0
KEJ	88Nov1	0800	0/0	0/0	0/0	0/0
MOM	88Nov1	0800	0/9	1/9	0/0	1/0
SHK	88Nov1	0800	0/0	0/1	0/0	0/0

Day 2, Profile 2 — Square

... 45/65 + 15/3 + 0/130 ...

Subject	Date	Time	R1	F1	R2	F2
GAR	88Nov1	1015	0/9	0/9	0/0	0/0
KEJ	88Nov1	1015	0/0	0/0	0/0	0/0
MOM	88Nov1	1015	0/0	1/0	0/0	1/2
SHK	88Nov1	1015	0/0	0/0	1/2	1/2

Day 2, Profile 3 — Multilevel 2

... { 85/20 + 45/26 } + 15/3 + 0/60 ...

Subject	Date	Time	R1	F1	R2	F2
GAR	88Nov1	1335	0/9	0/0	0/9	0/9
KEJ	88Nov1	1335	0/0	0/0	0/9	0/9
MOM	88Nov1	1335	0/0	2/3	0/0	0/0
SHK	88Nov1	1335	0/0	0/0	0/9	0/9

Day 2, Profile 4 — Multilevel 2

... { 75/16 + 40/34 } + 15/3 + 0/60 ...

Subject	Date	Time	R1	F1	R2	F2
GAR	88Nov1	1529	0/9	0/9	0/0	0/0
KEJ	88Nov1	1529	0/0	0/0	0/0	0/1
MOM	88Nov1	1529	0/0	0/0	0/0	0/0
SHK	88Nov1	1529	0/9	0/9	0/0	0/-

Day 2, Profile 5 — Multilevel 2

... { 80/12 + 40/34 } + 15/3 + 0/87 ...

Subject	Date	Time	R1	F1	R2	F2
GAR	88Nov1	1731	0/0	0/9	0/0	0/2
KEJ	88Nov1	1731	0/9	0/0	0/0	0/0
MOM	88Nov1	1731	0/0	2/3	0/0	0/3
SHK	88Nov1	1731	0/0	0/0	0/9	0/0

Day 2, Profile 6 — Multilevel 4

...{110/7+65/10+50/11+40/19 } +15/3 +0/692

Subject	Date	Time	R1	F1	R2	F2
GAR	88Nov1	1946	0/0	3/3	0/-	1/-
KEJ	88Nov1	1946	0/0	0/0	0/-	0/-
MOM	88Nov1	1946	0/0	1/1	0/-	0/-
SHK	88Nov1	1946	0/0	0/0	0/-	0/-

Day 3, Profile 1 — Square

110/16 + 0/65 ...

Subject	Date	Time	R1	F1	R2	F2
KEJ	88Nov2	0830	0/0	0/2	0/-	0/-
MOM	88Nov2	0830	0/0	1/0	0/-	0/-
SHK	88Nov2	0830	0/0	1/0	0/-	0/-

Appendix C2. Profiles from Phase IIb, 4x6 study

Phase IIb consisted of 4 dives per day over 6 days. The profiles are summarized here using the same time/depth format as for Phase IIa, with braces around the multilevel dives. For the Phase II exposures all of the RDP rules were followed, including the safety stop at 15 fsw for 3 min at the end of each dive, which is shown.

Some additional information is given here. Two columns at the right show the pressure group on surfacing from each individual dive and the new group at the end of the surface interval.

Appendix C2. Profiles from Phase IIb. Four dives per day for 6 days. Profiles are depth/time (fsw/min) with ellipses showing continuity, and braces multilevel dives. Columns at right show pressure groups at the end of each dive and after intervals.

Day #	Dive #	Profiles, as Depth/Time	Number of dives	Doppler runs with bubbles	PG, end of dive	PG after interval
1	1-1	{120/13 + 70/11 + 50/14 + 35/13} + 15/3 + 0/80 ... Multilevel 4	18	1 of 72	X	F
1	1-2	... {80/16 + 50/13 + 40/25} + 15/3 + 0/180 ... Multilevel 3	19	0 of 75	Z	A
1	1-3	... {60/48 + 35/54} + 15/3 + 0/180 ... Multilevel 2	19	7 of 75	Z	A
1	1-4	... 40/90 + 15/3 + 0/689 Square	20	9 of 79	V	-
2	2-1	{95/22 + 65/5 + 50/13 + 35/6} + 15/3 + 0/72 ... Multilevel 4	20	4 of 74	X	G
2	2-2	... {70/22 + 40/37} + 15/3 + 0/180 ... Multilevel 2	20	7 of 72	Z	A
2	2-3	... 55/59 + 15/3 + 0/180 ... Square	20	11 of 74	Z	A
2	2-4	... 45/92 + 15/3 + 0/716 Square	20	11 of 77	Y	-
3	3-1	{90/25 + 55/9 + 35/40} + 15/3 + 0/87 ... Multilevel 3	20	4 of 77	X	E
3	3-2	... 60/38 + 15/3 + 0/92 ... Square	20	5 of 80	W	D
3	3-3	... 50/61 + 15/3 + 0/180 ... Square	20	15 of 80	Y	A
3	3-4	... 40/90 + 15/3 + 0/802 Square	20	7 of 78	V	-
4	4-1	{110/16 + 70/8 + 50/13 + 40/15} + 15/3 + 0/66 ... Multilevel 4	20	5 of 77	X	H
4	4-2	... {75/17 + 50/11 + 35/55} + 15/3 + 0/180 ... Multilevel 3	20	6 of 79	Z	A
4	4-3	... {60/49 + 35/41} + 15/3 + 0/180 ... Multilevel 2	20	7 of 80	Z	A
4	4-4	... 40/90 + 15/3 + 0/682 Square	19	4 of 69	V	-
5	5-1	{100/20 + 65/6 + 50/13 + 35/26} + 15/3 + 0/80 ... Multilevel 4	20	7 of 78	X	F
5	5-2	... {70/24 + 40/49} + 15/3 + 0/180 ... Multilevel 2	20	2 of 79	Z	A
5	5-3	... 50/73 + 15/3 + 0/180 ... Square	20	13 of 80	Y	A
5	5-4	... 45/92 + 15/3 + 0/680 Square	20	13 of 80	Z	-
6	6-1	{ 85/27 + 50/17 + 35/26} + 15/3 + 0/95 ... Multilevel 3	20	6 of 80	X	D
6	6-2	65/31 + 15/3 + 0/117 ... Square	20	3 of 79	U	B
6	6-3	... 55/53 + 15/3 + 0/60 ... Square	20	14 of 79	X	I
6	6-4	...40/100 + 15/3 + 0/ - - - Square	20	26 of 80	Z	-
		Totals:	475	187 of 1853		

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Appendix C3. Exposures and Doppler results from Phase IIb, 4x6 study

Each full Phase IIb exposure consisted of 4 dives per day for 6 days. The profiles are shown in a manner similar to those of Phase I and IIa. The 3 min safety stop at 15 fsw was performed on these dives, and is shown. Results of each individual dive profile are listed separately; results of four dives are shown on a single page. The line in the column of diver identifiers separates males (above the line) from females. If a diver missed a dive it is so indicated.

Like IIa, Phase IIb Doppler tapes were also read by two investigators. The scores for the on-site observer and the followup observer are shown as 0/0 under each rest or flex category. Ellipses (". . .") show continuation of the overall exposure over the day, either before or following the profile in question. None of these dives are listed as "repetitive" since in a sense all but the first one of the series are repetitive.

Appendix C3, page 1 of 6. Exposures and doppler results from Phase IIb. 4 dives per day for 6 days. Profiles are depth/time (fsw/min); ellipses show continuity and braces multilevel dives. Doppler scores for rest R and after flexing F are by two investigators separated by a diagonal. The first set (R1 and F1) were taken 20-25 min after surfacing and the second set (R2 and F2) were taken at 40-45 min. Grades other than 0 (including 9's) are in boldface. Males are above the line in subject column.

Day 1, Profile 1 — Multilevel 4

{120/13+70/11+50/14+35/13} +15/3 + 0/80 ...

			Doppler scores, by Observer 1 / 2			
Subject	Date	Time	R1	F1	R2	F2
BOP	89Apr24	0815	0/0	0/0	0/0	0/0
BRW	88Dec12	0810	0/0	0/0	0/0	0/0
FOM	88Nov14	0810	0/0	0/0	0/0	0/0
GUM	88Nov28	0800	0/0	0/0	0/0	0/0
HAM	88Nov14	0810	**0/2**	0/0	0/0	0/0
MAP	88Dec12	0810	0/0	0/0	0/0	0/0
NIE	88Nov14	0810	0/0	0/0	0/0	0/0
PEG	88Nov28	0800	0/0	0/0	0/0	0/0
PTG	88Dec12	0810	0/0	0/0	0/0	0/0
TAM	89Jan9	0810	0/0	0/0	0/0	0/0
WAB	88Nov28	0800	0/0	0/0	0/0	0/0
WIB	88Dec12	0810	0/0	0/0	0/0	0/0
BRT	89Apr24	0815	0/0	0/0	0/0	0/0
GAH	89Jan9	0810	0/0	0/0	0/0	0/0
HAL	89Jan9	0810	0/0	0/0	0/0	0/0
LOS	89Apr24	0815	0/0	0/0	0/0	0/0
MUC	89Apr24		(MUC did not make this dive)			
MUM	88Nov14		(MUM did not make this dive)			
NIG	88Dec12	0810	0/0	0/0	0/0	0/0
RDD	89Apr24	0815	0/0	0/0	0/0	0/0

Day 1, Profile 2 — Multilevel 3

... { 80/16 + 50/13 + 40/25 } + 15/3 + 0/180 ...

Subject	Date	Time	R1	F1	R2	F2
BOP	89Apr24	1031	0/0	0/0	0/0	0/0
BRW	88Dec12	1027	0/0	0/0	0/0	0/0
FOM	88Nov14	1026	0/0	0/0	0/0	0/0
GUM	88Nov28	1026	0/0	0/0	0/0	0/0
HAM	88Nov14	1026	0/0	0/0	0/0	0/0
MAP	88Dec12	1027	0/0	0/0	0/0	0/0
NIE	88Nov14	1026	0/0	0/0	0/0	0/0
PEG	88Nov28	1026	0/0	0/0	0/0	0/0
PTG	88Dec12	1027	0/0	0/0	0/0	0/0
TAM	89Jan9	1026	0/0	0/0	0/0	0/9
WAB	88Nov28	1026	0/0	0/0	0/0	0/0
WIB	88Dec12	1027	0/0	0/0	0/0	0/0
BRT	89Apr24	1031	0/0	0/0	0/0	0/0
GAH	89Jan9	1026	0/0	0/0	0/0	0/0
HAL	89Jan9	1026	0/0	0/9	0/0	0/0
LOS	89Apr24	1031	0/0	0/0	0/0	0/0
MUC	89Apr24		(MUC did not make this dive)			
MUM	88Nov14	1026	0/0	0/0	0/0	0/0
NIG	88Dec12	1027	0/0	0/0	0/0	0/0
RDD	89Apr24	1031	0/0	0/0	0/0	0/0

Day 1, Profile 3 — Multilevel 2

... { 60/48 + 35/54 } + 15/3 + 0/180 ...

			Doppler scores, by Observer 1 / 2			
Subject	Date	Time	R1	F1	R2	F2
BOP	89Apr24	1429	0/0	0/0	**0/1**	**0/1**
BRW	88Dec12	1428	0/0	0/0	0/0	0/0
FOM	88Nov14	1425	0/0	**1/2**	0/0	0/0
GUM	88Nov28	1424	0/0	0/0	0/0	0/0
HAM	88Nov14	1425	0/9	0/9	0/0	0/0
MAP	88Dec12	1428	0/0	**0/1**	0/0	**2/3**
NIE	88Nov14	1425	0/0	0/0	0/0	0/0
PEG	88Nov28	1424	0/0	0/0	0/0	0/0
PTG	88Dec12	1428	0/0	0/0	0/0	0/0
TAM	89Jan9	1424	0/0	0/0	0/0	0/0
WAB	88Nov28	1424	0/0	0/0	0/0	0/0
WIB	88Dec12	1428	0/0	0/0	0/0	0/0
BRT	89Apr24	1429	0/0	**0/1**	0/0	0/0
GAH	89Jan9	1424	0/0	0/0	0/0	0/0
HAL	89Jan9	1424	0/0	0/0	0/0	0/0
LOS	89Apr24	1429	0/0	0/0	0/0	0/0
MUC	89Apr24		(MUC did not make this dive)			
MUM	88Nov14	1425	0/0	0/0	0/0	0/0
NIG	88Dec12	1428	0/0	0/0	0/0	0/0
RDD	89Apr24	1429	0/0	0/0	0/0	0/0

Day 1, Profile 4 — Square

... 40/90 + 15/3 + 0/689

Subject	Date	Time	R1	F1	R2	F2
BOP	89Apr24	1916	0/0	**0/2**	**0/2**	**0/3**
BRW	88Dec12	1914	0/0	0/0	0/0	0/0
FOM	88Nov14	1910	**0/2**	**1/0**	0/0	**1/2**
GUM	88Nov28	1910	0/0	0/0	0/0	0/0
HAM	88Nov14	1910	0/0	0/0	0/0	0/9
MAP	88Dec12	1914	0/0	0/0	0/0	0/0
NIE	88Nov14	1910	0/0	0/0	0/0	0/0
PEG	88Nov28	1910	0/0	0/0	0/0	0/0
PTG	88Dec12	1914	0/0	0/0	0/0	0/0
TAM	89Jan9	1910	0/0	**0/1**	0/0	**0/1**
WAB	88Nov28	1910	0/0	0/0	0/0	0/0
WIB	88Dec12	1914	0/0	0/0	0/0	0/0
BRT	89Apr24	1916	**0/1**	**0/1**	0/0	0/0
GAH	89Jan9	1910	0/0	0/0	0/0	0/0
HAL	89Jan9	1910	0/0	0/0	0/0	0/0
LOS	89Apr24	1916	0/0	0/0	0/0	0/0
MUC	89Apr24	1916	0/0	0/0	0/0	0/0
MUM	88Nov14	1910	0/0	0/0	0/0	0/0
NIG	88Dec12	1914	0/0	0/0	0/0	0/0
RDD	89Apr24	1916	0/0	0/0	0/0	0/0

Appendix C3, page 2 of 6. Exposures and doppler results from Phase IIb. 4 dives per day for 6 days. Profiles are depth/time (fsw/min); ellipses show continuity and braces multilevel dives. Doppler scores for rest R and after flexing F are by two investigators separated by a diagonal. The first set (R1 and F1) were taken 20-25 min after surfacing and the second set (R2 and F2) were taken at 40-45 min. Grades other than 0 (including 9's) are in boldface. Males are above the line in subject column.

Day 2, Profile 1 — **Multilevel 4**

{ 95/22+65/5+50/13+35/26 } + 15/3 + 0/72 ...

Subject	Date	Time	R1	F1	R2	F2
			Doppler scores, by Observer 1 / 2			
BOP	89Apr25	0800	0/0	0/0	0/0	0/0
BRW	88Dec13	0800	0/0	0/0	0/0	0/0
FOM	88Nov15	0800	0/0	**0/1**	**0/2**	**0/2**
GUM	88Nov29	0800	0/0	0/0	0/-	0/-
HAM	88Nov15	0800	**0/1**	**0/2**	0/0	0/0
MAP	88Dec13	0800	0/0	0/0	0/0	0/0
NIE	88Nov15	0800	0/0	0/0	0/0	0/0
PEG	88Nov29	0800	0/-	0/-	0/-	0/-
PTG	88Dec13	0800	0/0	0/0	0/0	0/0
TAM	89Jan10	0800	0/0	0/9	0/0	0/9
WAB	88Nov29	0800	0/0	0/0	0/-	0/-
WIB	88Dec13	0800	0/0	0/0	0/0	0/0
BRT	89Apr25	0800	0/0	0/0	0/0	0/0
GAH	89Jan10	0800	0/0	0/0	0/0	0/0
HAL	89Jan10	0800	0/0	0/0	0/0	0/0
LOS	89Apr25	0800	0/0	0/0	0/0	0/0
MUC	89Apr25	0800	0/0	0/0	0/0	0/0
MUM	88Nov15	0800	**0/1**	**0/1**	0/0	0/0
NIG	88Dec13	0800	0/0	0/0	0/0	0/0
RDD	89Apr25	0800	0/0	0/0	0/0	0/0

Day 2, Profile 2 — **Multilevel 2**

... { 70/22 + 40/37 } + 15/3 + 0/180 ...

Subject	Date	Time	R1	F1	R2	F2
BOP	89Apr25	1022	0/0	0/0	0/0	0/0
BRW	88Dec13	1023	0/0	0/0	0/0	0/0
FOM	88Nov15	1022	0/0	0/0	0/0	**0/2**
GUM	88Nov29	1022	0/-	**1/-**	**1/-**	**1/-**
HAM	88Nov15	1022	0/0	0/9	0/0	0/0
MAP	88Dec13	1023	0/0	0/0	0/0	0/0
NIE	88Nov15	1022	0/0	0/0	0/0	0/0
PEG	88Nov29	1022	0/-	0/-	0/-	0/-
PTG	88Dec13	1023	0/0	0/0	0/0	0/0
TAM	89Jan10	1022	0/0	0/0	0/0	0/0
WAB	88Nov29	1022	0/-	**1/-**	**1/-**	**2/-**
WIB	88Dec13	1023	0/0	0/0	0/0	0/0
BRT	89Apr25	1022	**0/2**	**0/2**	0/0	**0/2**
GAH	89Jan10	1022	0/0	0/0	0/0	0/0
HAL	89Jan10	1022	0/0	0/0	0/0	0/0
LOS	89Apr25	1022	0/0	0/9	0/0	0/0
MUC	89Apr25	1022	0/0	0/0	0/0	0/0
MUM	88Nov15	1022	0/0	0/0	0/0	0/0
NIG	88Dec13	1023	0/0	0/0	0/0	0/0
RDD	89Apr25	1022	0/0	0/0	0/0	0/0

Day 2, Profile 3 — **Square**

... 55/59 + 15/3 + 0/180 ...

Subject	Date	Time	R1	F1	R2	F2
			Doppler scores, by Observer 1 / 2			
BOP	89Apr25	1427	0/0	**0/1**	0/0	0/0
BRW	88Dec13	1425	0/-	0/-	0/0	0/0
FOM	88Nov15	1425	0/0	0/0	0/0	0/0
GUM	88Nov29	1425	0/0	0/0	0/0	**1/2**
HAM	88Nov15	1425	0/0	0/0	0/0	0/0
MAP	88Dec13	1425	0/-	0/-	0/0	0/0
NIE	88Nov15	1425	0/0	0/0	0/0	0/0
PEG	88Nov29	1325	0/0	0/0	0/0	0/0
PTG	88Dec13	1425	0/-	0/-	0/0	0/0
TAM	89Jan10	1425	0/0	**0/2**	0/0	**0/2**
WAB	88Nov29	1425	0/0	**1/1**	0/0	0/0
WIB	88Dec13	1425	0/-	0/-	0/0	0/0
BRT	89Apr25	1427	0/0	**2/0**	**1/1**	**3/2**
GAH	89Jan10	1425	0/0	**0/1**	0/0	0/0
HAL	89Jan10	1425	0/0	0/0	0/0	0/0
LOS	89Apr25	1427	0/0	0/0	0/0	0/0
MUC	89Apr25	1427	0/0	0/0	0/0	0/0
MUM	88Nov15	1425	0/0	0/9	0/0	0/0
NIG	88Dec13	1425	0/-	0/-	0/0	0/0
RDD	89Apr25	1427	0/0	0/0	0/0	0/0

Day 2, Profile 4 — **Square**

... 45/92 + 15/3 + 0/716

Subject	Date	Time	R1	F1	R2	F2
BOP	89Apr25	1829	**0/1**	**0/2**	0/0	**0/2**
BRW	88Dec13	1831	0/0	0/0	0/0	0/0
FOM	88Nov15	1829	0/0	0/0	0/0	0/0
GUM	88Nov29	1828	0/0	**0/1**	0/0	0/0
HAM	88Nov15	1829	0/0	0/0	0/0	0/0
MAP	88Dec13	1831	0/0	0/0	0/0	0/0
NIE	88Nov15	1829	0/0	0/0	0/0	0/0
PEG	88Nov29	1828	0/0	0/0	0/0	0/0
PTG	88Dec13	1831	0/0	0/0	0/0	0/0
TAM	89Jan10	1628	0/0	0/0	0/0	0/9
WAB	88Nov29	1828	0/9	0/9	0/0	0/0
WIB	88Dec13	1831	0/0	0/0	0/0	0/0
BRT	89Apr25	1829	0/0	0/0	0/0	**2/2**
GAH	89Jan10	1628	0/0	0/0	0/0	0/0
HAL	89Jan10	1628	0/0	0/9	0/0	0/0
LOS	89Apr25	1829	0/0	0/0	0/0	0/0
MUC	89Apr25	1829	0/0	**0/1**	0/0	**0/2**
MUM	88Nov15	1829	0/0	0/0	**2/0**	**3/3**
NIG	88Dec13	1831	0/0	0/0	0/0	0/0
RDD	89Apr25	1829	0/0	**1/1**	0/0	0/0

Appendix C3, page 3 of 6. Exposures and doppler results from Phase IIb. 4 dives per day for 6 days. Profiles are depth/time (fsw/min); ellipses show continuity and braces multilevel dives. Doppler scores for rest R and after flexing F are by two investigators separated by a diagonal. The first set (R1 and F1) were taken 20-25 min after surfacing and the second set (R2 and F2) were taken at 40-45 min. Grades other than 0 (including 9's) are in boldface. Males are above the line in subject column.

Day 3, Profile 1 — Multilevel 3

{ 90/25 + 55/ 9 + 35/40 } + 15/3 + 0/87 ...

Subject	Date	Time	R1	F1	R2	F2
			Doppler scores, by Observer 1 / 2			
BOP	89Apr26	0800	0 / 0	0 / 9	0 / 0	0 / 0
BRW	88Dec14	0800	0 / 0	0 / 0	0 / 0	0 / 0
FOM	88Nov16	0800	0 / 0	0 / 0	0 / 0	0 / 0
GUM	88Nov30	0800	0 / 0	**0 / 1**	0 / 0	0 / 0
HAM	88Nov16	0800	0 / 0	0 / 0	0 / 0	0 / 0
MAP	88Dec14	0800	0 / 0	0 / 0	0 / 0	0 / 0
NIE	88Nov16	0800	0 / 0	0 / 0	0 / 0	0 / 0
PEG	88Nov30	0800	0 / 0	0 / 0	0 / 0	**0 / 3**
PTG	88Dec14	0800	0 / 0	0 / 0	0 / 0	0 / 0
TAM	89Jan11	0800	**0 / 1**	**0 / 2**	0 / 0	**0 / 2**
WAB	88Nov30	0800	0 / 0	0 / 0	0 / 0	0 / 0
WIB	88Dec14	0800	0 / 0	0 / 0	0 / 0	0 / 0
BRT	89Apr26	0800	0 / 0	0 / 0	0 / 0	0 / 0
GAH	89Jan11	0800	0 / 0	0 / 0	0 / 0	0 / 9
HAL	89Jan11	0800	0 / 0	0 / 0	0 / 0	0 / 9
LOS	89Apr26	0800	0 / 0	0 / 0	0 / 0	0 / 0
MUC	89Apr26	0800	0 / 0	0 / 0	0 / 0	0 / 0
MUM	88Nov16	0800	0 / 0	0 / 0	0 / 0	0 / 0
NIG	88Dec14	0800	0 / 0	0 / 0	0 / 0	0 / 0
RDD	89Apr26	0800	0 / 0	0 / 0	0 / 0	0 / 0

Day 3, Profile 2 — Square

... 60/38 + 15/3 + 0/92 ...

Subject	Date	Time	R1	F1	R2	F2
BOP	89Apr26	1003	0 / 0	0 / 0	0 / 0	0 / 0
BRW	88Dec14	1046	0 / 0	0 / 0	**0 / 1**	**1 / 1**
FOM	88Nov16	1045	0 / 0	0 / 0	0 / 0	0 / 0
GUM	88Nov30	1045	0 / 0	0 / 0	0 / 0	0 / 0
HAM	88Nov16	1045	0 / 0	0 / 0	0 / 0	0 / 0
MAP	88Dec14	1046	0 / 0	0 / 0	0 / 0	0 / 0
NIE	88Nov16	1045	0 / 0	0 / 0	0 / 0	0 / 0
PEG	88Nov30	1045	0 / 0	0 / 0	0 / 0	**0 / 3**
PTG	88Dec14	1046	0 / 0	0 / 0	0 / 0	0 / 0
TAM	89Jan11	1047	0 / 0	0 / 0	0 / 0	0 / 0
WAB	88Nov30	1045	0 / 0	0 / 0	0 / 0	0 / 0
WIB	88Dec14	1046	0 / 0	0 / 0	0 / 0	0 / 0
BRT	89Apr26	1003	0 / 0	0 / 0	0 / 0	**0 / 1**
GAH	89Jan11	1047	0 / 0	**0 / 1**	0 / 0	0 / 0
HAL	89Jan11	1047	0 / 0	0 / 0	0 / 0	0 / 0
LOS	89Apr26	1003	0 / 0	0 / 0	0 / 0	0 / 0
MUC	89Apr26	1003	0 / 0	0 / 0	0 / 0	0 / 0
MUM	88Nov16	1045	0 / 0	0 / 0	0 / 0	0 / 0
NIG	88Dec14	1046	0 / 0	0 / 0	0 / 0	0 / 0
RDD	89Apr26	1003	0 / 0	0 / 0	0 / 0	0 / 0

Day 3, Profile 3 — Square

... 50/61 + 15/3 + 0/180 ...

Subject	Date	Time	R1	F1	R2	F2
			Doppler scores, by Observer 1 / 2			
BOP	89Apr26	1300	0 / 0	**0 / 1**	0 / 0	0 / 0
BRW	88Dec14	1259	0 / 0	0 / 0	0 / 0	0 / 0
FOM	88Nov16	1259	0 / 0	**1 / 1**	0 / 0	0 / 0
GUM	88Nov30	1259	0 / 0	0 / 0	0 / 0	0 / 0
HAM	88Nov16	1259	**1 / 0**	**2 / 0**	**0 / 2**	**1 / 2**
MAP	88Dec14	1259	0 / 0	0 / 0	0 / 0	0 / 0
NIE	88Nov16	1259	0 / 0	0 / 0	0 / 0	0 / 0
PEG	88Nov30	1259	**0 / 2**	**0 / 1**	0 / 0	**1 / 1**
PTG	88Dec14	1259	0 / 0	0 / 0	0 / 0	0 / 0
TAM	89Jan11	1259	0 / 0	0 / 0	0 / 0	0 / 0
WAB	88Nov30	1259	0 / 0	0 / 0	0 / 0	**1 / 1**
WIB	88Dec14	1259	0 / 0	0 / 0	0 / 0	0 / 0
BRT	89Apr26	1300	0 / 0	0 / 0	0 / 0	0 / 0
GAH	89Jan11	1259	0 / 0	0 / 0	0 / 0	0 / 0
HAL	89Jan11	1259	0 / 0	0 / 0	0 / 0	0 / 0
LOS	89Apr26	1300	0 / 0	0 / 0	0 / 0	0 / 0
MUC	89Apr26	1300	0 / 0	0 / 0	0 / 0	0 / 0
MUM	88Nov16	1259	**1 / 0**	**3 / 2**	**1 / 2**	**3 / 3**
NIG	88Dec14	1259	0 / 0	0 / 0	0 / 0	0 / 0
RDD	89Apr26	1300	0 / 0	0 / 0	0 / 0	0 / 0

Day 3, Profile 4 — Square

... 40/90 + 15/3 + 0/802

Subject	Date	Time	R1	F1	R2	F2
BOP	89Apr26	1704	0 / 0	**0 / 2**	0 / 0	0 / 0
BRW	88Dec14	1705	0 / 0	0 / 0	0 / 0	0 / 0
FOM	88Nov16	1705	0 / 0	**1 / 0**	0 / 0	**1 / 0**
GUM	88Nov30	1704	0 / 0	0 / 0	0 / 0	0 / 0
HAM	88Nov16	1705	0 / 0	0 / 0	0 / 0	0 / 0
MAP	88Dec14	1705	**1 / 1**	**2 / 2**	**0 / 2**	**2 / 2**
NIE	88Nov16	1705	0 / 0	0 / 0	0 / 0	0 / 0
PEG	88Nov30	1704	0 / 0	0 / 0	0 / 0	0 / 0
PTG	88Dec14	1705	0 / 0	0 / 0	0 / 0	0 / 0
TAM	89Jan11	1704	0 / 0	0 / 0	0 / 0	0 / 0
WAB	88Nov30	1704	0 / 0	0 / 0	0 / 0	0 / 0
WIB	88Dec14	1705	0 / 0	0 / 0	0 / 0	0 / 0
BRT	89Apr26	1704	0 / 0	0 / 0	0 / -	0 / -
GAH	89Jan11	1704	0 / 0	0 / 0	0 / 0	0 / 0
HAL	89Jan11	1704	0 / 0	0 / 0	0 / 0	0 / 0
LOS	89Apr26	1704	0 / 0	0 / 0	0 / 0	0 / 0
MUC	89Apr26	1704	0 / 0	0 / 0	0 / -	0 / -
MUM	88Nov16	1705	0 / 0	0 / 0	0 / 0	0 / 0
NIG	88Dec14	1705	0 / 0	0 / 0	0 / 0	0 / 0
RDD	89Apr26	1704	0 / 0	0 / 0	0 / 0	0 / 0

APP_C3CL.XLS

Appendix C3, page 4 of 6. Exposures and doppler results from Phase IIb. 4 dives per day for 6 days. Profiles are depth/time (fsw/min); ellipses show continuity and braces multilevel dives. Doppler scores for rest R and after flexing F are by two investigators separated by a diagonal. The first set (R1 and F1) were taken 20-25 min after surfacing and the second set (R2 and F2) were taken at 40-45 min. Grades other than 0 (including 9's) are in boldface. Males are above the line in subject column.

Day 4, Profile 1 — **Multilevel 4**

{ 110/16+70/8+50/13+40/15 } + 15/3 + 0/66 ...

Subject	Date	Time	R1	F1	R2	F2
			Doppler scores, by Observer 1 / 2			
BOP	89Apr27	0800	**0 / 3**	**0 / 3**	**0 / 2**	**0 / 2**
BRW	88Dec15	0800	0 / 0	0 / 0	0 / 0	0 / 0
FOM	88Nov17	0800	0 / 0	0 / 0	0 / 0	0 / 0
GUM	88Dec1	0800	0 / 0	0 / 0	0 / 0	0 / 0
HAM	88Nov17	0800	0 / 0	0 / 0	0 / 0	0 / 0
MAP	88Dec15	0800	0 / 0	0 / 0	0 / 0	0 / 0
NIE	88Nov17	0800	0 / 0	0 / 0	0 / 0	**1 / 0**
PEG	88Dec1	0800	0 / 0	**0 / 2**	0 / 0	0 / 0
PTG	88Dec15	0800	0 / 0	0 / 0	0 / 0	0 / 0
TAM	89Jan12	0800	0 / -	0 / -	0 / 0	0 / 0
WAB	88Dec1	0800	0 / 0	0 / 0	**1 / 0**	0 / 0
WIB	88Dec15	0800	0 / 0	0 / 0	0 / 0	0 / 0
BRT	89Apr27	0800	0 / 0	0 / 0	0 / 0	0 / 0
GAH	89Jan12	0800	0 / -	0 / -	0 / 0	0 / 0
HAL	89Jan12	0800	0 / -	0 / -	0 / 0	0 / 0
LOS	89Apr27	0800	0 / 0	0 / 0	0 / 0	0 / 0
MUC	89Apr27	0800	0 / 0	0 / 0	0 / 0	0 / 0
MUM	88Nov17	0800	0 / 0	0 / 0	0 / 0	0 / 0
NIG	88Dec15	0800	0 / 0	0 / 0	0 / 0	0 / 0
RDD	89Apr27	0800	0 / 0	0 / 0	0 / 0	0 / 0

Day 4, Profile 2 — **Multilevel 3**

... { 75/17 +50/11 +35/55 } + 15/3 + 0/180 ...

Subject	Date	Time	R1	F1	R2	F2
BOP	89Apr27	1003	0 / 0	0 / 0	0 / 0	0 / 0
BRW	88Dec15	1005	0 / 0	0 / 0	0 / 0	0 / 0
FOM	88Nov17	1003	0 / 0	0 / 0	0 / 0	**0 / 1**
GUM	88Dec1	1003	0 / 0	0 / 0	0 / 0	0 / 0
HAM	88Nov17	1003	0 / 0	0 / 0	0 / 0	0 / 0
MAP	88Dec15	1005	0 / 0	0 / 0	0 / 0	0 / 0
NIE	88Nov17	1003	0 / 0	0 / 0	0 / 0	**0 / 1**
PEG	88Dec1	1003	0 / 0	0 / 0	**0 / 1**	0 / 0
PTG	88Dec15	1005	0 / 0	0 / 0	0 / 0	0 / 0
TAM	89Jan12	1003	0 / 0	0 / 0	**1 / 0**	**2 / 2**
WAB	88Dec1	1003	0 / 0	0 / 0	0 / 0	0 / 0
WIB	88Dec15	1005	0 / 0	0 / 0	0 / 0	0 / 0
BRT	89Apr27	1003	0 / 0	0 / 0	0 / 0	0 / 0
GAH	89Jan12	1003	0 / 0	0 / 0	0 / 0	0 / 0
HAL	89Jan12	1003	0 / 0	0 / 0	0 / 0	0 / 0
LOS	89Apr27	1003	0 / 0	0 / 0	0 / 0	**0 / 1**
MUC	89Apr27	1003	0 / -	0 / -	0 / 0	0 / 0
MUM	88Nov17	1003	0 / 0	0 / 0	0 / 0	0 / 0
NIG	88Dec15	1005	0 / 0	0 / 0	0 / 0	0 / 0
RDD	89Apr27	1003	0 / 0	0 / 0	0 / 0	0 / 0

Day 4, Profile 3 — **Multilevel 2**

... { 60/49 + 35/41 } + 15/3 + 0/180 ...

Subject	Date	Time	R1	F1	R2	F2
			Doppler scores, by Observer 1 / 2			
BOP	89Apr27	1430	0 / 0	0 / 0	**0 / 1**	**0 / 1**
BRW	88Dec15	1430	0 / 0	0 / 0	0 / 0	0 / 0
FOM	88Nov17	1431	0 / 0	0 / 0	0 / 0	0 / 0
GUM	88Dec1	1430	0 / 0	0 / 0	0 / 0	0 / 0
HAM	88Nov17	1431	0 / 0	0 / 0	0 / 0	0 / 0
MAP	88Dec15	1430	0 / 0	0 / 0	0 / 0	0 / 0
NIE	88Nov17	1431	0 / 0	0 / 0	0 / 0	0 / 0
PEG	88Dec1	1430	0 / 0	0 / 0	**0 / 1**	**0 / 3**
PTG	88Dec15	1430	0 / 0	0 / 0	0 / 0	0 / 0
TAM	89Jan12	1430	**1 / 0**	**2 / 2**	0 / 0	**2 / 0**
WAB	88Dec1	1430	0 / 0	0 / 0	0 / 0	0 / 0
WIB	88Dec15	1430	0 / 0	0 / 0	0 / 0	0 / 0
BRT	89Apr27	1430	0 / 0	0 / 0	0 / 0	0 / 0
GAH	89Jan12	1430	0 / 0	0 / 0	0 / 0	0 / 0
HAL	89Jan12	1430	0 / 0	0 / 0	0 / 0	0 / 0
LOS	89Apr27	1430	0 / 0	0 / 0	0 / 0	**0 / 1**
MUC	89Apr27	1430	0 / 0	0 / 0	0 / 0	0 / 0
MUM	88Nov17	1431	0 / 0	0 / 0	0 / 0	**0 / 1**
NIG	88Dec15	1430	0 / 0	0 / 0	0 / 0	0 / 0
RDD	89Apr27	1430	0 / 0	0 / 0	0 / 0	0 / 0

Day 4, Profile 4 — **Square**

... 40/90 + 15/3 + 0/682

Subject	Date	Time	R1	F1	R2	F2
BOP	89Apr27	1904	**0 / 0**	**0 / 2**	**0 / 1**	**0 / 2**
BRW	88Dec15	1904	0 / 0	0 / 0	0 / 0	0 / 0
FOM	88Nov17	1904	0 / 0	0 / 0	0 / 0	0 / 0
GUM	88Dec1	1904	0 / 0	0 / 0	0 / 0	0 / 0
HAM	88Nov17	1904	0 / 0	**0 / 1**	0 / 0	0 / 0
MAP	88Dec15	1904	0 / 0	0 / 0	0 / 0	0 / 0
NIE	88Nov17	1904	0 / 0	0 / 0	0 / 0	0 / 0
PEG	88Dec1	1904	0 / 0	0 / 0	0 / 0	0 / 0
PTG	88Dec15	1904	0 / 0	0 / 0	0 / 0	0 / 0
TAM	89Jan12	1904	0 / -	0 / -	0 / -	0 / -
WAB	88Dec1	1904	0 / 0	0 / 0	0 / 0	0 / 0
WIB	88Dec15	1904	0 / 0	0 / 0	0 / 0	0 / 0
BRT	89Apr27	1904	0 / 0	**0 / 1**	0 / 0	0 / 0
GAH	89Jan12	1904	0 / -	0 / -	0 / -	0 / -
HAL	89Jan12	1904	0 / -	0 / -	0 / -	0 / -
LOS	89Apr27	1904	0 / 0	0 / 0	0 / 0	0 / 0
MUC	89Apr27		(MUC did not make this dive)			
MUM	88Nov17	1904	0 / 0	0 / 0	0 / 0	**0 / 9**
NIG	88Dec15	1904	0 / 0	0 / 0	0 / 0	0 / 0
RDD	89Apr27	1904	0 / 0	0 / 0	0 / 0	0 / 0

Appendix C3, page 5 of 6. Exposures and doppler results from Phase IIb. 4 dives per day for 6 days. Profiles are depth/time (fsw/min); ellipses show continuity and braces multilevel dives. Doppler scores for rest R and after flexing F are by two investigators separated by a diagonal. The first set (R1 and F1) were taken 20-25 min after surfacing and the second set (R2 and F2) were taken at 40-45 min. Grades other than 0 (including 9's) are in boldface. Males are above the line in subject column.

Day 5, Profile 1 — Multilevel 4

{100/20+65/6+50/13+35/26 } + 15/3 + 0/80 ...

Subject	Date	Time	R1	F1	R2	F2
			Doppler scores, by Observer 1 / 2			
BOP	89Apr28	0802	0/0	**0/1**	0/0	0/0
BRW	88Dec16	0800	0/0	0/0	0/0	0/0
FOM	88Nov18	0800	**1/0**	**2/2**	**1/1**	0/0
GUM	88Dec2	0800	0/0	0/0	0/0	0/0
HAM	88Nov18	0800	0/0	0/0	0/0	0/0
MAP	88Dec16	0800	0/0	0/0	0/0	0/0
NIE	88Nov18	0800	0/0	0/0	0/0	0/0
PEG	88Dec2	0800	0/0	0/0	0/0	0/0
PTG	88Dec16	0800	0/0	0/0	0/0	0/0
TAM	89Jan13	0800	0/0	0/0	0/0	0/0
WAB	88Dec2	0800	0/0	0/0	**1/0**	0/0
WIB	88Dec16	0800	0/0	0/0	0/0	0/0
BRT	89Apr28	0802	0/0	0/0	0/0	0/0
GAH	89Jan13	0800	0/0	0/0	0/-	0/-
HAL	89Jan13	0800	0/0	0/0	0/-	0/-
LOS	89Apr28	0802	0/0	0/0	0/0	0/0
MUC	89Apr28	0802	0/0	0/0	**0/1**	**0/2**
MUM	88Nov18	0800	0/0	0/0	0/0	0/0
NIG	88Dec16	0800	0/0	0/0	0/0	0/0
RDD	89Apr28	0802	0/0	0/0	0/0	0/0

Day 5, Profile 2 — Multilevel 2

... { 70/24 + 40/49 } + 15/3 + 0/180 ...

Subject	Date	Time	R1	F1	R2	F2
BOP	89Apr28	1030	0/0	0/0	0/0	0/0
BRW	88Dec16	1030	0/0	0/0	0/0	0/0
FOM	88Nov18	1030	0/0	0/0	0/0	0/0
GUM	88Dec2	1030	0/0	0/0	0/0	0/0
HAM	88Nov18	1030	0/0	0/0	0/0	0/0
MAP	88Dec16	1030	0/0	0/0	0/0	0/0
NIE	88Nov18	1030	0/0	0/0	0/0	0/0
PEG	88Dec2	1030	0/0	**0/2**	0/0	0/0
PTG	88Dec16	1030	0/0	0/0	0/0	0/0
TAM	89Jan13	1030	0/0	0/0	0/0	0/0
WAB	88Dec2	1030	0/0	0/0	0/0	0/0
WIB	88Dec16	1030	0/0	0/0	0/0	0/0
BRT	89Apr28	1030	0/0	0/0	0/0	0/0
GAH	89Jan13	1030	**1/0**	**2/2**	0/0	0/0
HAL	89Jan13	1030	0/0	0/0	0/0	0/0
LOS	89Apr28	1030	**0/9**	**0/9**	0/0	0/0
MUC	89Apr28	1030	0/0	0/0	0/0	0/0
MUM	88Nov18	1030	0/0	**0/2**	**0/9**	0/0
NIG	88Dec16	1030	0/0	0/0	0/0	0/0
RDD	89Apr28	1030	0/0	0/0	0/0	0/0

Day 5, Profile 3 — Square

... 50/73 + 15/3 + 0/180 ...

Subject	Date	Time	R1	F1	R2	F2
			Doppler scores, by Observer 1 / 2			
BOP	89Apr28	1458	0/0	0/0	0/0	0/0
BRW	88Dec16	1447	0/0	0/0	0/0	0/0
FOM	88Nov18	1447	0/0	0/0	0/0	0/0
GUM	88Dec2	1447	0/0	0/0	0/0	0/0
HAM	88Nov18	1447	0/0	0/0	0/0	0/0
MAP	88Dec16	1447	0/0	0/0	0/0	**2/2**
NIE	88Nov18	1447	**0/1**	**0/1**	0/0	0/0
PEG	88Dec2	1447	0/0	**0/2**	0/0	**0/2**
PTG	88Dec16	1447	0/0	0/0	0/0	0/0
TAM	89Jan13	1447	0/0	0/0	0/0	0/0
WAB	88Dec2	1447	**1/1**	**2/2**	0/0	**1/2**
WIB	88Dec16	1447	0/0	0/0	0/0	0/0
BRT	89Apr28	1458	**2/2**	**2/9**	**1/2**	**2/3**
GAH	89Jan13	1447	0/0	0/0	0/0	0/0
HAL	89Jan13	1447	0/0	0/0	0/0	0/0
LOS	89Apr28	1458	0/0	0/0	0/0	0/0
MUC	89Apr28	1458	0/0	0/0	0/0	0/0
MUM	88Nov18	1447	0/0	0/0	0/0	0/0
NIG	88Dec16	1447	0/0	0/0	0/0	0/0
RDD	89Apr28	1458	0/0	0/0	0/0	0/0

Day 5, Profile 4 — Square

... 45/92 + 15/3 + 0/680

Subject	Date	Time	R1	F1	R2	F2
BOP	89Apr28	1906	0/0	0/0	0/0	0/0
BRW	88Dec16	1904	0/0	0/0	0/0	0/0
FOM	88Nov18	1905	0/0	0/0	0/0	0/0
GUM	88Dec2	1904	0/0	0/0	0/0	0/0
HAM	88Nov18	1905	0/0	0/0	0/0	**0/1**
MAP	88Dec16	1904	0/0	**0/1**	0/0	0/0
NIE	88Nov18	1905	0/0	**0/1**	0/0	0/0
PEG	88Dec2	1904	0/0	**1/0**	0/0	**1/0**
PTG	88Dec16	1904	0/0	0/0	0/0	0/0
TAM	89Jan13	1904	0/0	0/0	0/0	0/0
WAB	88Dec2	1904	0/0	**2/2**	0/0	0/0
WIB	88Dec16	1904	0/0	0/0	0/0	0/0
BRT	89Apr28	1906	0/0	**0/2**	0/0	0/0
GAH	89Jan13	1904	**1/2**	**2/2**	**1/1**	**2/2**
HAL	89Jan13	1904	0/0	0/0	0/0	0/0
LOS	89Apr28	1906	0/0	0/0	0/0	0/0
MUC	89Apr28	1906	0/0	0/0	0/0	0/0
MUM	88Nov18	1905	0/0	0/0	**0/9**	**0/1**
NIG	88Dec16	1904	0/0	0/0	0/0	0/0
RDD	89Apr28	1906	0/0	0/0	0/0	0/0

Appendix C3, page 6 of 6. Exposures and doppler results from Phase IIb. 4 dives per day for 6 days. Profiles are depth/time (fsw/min); ellipses show continuity and braces multilevel dives. Doppler scores for rest R and after flexing F are by two investigators separated by a diagonal. The first set (R1 and F1) were taken 20-25 min after surfacing and the second set (R2 and F2) were taken at 40-45 min. Grades other than 0 (including 9's) are in boldface. Males are above the line in subject column.

Day 6, Profile 1 — **Multilevel 3**

{ 85/27 + 50/17 + 35/26 } + 15/3 + 0/95 ...

Subject	Date	Time	R1	F1	R2	F2
			Doppler scores, by Observer 1 / 2			
BOP	89Apr29	0800	0/0	0/0	0/0	**0/2**
BRW	88Dec17	0802	0/0	0/0	0/0	0/0
FOM	88Nov19	0800	0/0	0/0	0/0	0/0
GUM	88Dec3	0800	0/0	0/0	0/0	0/0
HAM	88Nov19	0800	0/0	0/0	0/0	**1/1**
MAP	88Dec17	0802	0/0	0/0	0/0	0/0
NIE	88Nov19	0800	0/0	0/0	0/0	0/0
PEG	88Dec3	0800	0/0	**0/1**	0/0	0/0
PTG	88Dec17	0802	0/0	0/0	0/0	0/0
TAM	89Jan14	0802	0/0	0/0	0/0	0/0
WAB	88Dec3	0800	0/0	0/0	0/0	**1/1**
WIB	88Dec17	0802	0/0	0/0	0/0	0/0
BRT	89Apr29	0800	0/0	0/0	0/0	0/0
GAH	89Jan14	0802	0/0	0/0	0/0	0/0
HAL	89Jan14	0802	0/0	0/0	0/0	0/0
LOS	89Apr29	0800	0/0	0/0	0/0	0/0
MUC	89Apr29	0800	0/0	0/0	0/0	0/0
MUM	88Nov19	0800	0/0	0/0	0/0	0/0
NIG	88Dec17	0802	0/0	0/0	0/0	0/0
RDD	89Apr29	0800	0/0	0/0	0/0	0/0

Day 6, Profile 2 — **Square**

... 65/31 + 15/3 + 0/117 ...

Subject	Date	Time	R1	F1	R2	F2
BOP	89Apr29	1049	0/0	**0/1**	0/0	**0/2**
BRW	88Dec17	1049	0/0	0/0	0/0	0/0
FOM	88Nov19	1049	0/0	0/0	0/0	0/0
GUM	88Dec3	1049	0/0	0/0	0/0	0/0
HAM	88Nov19	1049	0/9	0/9	0/0	0/0
MAP	88Dec17	1049	0/0	0/0	0/0	0/0
NIE	88Nov19	1049	0/0	0/0	0/0	0/0
PEG	88Dec3	1049	0/0	0/0	**0/1**	**0/3**
PTG	88Dec17	1049	0/0	0/0	0/0	0/0
TAM	89Jan14	1049	0/0	0/0	0/0	0/0
WAB	88Dec3	1049	0/0	0/0	0/0	0/0
WIB	88Dec17	1049	0/0	0/0	0/0	0/0
BRT	89Apr29	1049	0/0	0/0	0/0	0/0
GAH	89Jan14	1049	0/0	0/0	0/0	0/0
HAL	89Jan14	1049	0/0	0/0	0/0	0/0
LOS	89Apr29	1049	0/0	0/0	0/0	0/0
MUC	89Apr29	1049	0/0	0/0	0/0	0/0
MUM	88Nov19	1049	0/0	0/0	0/0	0/0
NIG	88Dec17	1049	0/0	0/0	0/0	0/0
RDD	89Apr29	1049	0/0	0/0	0/0	0/0

Day 6, Profile 3 — **Square**

... 55/53 + 15/3 + 0/60 ...

Subject	Date	Time	R1	F1	R2	F2
			Doppler scores, by Observer 1 / 2			
BOP	89Apr29	1323	**0/1**	**0/2**	0/0	**0/2**
BRW	88Dec17	1326	0/-	0/-	0/0	0/0
FOM	88Nov19	1321	0/0	0/0	0/0	0/0
GUM	88Dec3	1339	0/0	0/0	0/0	0/0
HAM	88Nov19	1321	**1/1**	**2/1**	0/0	0/0
MAP	88Dec17	1326	0/0	0/0	0/0	0/0
NIE	88Nov19	1321	0/0	**0/1**	0/0	0/0
PEG	88Dec3	1339	**0/2**	**1/2**	0/0	**0/2**
PTG	88Dec17	1326	0/0	0/0	0/0	0/0
TAM	89Jan14	1321	0/0	0/0	0/0	0/0
WAB	88Dec3	1339	0/0	0/0	**0/1**	**1/1**
WIB	88Dec17	1326	0/0	0/0	0/0	0/0
BRT	89Apr29	1323	0/0	0/0	0/0	0/0
GAH	89Jan14	1321	0/0	0/0	0/0	0/0
HAL	89Jan14	1321	0/0	0/0	0/0	0/0
LOS	89Apr29	1323	0/0	0/0	0/0	**2/1**
MUC	89Apr29	1323	0/0	0/0	0/0	0/0
MUM	88Nov19	1321	0/0	0/0	0/0	0/0
NIG	88Dec17	1326	0/0	0/0	0/0	0/0
RDD	89Apr29	1323	0/0	0/0	0/0	**2/2**

Day 6, Profile 4 — **Square**

...40/100 + 15/3 + 0/ ∞

Subject	Date	Time	R1	F1	R2	F2
BOP	89Apr29	1520	0/0	**0/1**	0/0	**0/2**
BRW	88Dec17	1520	0/0	0/0	0/0	0/0
FOM	88Nov19	1522	0/0	0/0	0/0	0/0
GUM	88Dec3	1518	0/0	0/0	0/0	0/0
HAM	88Nov19	1522	**1/2**	**1/2**	0/9	**1/3**
MAP	88Dec17	1520	**0/2**	**2/3**	0/0	0/0
NIE	88Nov19	1522	**1/1**	**3/1**	**1/2**	**2/2**
PEG	88Dec3	1518	0/0	1/3	0/0	**0/2**
PTG	88Dec17	1520	0/0	0/0	0/0	0/0
TAM	89Jan14	1518	0/0	0/0	0/0	**2/2**
WAB	88Dec3	1518	**0/1**	**1/0**	0/0	**1/1**
WIB	88Dec17	1520	0/0	0/0	0/0	**2/2**
BRT	89Apr29	1520	0/0	0/0	0/0	0/0
GAH	89Jan14	1518	**0/1**	**1/1**	**1/2**	**2/3**
HAL	89Jan14	1518	0/0	0/0	0/0	0/0
LOS	89Apr29	1520	0/0	0/0	0/0	**0/1**
MUC	89Apr29	1520	0/0	0/0	0/0	0/0
MUM	88Nov19	1522	0/0	0/0	0/0	0/0
NIG	88Dec17	1520	0/0	0/0	0/0	0/0
RDD	89Apr29	1520	0/0	0/0	0/0	0/0

Appendix D. Summary of Pressure Groups.

This appendix lists the Pressure Group (PG) at the end of each dive for all phases. A pressure group (also called in other contexts a Repetitive Dive Group, RDG) is a measure of the calculated gas loading assumed by the RDP to be present. Also listed is some abbreviated Doppler bubble information, the number of dives on a given profile and the number of dives with bubbles.

The selection criteria of Phase I profiles caused atypical surfacing pressure groups. Surfacing pressures were within the limits of the algorithm, but were usually beyond the limits of the RDP. Phase I employed neither safety stops nor the long surface interval rules (W-X, Y-Z rules).

In Phase IIa and IIb RDP limits were strictly observed. Safety stops and long surface intervals were used when indicated by operational rules.

Appendix D. Surfacing pressure groups after each dive.

	Prof.	Dive	w/ bubbles			Surf. PG
Phase I:	1	1	0	of	25	L
		2	2	of	25	Z
	2	1	4	of	18	X
		2	5	of	18	Z
	3	1	0	of	20	Q
		2	0	of	20	Z
	4	1	0	of	5	Z
		2	0	of	5	W
	5	1	4	of	32	W
	6	1	2	of	18	X
	7	1	4	of	15	Y
	8	1	6	of	24	Z
	9	1	2	of	27	M
		2	3	of	27	Y
	10	1	1	of	6	S
		2	2	of	6	Z
	11	1	0	of	15	O
		2	1	of	15	V
	12	1	2	of	19	Z
	13	1	0	of	2	N
		2	0	of	2	W
		3	0	of	2	X
	14	1	0	of	15	Z
	15	1	1	of	5	L
		2	1	of	5	S
		3	1	of	5	Y
		4	1	of	5	Past Z
	16	1	1	of	2	Y
		2	1	of	2	Y
	17	1	0	of	4	X
		2	0	of	4	Past Z
	18	1	0	of	15	X
		2	0	of	15	Past Z
	19	1	1	of	17	S
		2	0	of	17	Past Z
		3	1	of	17	Past Z
	20	1	1	of	17	Z
		2	3	of	17	Past Z
	21	1	0	of	3	U
		2	0	of	3	Past Z
	22	1	0	of	2	P
		2	0	of	2	Past Z
	51	1	2	of	48	M
		2	4	of	48	U
		3	6	of	48	Y
	52	1	0	of	40	K
		2	2	of	40	U
		3	1	of	40	W
	53	1	1	of	43	P
		2	1	of	43	V
		3	3	of	43	Y

	Day	Dive	w/ bubbles			Surf. PG
Phase IIa:	1	1	0	of	4	P
		2	0	of	4	U
		3	4	of	4	X
		4	2	of	4	X
		5	3	of	4	X
		6	1	of	4	Z
	2	1	2	of	4	W
		2	2	of	4	X
		3	1	of	4	X
		4	1	of	4	X
		5	2	of	4	X
		6	2	of	4	Z
	3	1	3	of	3	M

	Day	Dive	w/ bubbles			Surf. PG
Phase IIb:	1	1	1	of	18	X
		2	0	of	19	Z
		3	4	of	29	Z
		4	4	of	20	V
	2	1	3	of	20	X
		2	4	of	20	Z
		3	6	of	20	Z
		4	6	of	20	Y
	3	1	3	of	20	X
		2	4	of	20	W
		3	6	of	20	Y
		4	3	of	20	V
	4	1	4	of	20	X
		2	5	of	20	Z
		3	5	of	20	Z
		4	3	of	19	V
	5	1	4	of	20	X
		2	2	of	20	Z
		3	5	of	20	Y
		4	8	of	20	Z
	6	1	4	of	20	X
		2	2	of	20	U
		3	7	of	20	X
		4	10	of	20	Z

Phase I: Safey stops were not made and long surface interval rules (W-X, Y-Z rules) were not employed. (Profile selection protocols were rigorous; most of the Phase I dives would not be permitted by the RDP.)

Phases IIa and IIb: Safety stops and long surface intervals were used when indicated by operational rules.

Appendix E. Comment and critique from the field

This appendix collects a few comments about the RDP, some of them critical, and attempts to address the "bottom line" in assessment of a decompression procedure, how well it works in actual use.

1. The Davis and Davies articles

F. Michael Davis of New Zealand issued a strongly critical article (1989 Dec) which was apparently based on an incomplete report of the DSAT work, and which clearly reflects a lack of understanding on his part of both the modelling and the validation processes. His article considers the algorithm "fundamentally flawed," apparently because of the presence of bubbles in tables calculated with Haldane methods. For over a quarter of a century, as mentioned earlier, decompression researchers using Haldanian methods have been aware of bubbles in dives with otherwise effective tables, and have realized that the different versions of the algorithm—which are all based on empirical results—strive to limit bubble formation to a tolerable amount. It is certainly not a valid criticism to say that the presence of bubbles "invalidates the theoretical basis" of the tables. Davis' article also felt the testing was inadequate, calling it "the cart before the horse." This is a strange position to take about the only recreational tables ever developed with such an extensive testing program, roughly twice the number of test dives as used for the DCIEM tables, which were much more complex. It can only be explained by an apparent lack of knowledge on his part of the actual experimental results at the time. For example, he seems to have been unaware of nearly 400 open water dives. His article is effectively answered by RER and MRP (Rogers, 1989 Dec; Powell, 1989 Dec).

Another exchange of letters in the journal of the South Pacific Underwater Medical Association (Davies, 1989; Davis 1989 Jan; Richardson, 1989 Jan) initiated by David E. Davies discussed reviews by Australian diving researchers Brian Hills and Des Gorman of the very earliest report on the DSAT study. Comments such as "were not titrated to the bends point" and "the assumption that the diver is bubble free" also indicate a lack of understanding of what was being done and why. This is effectively answered in a response by DR.

2. The Scott article

Samuel T. Scott, a NAUI instructor, (1992 May) examined several sets of no-stop and repetitive procedures, including the RDP. He regards the RDP no-stop times as conservative, using the U.S. Navy air tables as a standard, along with the other tables examined. In comparing allowable times on repetitive dives he finds, as expected, that the RDP allows more time for a given interval. He offers the opinion that this "flies in the face of conventional wisdom" regarding its reliability for multiple dives over multiple days. To get these improved efficiencies was in fact the reason for the RDP in the first place, but because it was a step beyond the comfortable envelope of experience it was necessary to perform testing. Unfortunately Mr. Scott did not have detailed information about the test program and its results nor did he contact either PADI or the authors to get more information. Scott also was bothered by the requirement for extra restrictions in some parts the of RDP domain. The rationale for these, as well as troubles with the terminology, are covered in this report. Responses to this article offered some of these same explanations (Rogers, 1992; Hamilton, 1992; Scott, 1992 Nov). One point about the "safety" stop. It is required in certain cases to meet the desired conservatism, and to conform to the test program which supports the RDP. It is indeed a stop; as such it allows the diver to benefit from the more efficient capabilities of the RDP, and euphemism or not, it hardly takes diving with the RDP out of the realm of recreational no-stop diving.

3. The BSAC'88 Tables

Another decompression planner that has some characteristics in common with the RDP has been developed by BSAC, the British Sub-Aqua Club (BSAC, 1988). The main resemblance is that this is a set of tables prepared exclusively for recreational diving; they were prepared by Dr. Tom Hennessy, a mathematician and fluid mechanicist with the Admiralty Research Establishment who worked for several years at the Royal Navy Physiological Laboratory. The BSAC'88 tables address repetitive diving and diving at altitude as part of their design concept. There are many differences between the BSAC tables and the RDP, however. To begin with BSAC is a different type of organization, but the main difference is that theirs are **decompression** tables, designed to provide proper and intuitive decompressions for recreational divers; the RDP, on the other hand, is designed specifically to avoid "decompression" or dives requiring stops. This reflects a difference in diving practice and philosophy between the two recreational communities. The BSAC tables can be used for calculating multilevel dives, but this practice is not officially sanctioned by BSAC. One of BSAC's motivations to get these tables was the set of many curious rules and limitations forced on them by the one-card table they were then using (based on the RN air tables; Ministry of Defense, 1972). A review of the track record of these tables (it is good) is not relevant to the RDP, but the big improvement BSAC has seen in the understanding of decompression principles and their improved implementation make these tables quite successful in that respect. The BSAC tables were not tested experimentally.

4. Dive computers

One would be remiss in addressing decompression in recreational diving today without taking notice of diver-carried electronic dive computers. These, too, have been subjected to considerable scrutiny and criticism, although their track record seems to be quite good computers relate to the RDP is that a diver contemplating a dive series equivalent to or more strenuous than the Phase IIb sequence would almost certainly do it with a computer. It has not been general practice for dive computers to be tested experimentally before being issued, on the theory that they are based on established models; we do not address that issue. One might wonder why the DAN committee has ignored this phenomenon.

5. Common questions about the RDP

A number of questions have come up during the introduction of the RDP. Some of these are based on assumptions about the program that are not quite correct, and some are legitimate. A few selected ones are reviewed here. That the RDP is "based" on the 60 min compartment must mean that fast and slow compartments are ignored. Not really, since the no-stop limits for deep, short dives are controlled by short compartments, and the long compartments are addressed by the special rules; both are considered in the multilevel calculations. The notion that PADI has developed a "new theory" is of course wrong; what was done was an application of well-worn ideas.

We acknowledge criticism of the limitations of Doppler techniques; some of these are mentioned in this report. One criticism was that not enough tests were done. We suspect that some of this may have been based on incomplete information. It is intriguing that people can single out DSAT for not doing enough tests when no other organization promoting recreational tables has done any. We, too, would like to have more tests, but this is what could be done with available resources.

We are comfortable with the upper limit of 60 fsw/min as an ascent rate. PADI does not encourage divers to go this fast, but rather to use it as an outside limit. The findings of the AAUS ascent rate workshop (Lang and Egstrom, 1990) make the case that one is not likely to improve on a requirement for controlled ascent at no more than 60 fsw/min.

6. Field experience with the RDP

It would be nice if we could pair this report with one on field experience with the RDP. There is some limited data on this, but not enough for a complete report at this time, nor enough to include here. When such data become available we look forward to it in another report.

We asked if PADI had relevant experience. Like DAN, they have no firm data collection because a denominator giving the level of use is not available. It is reasonable to assume that if the RDP were proving to be generally inadequate in managing recreational diver decompression then the first to hear about it would be the manufacturer of The Wheel and the instructors who teach it (Rogers, 1992 Jan). They are seeing no more problems with the RDP than is evident in the general "back - ground" level of DCS in the overall diver population. Many such cases are from apparently benign exposures, well within the limits. What this means in terms of "incidence" is of course impossible to say without a baseline of the number of relevant dives. On the order of half a million RDP's have been distributed. If each of these has been used for only a few near-limit dives it makes up a huge data base that speaks for itself.

PADI's experience in teaching The Wheel has been quite good. Many thousands of divers have learned it and are using it successfully.