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OFFSHORE TECHNOLOGY REPORT - OTO 97 812

THE INCIDENCE OF DECOMPRESSION SICKNESS ARISING FROM COMMERCIAL OFFSHORE AIR-DIVING OPERATIONS IN THE UK SECTOR OF THE NORTH SEA DURING 1982/83

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HYPERBARIC MEDICINE UNIT

The Incidence of Decompression Sickness arising from Commercial Offshore Air-Diving Operations in the UK Sector of the North Sea during 1982/83

TG Shields and WB Lee

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Thomas G. Shields
BSc(Hons) PhD FRCP (Glas) AFOM

Consultant in Hyperbaric Medicine, Grampian Health Board
Honorary Consultant, Centre for Offshore Health,
Robert Gordon's Institute of Technology

William B. Lee
BSc(Hons) PhD

Research Fellow, Centre for Offshore Health,
Robert Gordon's Institute of Technology

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FOREWORD

This report is published by the Health and Safety Executive as part of a programme of work which was commissioned in support of the Offshore Safety Division's (OSD) diving research strategy. The full programme of work covers the period from the late 1970's to 1997; some reports from the programme have hitherto not been published.

Some research was sponsored by the Department of Energy prior to the transfer of their responsibilities for offshore safety to the Health and Safety Executive. Other studies were originally commissioned by OSD for internal use. It has now been decided to issue the reports relating to this work so that the information they contain is in the public domain.

In view of the extended period of the research programme, some reports may contain information or recommendations which have been superseded. The structure of others may not meet the standard now expected of an Offshore Technology series report. Nevertheless it is HSE's intention that all such documents should be in the public domain.

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SUMMARY

A survey of air diving activity in the UK sector of the North Sea was carried out for the two year period 1982/1983. In particular, the incidence of decompression sickness was evaluated and an assessment of contributory factors made.

A wide range of parameters (15) were recorded. These included dive depth/bottom time, decompression technique, type of thermal protection and, when decompression sickness (DCS) occurred, the manifestation category. Two derived variables were calculated; the Decompression Penalty Index (DP Index), a measure of the hyperbaric stress imposed by the dive, and the Safety Factor Index, a measure of the amount of additional decompression time added to a dive.

A retrospective analysis of dive logs from all major diving contractors operating during the survey period resulted in 25,740 man-dive records. Surface decompression diving accounted for approximately 60% of the dives, no-stop diving for 30%, and in-water-stop diving for only 10%. Dives carried out with in-water decompression had a less severe hyperbaric exposure than those carried out using surface decompression.

During the survey period, 79 cases of DCS were recorded; 44 with Type 1 manifestations and 35 Type 2 (neurological) manifestations. The influence of four contributing factors are examined and discussed: the severity of the hyperbaric stress; the decompression procedure; the extent of applied safety factors; and the type of thermal protection.

The severity of the hyperbaric exposure contributed significantly to the incidence of DCS. As dive severity increased, there was a greater incidence of DCS. It was possible to compare the technique of Sur-D with in-water stops only for dives of moderate severity.

Thermal protection also influenced DCS, with a higher incidence resulting from the use of actively heated (hot water) suits. This difference was most marked in dives of high hyperbaric stress. Of particular concern was the greater proportion of Type 2 manifestations resulting from the use of active thermal protection.

It was concluded from these findings that a problem did exist in the offshore air diving activities of the UK sector of the North Sea. Concern was directed at the number of Type 2 manifestations. The principle factor appeared to be the severity of the hyperbaric exposure, with a contribution from the use of hot water suits. When these variables were controlled, there was no evidence to suggest that the technique of Sur-D was any more hazardous than the use of in-water stops, at least for dives of moderate severity.

The recommendation of this report is that a limit should be placed on the severity of the hyperbaric exposure of air diving, using the DP Index as an indicator of the stress. Different limits are proposed depending on whether hot-water suits are used.

Statement of Confidentiality

At the start of this project we gave the diving companies an assurance of confidentiality of their records.

The anonymity of the individual diver has been preserved absolutely. We have no record on our files of any diver's name nor of a coded entry relating to a diver's name. The only way which we can identify an individual diver is by reference back to the diving company's records.

We are able to identify the diving company responsible for each dive from a coded entry in the computer file. There is however no reference anywhere in this report to an individual diving company and no means in the report of identifying a company with a dive or group of dives. This information is available only to the authors of the report and will not under any circumstances be divulged to the Department of Energy nor to any other party.

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Terms of Reference

In a survey limited to a study of offshore commercial air-diving activity in the UK sector of the North Sea during the two-year period 1982/83:

a) to determine whether any significant problem exists with regard to decompression sickness arising from diving schedules and practices currently used in North Sea operations, and,

b) if such a problem exists, to identify the particular schedules and practices responsible, and to advise on modifications and safe procedures.

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BACKGROUND TO THE PROJECT

1. Initial Concern.

During discussions at a meeting of the Diving Medical Advisory Committee (DMAC) in October 1982, several members reported that they had been approached for advice on the use of air diving tables at the "bottom end" of the air diving range. The sensing was that as air dives became longer and deeper, there was an unacceptably high incidence of decompression sickness (DCS). There were anecdotal reports of an increase in the number of neurological cases, and a suspicion that the USN Surface Decompression (Sur-D) Tables (when used for such exposures) were suspect.

At the following meeting of DMAC in February 1983, The Association of Offshore Diving Contractors (AODC) included in a list of seven research topics which should be given priority:

> "Preparation and publication of advice on more satisfactory surface decompression procedures and possible modifications to the USN schedules"

In view of the fact that almost all of the concern arose from anecdotal evidence, one of the authors of this report (TGS) was requested to carry out a pilot study, and a letter was sent from the AODC to all member companies in the following terms:

> "Many of the AODC members use the US Navy Surface Decompression Schedules, sometimes with 'modifications' for air diving operations. When used for depths of 100 feet and greater, these schedules sometimes result in a considerable increase in the number of incidents of decompression sickness, if used strictly as printed, hence the need for 'modification'.
>
> The number of incidents of decompression sickness using surface decompression has encouraged some doctors to begin a campaign to ban their use commercially.
>
> Acknowledging that improvements can be made, it is desirable for guidance to be generated to reduce decompression sickness before the lobby to ban the technique gains further momentum.
>
> I have been requested to solicit you for information on as many incidents as possible when using US Navy Surface Decompression Tables. In order to minimise any concern you may have regarding reporting incidents or near misses to a potential competitor, I propose that you send all communications (marked 'confidential') direct to the Institute."

The results of this pilot study were reported in detail in an elective medical student report (Macklin, 1983) and were described in outline at the Fifth Underwater Engineering Symposium (AODC) in Aberdeen (Shields, 1983); unfortunately, they raised as many questions as they answered. It had rapidly become clear that there was an alarming number of Type 2 (neurological) cases of DCS. However, nothing could be said of the incidence of the condition as no information was available on the total number of dives carried out. Furthermore, although the episodes of DCS tended to be clustered at particular depth and time exposures, no conclusion could be drawn on the safety of the decompression schedule used for these dives, as there was no information on the overall spread of diving activity in terms of depth and time.

Simultaneously with this study, and quite independently, the Department of Energy had set up its own study. Conducted by questionnaire, this examined the broader aspects of air diving incidents, to establish whether there might be areas of concern in addition to the decompression table or technique being used. As a result of these two studies, it was decided that a retrospective analysis of the dive logs for every air dive carried out offshore in the UK sector of the North Sea during the two year period 1982-1983 should be carried out. It was recognized that as such a survey would depend absolutely on the goodwill and co-operation of the diving contractors, it would have most chance of success if conducted by a wholly independent academic unit.

2. Continuing Concern.

For several reasons, it has taken much longer than originally anticipated to prepare this report. During this time the rumours of unacceptable damage have continued, and have tended to become directed towards one diving technique; surface decompression. These are best illustrated by quoting excerpts from a particularly irresponsible piece of journalism (Gillie, 1985) which received wide publicity:

> "North Sea divers are suffering brain and nerve damage because of poor techniques forced on companies competing for contracts. To save time and money, divers are being asked to come up quickly from the seabed without proper decompression so that replacements can go down to continue work with the minimum of delay."

> "The damage to brain and nerve results from the techniques of surface decompression. Divers come up quickly and have up to five minutes on the surface to clamber on deck, remove their gear and rush into a pressure chamber. While they are doing this, bubbles of gas are forming inside their bodies which may kill or maim them."

> "... during the few minutes when large numbers of bubbles are allowed to form, serious damage can occur to delicate nerve tissue. This can now be seen in pictures taken by a new technique using 'magnetic resonance'."

> "... medical studies show they may also suffer loss of hearing and intelligence."

> "The surface decompression technique was devised for use in emergencies, such as when divers run out of air or meet some other difficulty at depth and have to

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ascend rapidly. Now, though, it is routine among the 2000 divers in the North Sea and in other parts of the world."

"Since 1968 there have been more than 100 cases recorded in the southern sector of the North Sea, equivalent to one accident per 25 divers."

Also in this report, an eminent diving medical authority is quoted as saying:

"Surface decompression and diving on air below 100 feet should be banned."

The concern generated by this article reached Parliament, as quoted in Randall's Parliamentary Services on the 25th April 1985:

"Mr. Ward: asked the Secretary of State for Employment if he will take steps to prohibit the use of surface decompression techniques during North Sea diving operations except in the case of an emergency.

Mr. Peter Bottomley: A Government sponsored research project is currently being undertaken to examine the problems associated with decompression practices in North Sea diving operations and, as necessary, to advise on modification and safe procedures. Further action will be considered in the light of the research results."

3. Decompression techniques used in air diving.

There are three forms of decompression used in current commercial air diving practice.

a) No-Stop Diving.

The first, "no-stop diving" is limited to modest hyperbaric exposures (in terms of depth and time of the dive) where the inert gas uptake is insufficient to result in a DCS episode, even on an uninterrupted return to the surface. The threshold exposures for these dives have been well investigated and tested empirically over many decades, although it has been recognized recently that extremely long exposures at "sub-threshold depth" or a diving practice which includes multiple excursion from the dive depth to and from the surface, might result in "anomalous" DCS.

b) In-Water Stops

The second technique is to carry out a carefully controlled ascent through the water, at a rate which permits the elimination of dissolved inert gas to take place without any clinically detectable consequences. In practice, this is carried out by the diver ascending directly at a controlled rate (either on a shot rope or in a wet bell) to an intermediate depth in the water (the "first stop"), waiting

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there for a time determined by the particular decompression schedule in use, ascending to the next stop, waiting, ... and so on to the surface.

The technique has been used on countless dives over the best part of a century and where conditions are favourable has proven to be a very safe technique. There are however, two circumstances common in commercial diving practice which create potential danger. On long deep dives, the decompression time in the water can become excessive - for example, a dive to 160 ft. for anything between 40 and 50 minutes requires almost 100 minutes of decompression - and this can cause thermal problems. The second is that if there is any appreciable tide running, or if there is any wave swell, accurate depth keeping becomes extremely difficult, particularly on the crucial shallow stops.

c) Surface Decompression.

The third technique avoids these two problems by removing the diver from the water in a much shorter time than that required by the in-water decompression schedule for his dive, then recompressing him rapidly in a deck compression chamber (DDC) where he can carry out the remainder of his decompression. It takes advantage of the fact that there is always (in sub-saturation exposures) a latent period between the time of surfacing and the onset of symptoms of DCS, and makes the tacit assumption that lack of symptoms means lack of damage. It is this assumption which is challenged in the Sunday Times article (Page 2).

Contrary to a further statement in that article, surface decompression was not devised as an emergency procedure, but was first used (Saunders 1929) as a means of avoiding thermal problems on a deep military salvage operation where the water was particularly cold. The technique was formally adopted over the next few years (Hawkins, Shilling and Hansen, 1935; Hawkins and Shilling, 1936) and the raison d'etre for the procedure clearly stated:

> "The practice of surface decompression is desirable for a) it gets the diver out of the cold water and tides into a warm chamber where he can be more easily cared for; and b) it releases tenders and diving gear so another diver can be sent down sooner. Thus diving operations can be speeded up."

In these early procedures, the diver breathed air throughout the exposure. In 1951, new tables were published where the diver breathed oxygen during his time in the DDC (van der Aue, Brinton and Keller, 1945, van der Aue et al, 1951). This permitted a much shorter and more efficient decompression.

It is useful to list the advantages and possible disadvantages of the Sur-D technique.

Advantages

a) The diver spends a relatively short period of time in the water, and avoids thermal problems.

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b) The depth-keeping is precise, and the problems of large pressure swings close to the surface interface are avoided.

c) The diver is under direct observation during his decompression and can be more readily cared for in the event of illness or injury.

d) The use of oxygen allows a more rapid decompression.

e) The diver is dry and comfortable.

Disadvantages

a) There is the possibility of the diver suffering from oxygen toxicity.

b) The diver is supersaturated with gas during the surface interval, and there is no guarantee that circulating bubbles during this phase of the dive are not causing latent neurological damage.

4. Decompression Tables Used.

a) Air Diving

With one exception, where tables derived from French Navy experience are used, all the diving companies in the UK sector use the USN standard air diving table.

Very early decompression tables were calculated to give a linear ascent rate (Heller, Mager and von Schrotter, 1900), but these were soon abandoned in favour of the stage decompression method proposed to the Deep-Water Diving Committee of the British Admiralty by Haldane in 1907 (Boycott, Damant and Haldane, 1908). The "Haldane" tables were soon introduced into the United States Navy and were extended to cater for the deeper diving depths required by the salvage of the submarine F-4 at 304 ft. (French, 1916). These revised tables formed the basis of the Bureau of Construction and Repair ("C & R") table (Stillson, 1915) which is the parent of the USN standard air diving table.

The first major modification, with a revision of tissue half times involved, occurred in 1937 (Hawkins, Shilling and Hansen, 1935; Yarborough, 1937), with critical evaluation again in 1951 (van der Aue et al, 1951). The final modification which resulted in the current USN standard air diving table took place in 1956 (Desgranges, 1956).

We are not aware of any individual company modifications to this table, other than the addition of incremental safety factors (see below).

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b) Surface Decompression

The procedures developed by Hawkins Shilling and Hansen (1935) to permit surface decompression techniques using the C & R table were used until the adoption of the van der Aue tables by the USN in 1951 (van der Aue et al, 1945). Simultaneously with this introduction, van der Aue developed the technique of using oxygen in the DDC to shorten the decompression (van der Aue et al, 1951), the DDC depth being 40 ft. It should be noted that although the maximum bottom time permitted at the deeper depths remains the same in the later table, at shallower depths, the van der Aue table permits a longer maximum bottom time than the earlier Shilling procedures (for example, at 100 ft. the Shilling procedures were tested to a maximum of 90 minutes, whereas the van der Aue table allows up to 120 minutes).

This 1951 table is still published in unmodified form in the current USN manual and is used successfully in military diving operations. It proved less successful when adopted for commercial operations, and early experience led many of the diving companies to introduce their own modifications to the table in an attempt to decrease the DCS incidence. These modifications may include one or more of the following manipulations:

1). A compulsory in-water stop for ALL table schedules.

2). An increase in the initial DDC depth from 40 ft. to 50 ft. lasting for between 5 and 10 minutes duration. The procedure then returned to the USN schedule with a DDC depth of 40 ft.

3). Extension of "bleed time" to the surface following chamber recompression, from 2 minutes to between 5 and 30 minutes.

4). Empirical modifications to chamber oxygen times with no apparent rationale.

5). Calculation of extra depth/time schedules within the USN table profile.

6). Introduction of air breaks lasting 5 minutes, following every 20 minutes of oxygen breathing.

5. Safety factors applied to the decompression.

There are three areas in which factors can be applied to a dive to enhance the safety of the decompression:

a) the empirical modifications made to the tables in the light of experience by the individual diving companies. These include changes not only to the in-water profile, but also manipulations to the DDC phase of the decompression, as listed above.

b) the obligatory "rounding-up" of the actual dive depth and time to the next highest increment of the table, the element of safety increasing with the magnitude of the rounding up. The USN Diving Manual states:

"As assurance that the selected decompression schedule is always conservative - (A) always select the schedule depth to be equal to or the next depth greater than the actual depth to which the dive was conducted, and (B) always select the schedule bottom time to be equal to or the next longer bottom time than the actual bottom time of the dive."

It is reported (Hunter, Pope and Arsu, 1977) that USN divers are encouraged during training to be even more conservative:

"If the dive is within 2 feet or 2 minutes of the appropriate schedule, the next deeper and/or longer schedule should be used."

c) the random and impromptu addition of extra increments of depth and time beyond those actually required by the dive, universally known as "Jesus-factoring". In certain circumstances this practice (in terms of increment of time) is actually encouraged by the USN Manual.

"If the diver was exceptionally cold during the dive, or if his work load was relatively strenuous, the next longer decompression schedule than the one he would normally follow should be selected."

In some areas of commercial diving practice, such "Jesus-factoring" has become almost routine.

All these manipulations can be expected to add to the safety of the decompression. Unfortunately they confound any attempt at retrospective assessment of the efficacy of the original table.

6. Efficacy of the Decompression Tables.

The physics and physiology of gas movement in the body, and the pathophysiological consequences of bubble formation are still imperfectly understood. Individuals differ in their susceptibility to DCS and there are a large number of extraneous factors which might alter an individual's day-to-day susceptibility. It is clear that any attempt to describe this highly variable biological phenomenon by a mathematical formula - the decompression table - can only be approximate and therefore that no decompression table, unless it is extremely conservative, can guarantee complete protection from DCS for every diver, all the time. Published decompression tables are a compromise between an "acceptable" incidence of DCS and impracticably long decompression.

In considering "acceptability" one must take into account not only the overall incidence of DCS, but also its manifestations. Pain-only limb bends, although not desirable, might be acceptable as an occupational hazard of diving; neurological DCS with the possibility of cumulative and perhaps permanent damage, is not.

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a) Overall incidence of DCS

It is extremely difficult to obtain a reliable estimate of the efficacy of decompression tables from retrospective analysis of a large number of dives. One reason for this is that the tables are seldom dived as published and indeed, one is encouraged not to "push a table" to its limits, as would be done in a formal trial of the tables. A second difficulty is that a table might not be equally effective across all the depth/time schedules incorporated in it. In an analysis of 16,120 dives over the period 1971-1978 using the USN air-diving tables (Berghage and Durman, 1980), the overall incidence of DCS was 1.1%, but in particular areas - for example the 100 foot/60 minutes schedule - this could rise as high as 4.8%.

In sub-saturation diving, it has long been recognised that the decompression tables become less reliable as the severity of the hyperbaric stress increases - that is, as the dives become deeper and longer. (Davis 1962) In a recent predictive study of the incidence of air diving, Weathersby et al (1985) incorporated the experience of a large series of diving trials over two decades into a probabilistic model which they used to "test" the USN standard air table. Their conclusions are quoted:

> "air dives shallower than 150 ft. and shorter than 40 minutes are quite safe: the risk of DCS is less than one half of 1%. Dives longer than 2 hours and up to 80 ft. in depth, longer than 1.5 hours in the 90-120 ft. range and longer than 40-60 minutes and deeper than 120 ft. should produce bends at least 10% of the time. Dives that are both deep and long can result in DCS more often than not."

It is important also to consider any difference in the incidence of DCS from dives which, although of equal hyperbaric severity (measured in terms of the decompression time required), lie at opposite ends of the depth-time spectrum - that is, short deep dives compared with long shallow dives. In their analysis, Weathersby et al point out that:

> "it appears that short dives are quite safe even to a moderately deep depth, while long exposures are very risky regardless of depth."

b) Proportion of Type 2 cases

It is even more difficult to extract from published reports the proportion of Type 1 to Type 2 cases which one might expect from any particular diving activity. The reasons are two-fold. Many reports include cases from a wide range of diving activity, not only in terms of the depths and times of the dives but also different forms of hyperbaric exposure such as chamber and open-sea diving, different gas mixtures etc. An even greater source of difficulty is that many reports list all the symptoms and signs from which the diver might be suffering in the form of a percentage incidence, but as any one victim is probably suffering from more than one symptom or sign, these do not add up to 100%. It is frequently not possible from the layout of these reports to put an exact figure to the incidence of Type 1,

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Type 2 and combined Type 1/Type 2 cases. Review of a selection of these reports however, suggests an expected proportion of Type 2 cases of DCS following air diving would be in the order of 25% to 35%. That is, one might expect 1 case of Type 2 DCS for every 3 or 4 Type 1 cases (Duffner et al, 1946; Behnke, 1955; Slark, 1962; Rivera, 1963; Erde and Edmonds, 1975; Bayne, 1978; Kizer, 1980).

7. Thermal Protection.

Over the past ten years, the use of active diver heating by means of hot-water suits has extended from deep helium diving and is now common in the air-diving range. As a result, it is now possible for divers to remain at depth for much longer than previously.

There is concern however that the use of active heating, even on short dives, might result in an increased incidence of DCS.

The decompression tables were originally calculated for, and tested on divers who had only passive thermal protection. These divers would have been less warm while at depth and might consequently have absorbed less inert gas than a comparable diver wearing a hot-water suit. However, the diver wearing a hot-water suit and carrying out in-water stops might be expected to be at a decompression advantage over his passively protected buddy as he might eliminate more gas while warm on the stops. The same would not necessarily apply if he were on a Sur-D dive. It is unfortunate that the situation envisaged by the originators of the technique - that the diver is transferred to a warm chamber - does not always apply in commercial diving practice. The DDC might be located in an exposed situation and is frequently unheated. In these circumstances, cold could combine with the hyperoxia to reduce perfusion.

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METHODS

1. Parameters Recorded

The choice of parameters to be recorded in a survey of the incidence of DCS is a compromise between the ideal and the practicable. Ideally, one would wish to record not only every detail of the compression/decompression profile of every dive, but also the relevant past diving history, the physical state of the diver and a variety of environmental factors such as tide, sea state, water and chamber temperature, etc. In practice, we found that much of this information was either unavailable or was recorded in such a way that it would have taken an unacceptably long time to analyse each dive log. As a compromise, we collected the following information for each man-dive (a sample output of our computer records is shown in Appendix A).

1. Company code.
2. Date of dive.
3. Maximum depth.
4. Bottom time.
5. Decompression technique.
6. Type of decompression table.
7. Decompression table depth.
8. Decompression table time.
9. Surface Interval (where applicable).
10. Repetitive dive (Y/N).
11. Type of thermal protection.

If the dive resulted in decompression sickness, then the following additional parameters were recorded:-

12. Type of decompression sickness.
13. Time delay to therapy.
14. Therapeutic table.
15. Result of therapy.

Company code (1) was a coded number which allowed us to identify the dives belonging to a particular company, so that we could, if necessary, refer back to that company for further details. The coded number does not indicate the name of the company to which it belongs, and the key is known only to the authors of this report.

In order that dives could be grouped into year and month categories, and as a means of identifying a particular dive with the company concerned, a note was taken of the exact date of the dive (2).

Maximum depth (3) was defined as the maximum depth (measured in feet of sea water) attained during that particular dive. Where company policy was to measure depth in metres of sea water, depth was converted to feet by multiplying by 3.28. Maximum depth did not necessarily refer to the depth at which the diver spent most time.

Bottom time (4) was defined according to the USN air decompression table regulations and was taken as the total time elapsed (in minutes) from when the diver left the surface in descent to the time that he started his ascent.

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Decompression technique (5) classified a dive into one of four categories according to the type of decompression procedure used. Thus a dive could either be a no-stop decompression dive, an in-water decompression dive or a surface decompression dive using either air or oxygen.

Type of decompression table (6) was a coded number which identified the particular decompression table used. Companies who participated in this study used either their own decompression tables, or their own modifications to the USN tables. As some companies made further modifications to their tables during the two year span of this study, it was necessary to be able to identify the particular table used on every dive. The table is coded to guarantee company anonymity.

The decompression table depth (7) and time (8) refer to the specific decompression schedule used for a given combination of dive depth and bottom time, as listed in a decompression table.

Surface interval (9) was applicable to those dives in which surface decompression techniques were used. It was defined as the total time elapsed from a diver leaving his last in-water decompression stop (or if no in-water stop, the time he reached 30 feet) to the time that he reached the DDC recompression depth.

Repetitive dive (10) was a yes/no answer indicating whether or not the dive took place within 12 hours of the diver's previous excursion to depth. This corresponded to the definition of a repetitive dive under USN regulations.

Type of thermal protection (11) indicated whether the diver wore a dry suit/Unisuit (passively heated) or a hot water suit (actively heated).

If decompression sickness symptoms appeared following a dive then the manifestation category (type 1 or type 2) was recorded (12). This information was obtained from entries made in the dive logs and from company decompression sickness incident files. The diagnosis was reviewed in cases where medical details were available, either from company or outside sources.

Other parameters relating to decompression sickness were recorded from those dives in which the condition arose. Time delay to therapy (13) refered to the elapsed time from the end of the dive until the diver reported the onset of symptoms.

Therapeutic table (14) was a coded number which identified the precise therapeutic recompression table used to relieve the diver of the symptoms of decompression sickness. As not all companies used the USN tables, the number was encoded to ensure confidentiality of company therapeutic procedures.

Finally, the result of the therapy (15) was recorded as either the diver having been cured or not cured.

In addition to the parameters listed above, two derived variables were calculated for every man-dive. These were called the decompression penalty index and the safety factor index. Details of how these parameters were calculated is given below.

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2. Calculation of the Decompression Penalty Index.

In an attempt to obtain an index of the hyperbaric stress imposed by a dive which would take both depth and time into account, we decided to use the decompression penalty which that dive would have attracted had it been carried out conventionally by stage decompression, that is, the decompression time which would have been required by the USN standard air diving table.

In actual diving practice, decompression time is calculated by "rounding up" each dive to an increment of table depth and time. Thus the decompression time calculated from the tables is not exactly that required by the dive, but includes a "rounding up" factor. To avoid the error which this introduced into an estimate of "severity", we converted the incremental tables to a depth/time continuum. Thus a decompression time specific to the exact depth (nearest foot) and exact bottom time (nearest minute) of each dive could be obtained. The mathematical details of how the incremental tables were converted to a depth/time continuum is given in Appendix B.

We considered that the decompression time calculated in this way was a good measure of the hyperbaric stress resulting from a dive. Although derived from the decompression <u>time</u> required, we have chosen to express it without any dimension, and have simply called it the Decompression Penalty Index (D.P. Index). One reason for doing this is that we wish to avoid any possibility of these mathematically derived values being used in preference to the established practice of "rounding up" to the next table increment. Thus the D.P. Index is used as a measure of dive severity and as such can be used as a baseline to calculate the extent of any safety factors applied to the decompression time of a dive (see below).

3. Calculation of the Safety Factor Index.

It is common diving practice to apply additional decompression time to the dive decompression profile beyond that actually required, as an extra safety measure. There are three levels at which this "safety-factor" can be introduced: the obligatory "rounding up" of dive depth and time to the appropriate table increment; the modifications made to the "stem" decompression table by the diving company; and the random changes ("Jesus-factors") applied to individual dives by the dive supervisor. All of these act beneficially to lessen the incidence of DCS. It was therefore important that we examined this aspect of dive practice. A method had to be found which would allow us to combine these various forms of "safety factoring" into a single descriptive variable. The method chosen was to calculate the Decompression Penalty Index for the exact depth and time of each dive (as described above) and subtract this, from the calculated Decompression Penalty Index for the table schedule on which the diver was actually decompressed. This variable was called the Safety Factor Index (S.F. Index) and again was given no dimension. Thus we have:

Safety Factor Index = Schedule D.P.Index minus Dive D.P.Index

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It should be noted that the S.F. Index does NOT take into account any possible benefit from the company's decompression tables where these are more conservative than the USN standard air diving table nor any possible advantage of the surface decompression procedure nor any company modification to surface decompression techniques.

4. Source Of Data.

It was fundamental to the validity of this survey that as complete a record of dives as possible was collated from every diving contractor operating in the UK sector of the North Sea during 1982/1983. A 'representative sample' of dive logs was not acceptable. The A.O.D.C. furnished us with a list of diving contractors known to have been in operation during the survey period. This list formed the basis for the pool of information used in the survey.

It was realised that to collate the large volume of detailed information would be very time consuming. It was not our intention for this workload to be carried by the diving contractors and to this end a detailed letter was sent to all known contractors explaining that we would ourselves undertake to extract the information from company dive records. This raised the question of commercial confidentiality, but assurances were given to the industry that anonymity for both divers and contractors would be upheld.

We are pleased to record that in almost all instances we were given the fullest co-operation and that several of the major contractors permitted completely free and unsupervised access to their confidential files. We had difficulty with only two companies, one small and one large. In the latter case we were given a nine-month "run-around" which was a major contribution to the delay in producing this report.

The individual dive logs for every man-dive carried out by the diving contractors were examined, and the relevant information extracted from them. Those dive logs where some of the information required was not available (for example, when the dive supervisor failed to complete the log properly) were not included in our analysis. This only applied to a small percentage of the total dive logs, amounting to between two and three hundred man-dives (and did not include any cases of DCS).

5. Validation of Data.

Although we cannot be completely certain, we feel confident that we have collected almost all of the dive logs available. On the occasions when records have gone missing, the companies were able to indicate the extent of the missing data. This did not amount to more than four hundred man-dives in total.

The initial diagnosis of DCS, and the decision whether it was a Type 1 or Type 2 manifestation, was originally made offshore by the diving supervisor. In the majority of cases, we were furnished with sufficient details from company incident files to allow us to review the diagnosis, and in several instances, we revised the classification.

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For example, we found some cases labelled as Type 1 DCS where the diver, although initially presenting with joint pain only, later developed neurological symptoms. There was also a case with no evidence whatsoever of neurological involvement which had been labelled as Type 2, presumably on account of the diver being treated on a long oxygen table (USN 6).

Some cases were discarded altogether - for example, where a diver having developed DCS-like symptoms and having been recompressed as a "trial of pressure" at the time of the incident, was labelled as having had DCS, but in retrospect the symptoms clearly arose from some other medical condition.

Several of the cases of DCS recorded in company dive logs were discarded for other reasons and do not appear in our analysis. Four cases occurred as a result of dry compression chamber dives and were omitted as being irrelevant to any study of in-water activity. Four cases arose in circumstances where the appearance of DCS was inevitable: blow up from depth (1 case); delayed decompression due to fouling (1 case); and omitted in-water stops (2 cases). Although these cases contribute to the morbidity rate, they clearly do not provide a test of any decompression schedule or dive procedure, and have not been included in our calculation of incidence.

Because of the relatively small number of DCS cases, any inadvertent omission, or deliberate concealment of cases, would significantly alter the incidence. Deliberate concealment could occur either offshore, at a diver or supervisor level, or onshore at a company level. We are aware of the circumstances which might lead to a diver failing to report Type 2 symptoms - the financial penalty of an enforced lay-off following a therapy for Type 2 DCS, and the possibility of being considered unfit to dive following several incidents - but other than by anecdotal accounts picked up in general conversation with divers, are unable to make any estimate of the extent of the practice. Similarly, for cases where a diver and supervisor agree to the use of oxygen on the surface for minor symptoms.

We do however have a check on any inadvertent omission or attempt at concealment by the companies. In most episodes of DCS treated offshore (and in almost every Type 2 case) advice is sought from the company's medical advisor. Frequently, we were already aware of these cases as many had been dealt with by medical colleagues in our own organisation in Aberdeen. In other instances, we were able to discuss cases with the doctors involved, and are happy to report that we are not aware of a single case of DCS of which we had not been notified previously by the companies.

6 Data Analysis.

Dive details were transcribed directly from company records into a computer database. A commercially available software package (Condor Computing Corporation, Ann Arbor, Michigan) was used as a framework from which the data could be manipulated. The Condor database management system is particularly powerful in data selection and sorting and was extremely useful for this type of analysis.

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Initial analysis of the database was directed at a description of diving practices used by the contractors. Basic details of dive depths and times and the corresponding decompression table schedules being employed were tabulated. Furnished with this background information, more specific questions relating to decompression sickness could be asked. For example, the incidence of DCS in relation to such variables as thermal protection or decompression technique were examined. These data are presented in graphical and tabular form.

7. Statistics.

The nature of the data which make up this study, does not permit the use of simple statistical techniques.

The pattern of diving activity reflects particular contracts where the depth might have been fixed or the time might have been a function of the specific task which the divers had to carry out. Neither depth nor time fall into a normal (nor any other mathematically definable) distribution.

As a result of our guarantee of anonymity (and a practical difficulty in identification of individual divers from the offshore dive logs), we are unable to follow the activity of the individual diver. Thus we are unaware of the spread of individual activity over the total number of dives recorded. One diver might have carried out a thousand of these dives, or only ten. Thus the data are not random - each entry does not represent a discrete record as we do not know how many times each diver dived.

Furthermore, in our analysis of DCS incidents, we are aware of five divers who suffered more than one episode. Thus, the 79 cases of DCS recorded do not represent discrete events.

Statistical analysis is further confounded because the factors which influence the incidence of DCS do not act independently. For example, surface decompression techniques tend to be used on the more severe dives, as may also hot water suits.

If the number of incidents (and dives) on this survey were ten times greater, it might be possible to adjust for the strength of variables by techniques such as principle components analysis (Hope, 1968), but our numbers are still too small. We have decided therefore to present our results descriptively, without any attempt at determining "significance" or statistical validity. The only parameters where we have indicated a dispersal about a mean by use of standard deviation are the D.P. and Safety Factor Indices, as these follow a Gaussian distribution.

Where we have attempted to analyse the influence of different factors, we have done so by means of subsets which eliminate as many variables as possible. Should any further manipulation of the data displayed in the figures be required, we have in all instances provided the raw data in the tables of Appendix C.

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RESULTS

1: PATTERN OF DIVING ACTIVITY

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PATTERN OF DIVING ACTIVITY

1. Records on File

We have collected and analysed the logs of 25,740 man-dives. These are summarised, together with the accumulated bottom time, in Table 1.

Table 1

North Sea UK Sector Air Diving Summary

	1982	1983	Total
Number of Dives	10,853	14,887	25,740
Total bottom time (hours)	13,226	16,767	29,993

There was an increase in diving activity between 1982 and 1983 of 37% in terms of numbers of dives and 27% in terms of bottom time.

2. Decompression Procedures

The records were classified according to whether the dives did not require decompression stops ("no-stop"), or whether decompression was by in-water stops or by surface-decompression. These are shown in Figure 1, and the exact numbers, together with the total bottom-time in each category, in Table C1 of Appendix C.

Of the dives requiring decompression stops, much the larger proportion were carried out by surface decompression.

FIGURE 1 a): DIVING ACTIVITY ACCORDING TO DECOMPRESSION PROCEDURE DURING 1982

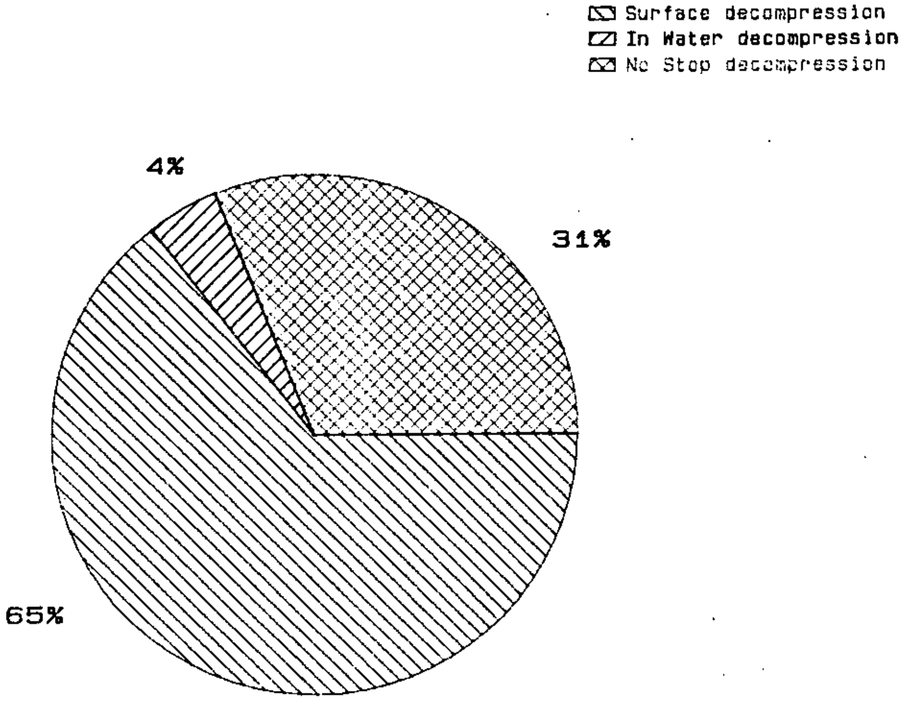
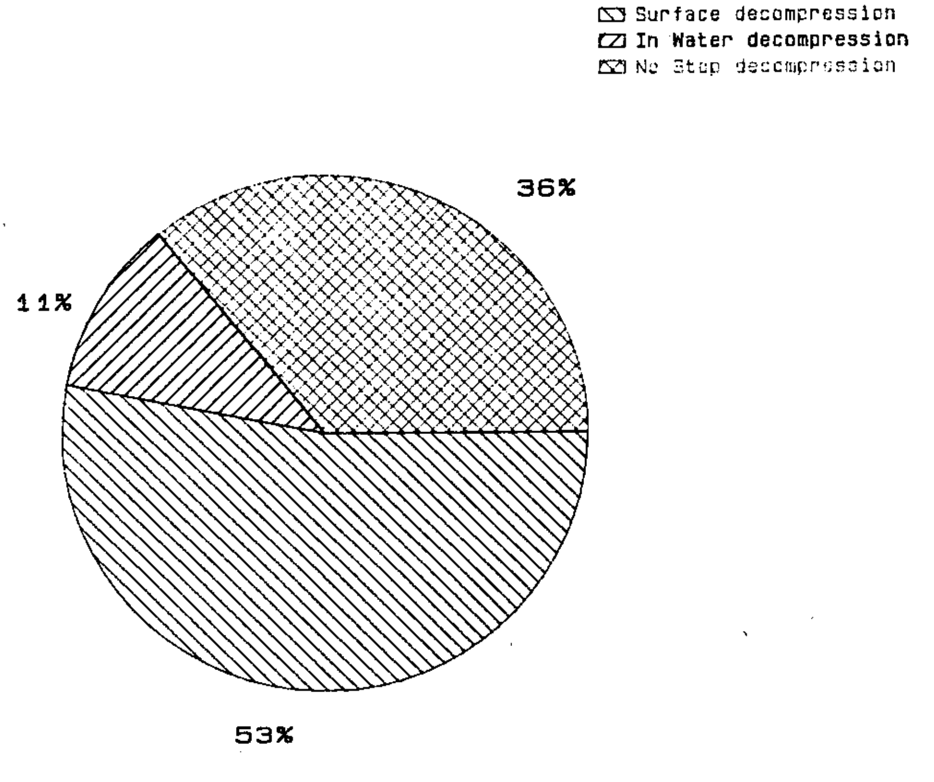


FIGURE 1 b): DIVING ACTIVITY ACCORDING TO DECOMPRESSION PROCEDURE DURING 1983



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3. Diving Activity Month-by-Month

The pattern of diving activity on a monthly basis is shown in Figures 2a (1982) and 2b (1983). Precise values are given in Table C2 of Appendix C.

The increased diving activity in 1983 followed the same seasonal pattern as 1982.

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FIGURE 2 a): PATTERN OF AIR DIVING DURING 1982

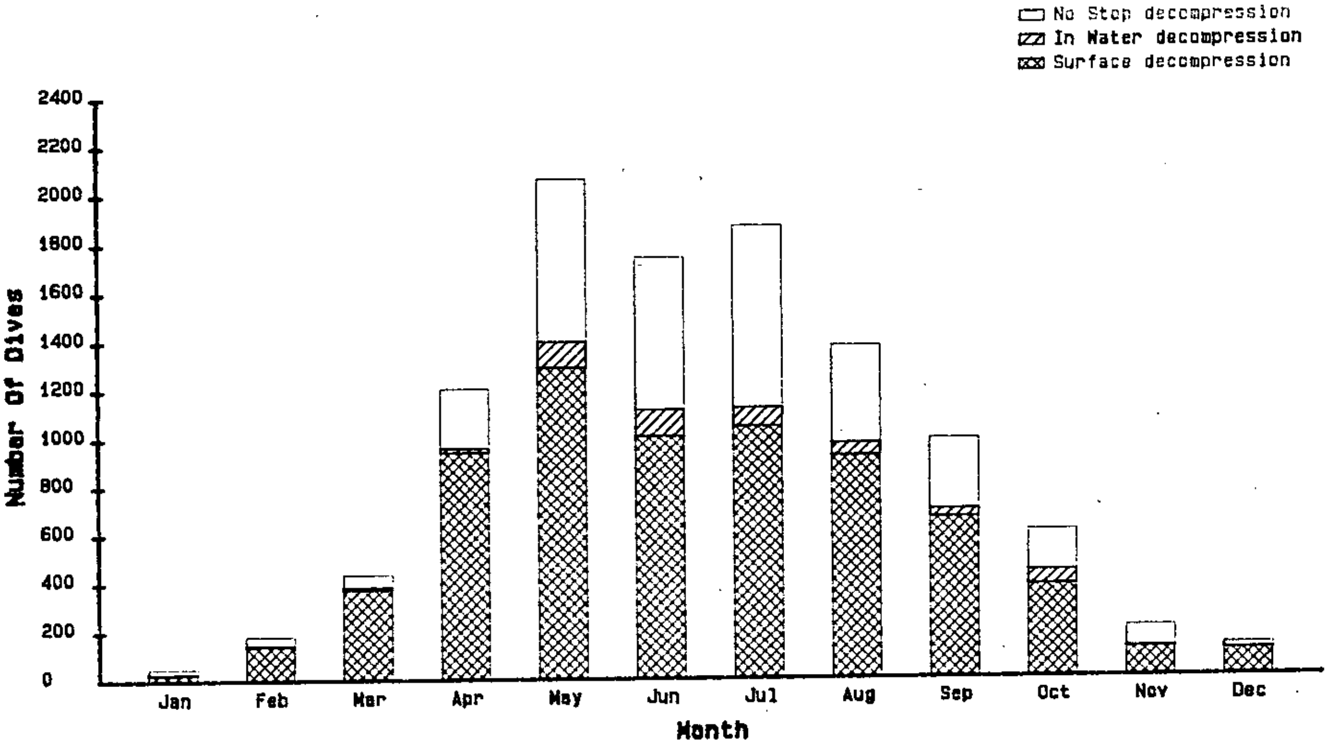
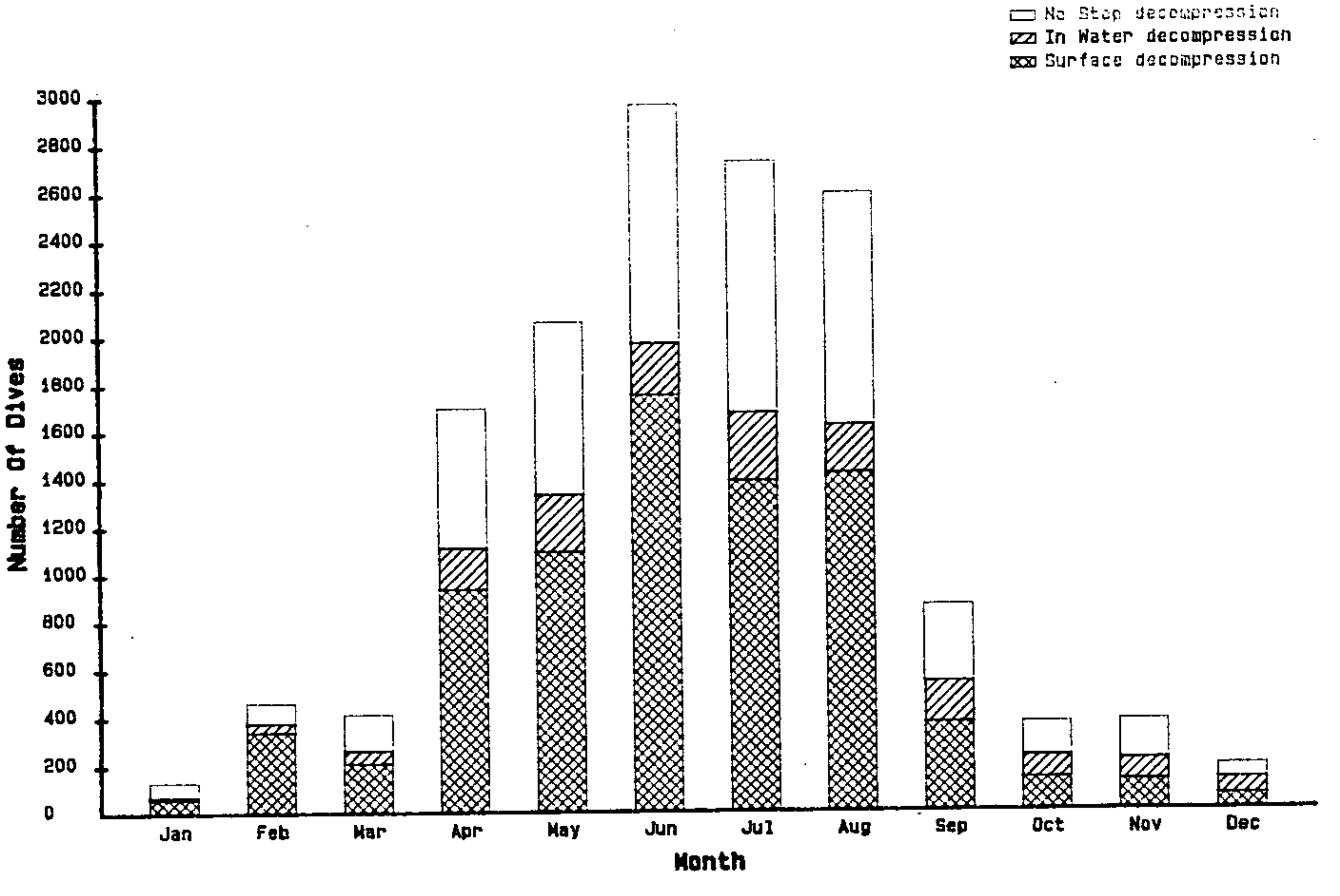


FIGURE 2 b): PATTERN OF AIR DIVING DURING 1983



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4. Diving activity in terms of dive depth and time

All of the dives on file with bottom times up to 220 minutes (n = 25,710) are shown in Figure 3 with dive depth plotted against time, and classified according to the decompression procedure. There were 30 dives with a bottom time greater than 220 minutes, the longest being 450 minutes.

Although there is some overlap in activity, it is very obvious from Figure 3 that dives carried out with in-water decompression tend to represent a less-severe hyperbaric exposure than those carried out using surface decompression.

A measure of this hyperbaric stress is given by the two curves superimposed on the scatter-diagram to represent those dives which (in conventional stage-decompression terms) would require a decompression time of 30 and 60 minutes - had all the dives been carried out as if they were in-water dives (see under "DP Index" Page 12).

Table 2 gives the frequency distribution of two dive procedures, in-water and surface decompression, falling into three categories of decompression penalty - A) up to 30 minutes, B) between 30 and 60 minutes, and C) greater than 60 minutes. The mean ($\pm$ S.D.) value of the DP Index for the in-water decompression dives was 5.9 $\pm$ 8.1, while that for the surface decompression dives was 32.9 $\pm$ 19.0. Sur-D dives are thus seen to incur a greater hyperbaric stress than in-water-stop dives.

Table 2
The relationship between the type of decompression procedure and the Severity of Hyperbaric Stress (DP Index)

Decompression Penalty Index	Number of Dives					
	In-water Decompression			Surface Decompression		
	1982	1983	Total	1982	1983	Total
< 30	457	1,624	2,081	3,143	3,956	7,099
31-60	10	21	31	3,349	3,321	6,670
> 60	2	2	4	504	618	1,122

The pattern of diving activity in terms of the depths of the dives is shown in Figure 4, and in terms of duration of bottom time, in Figure 5. Details of these dives in terms of depth (with average dive time) are given in Table C3 and in terms of time (with average dive depth) in Table C4 of Appendix C.

FIGURE 3: DIVING ACTIVITY IN TERMS OF DIVE DEPTH AND TIME

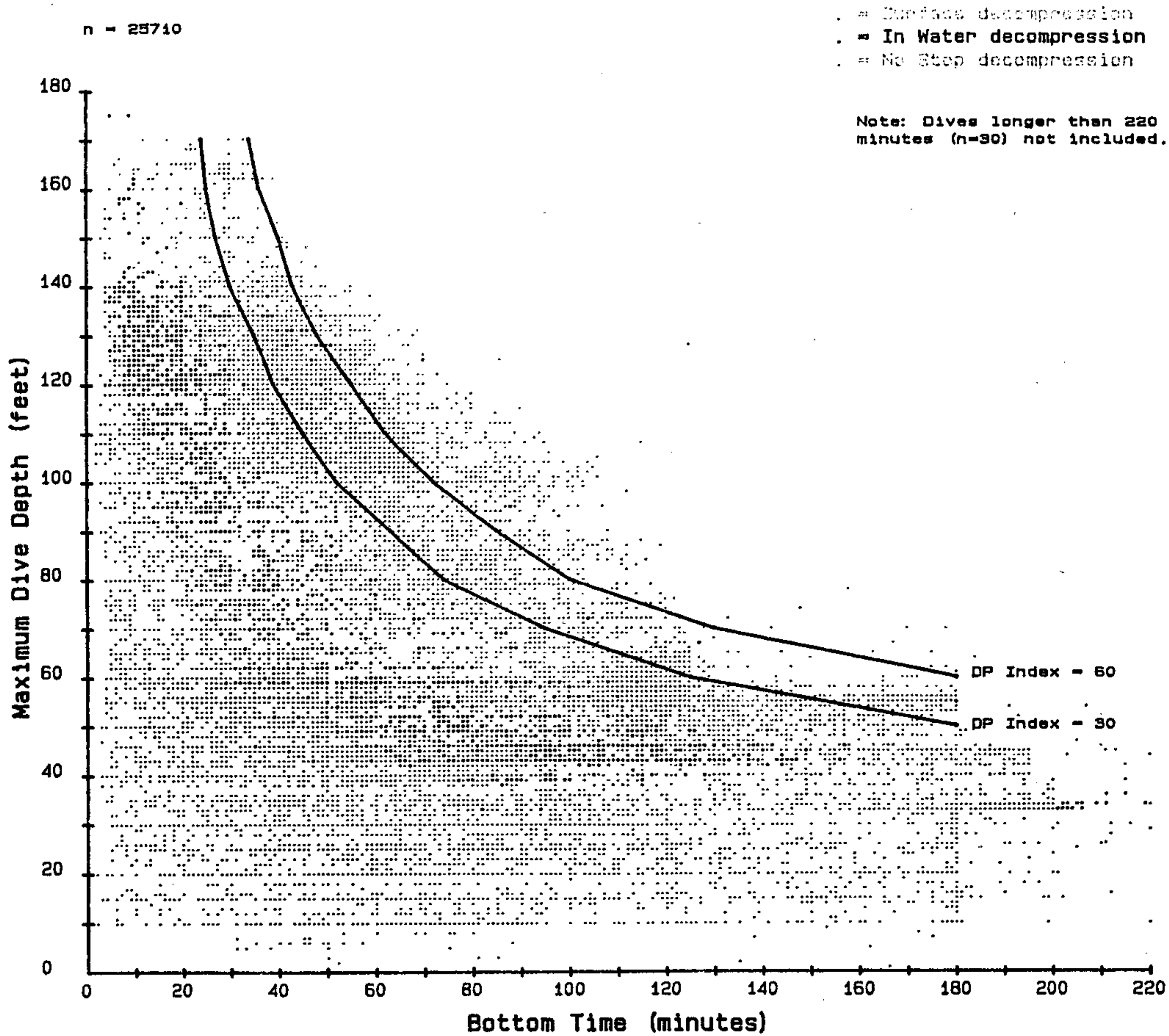

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FIGURE 4 a): DISTRIBUTION OF AIR DIVES BY MAXIMUM DEPTH DURING 1982

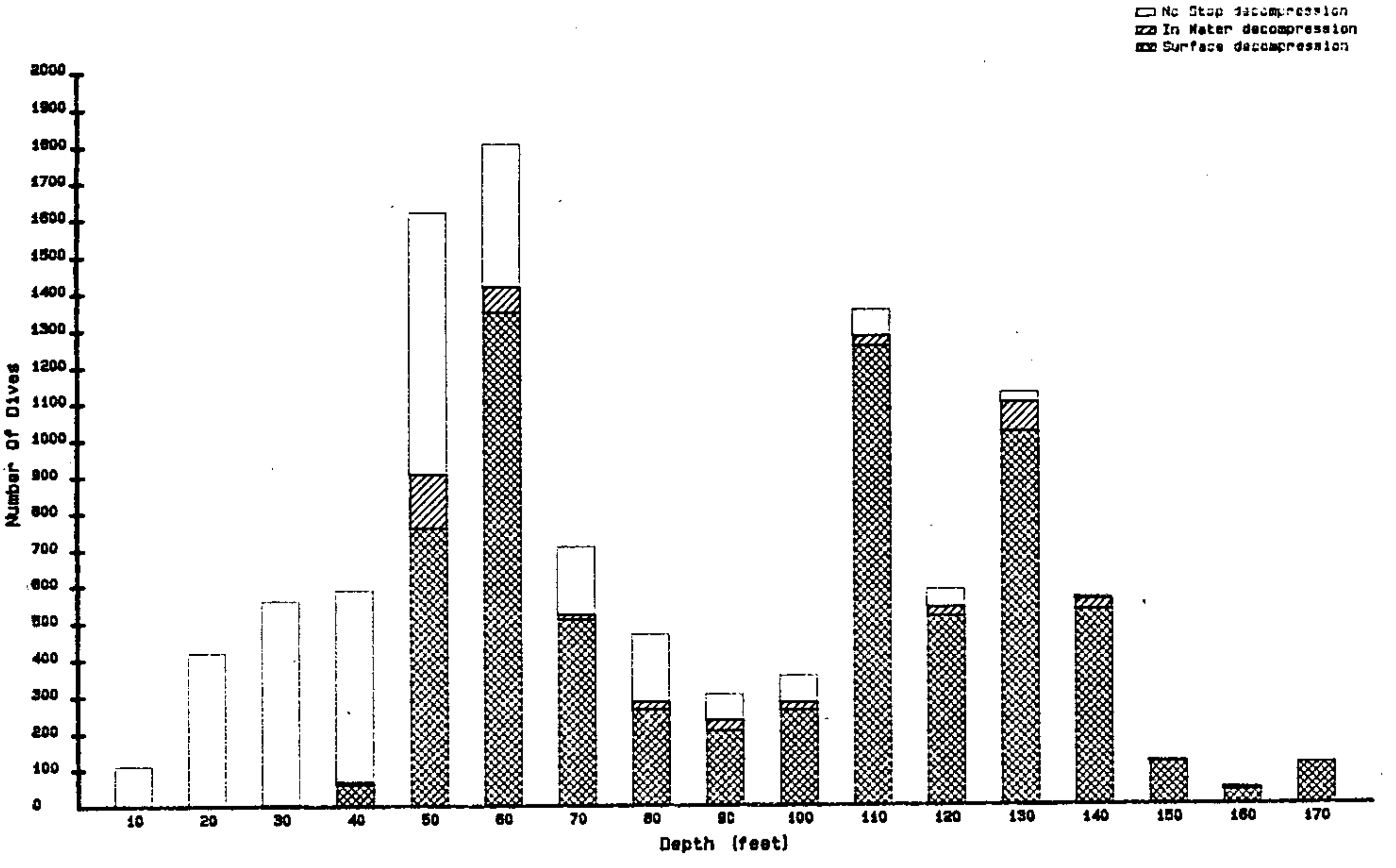

FIGURE 4 b): DISTRIBUTION OF AIR DIVES BY MAXIMUM DEPTH DURING 1983

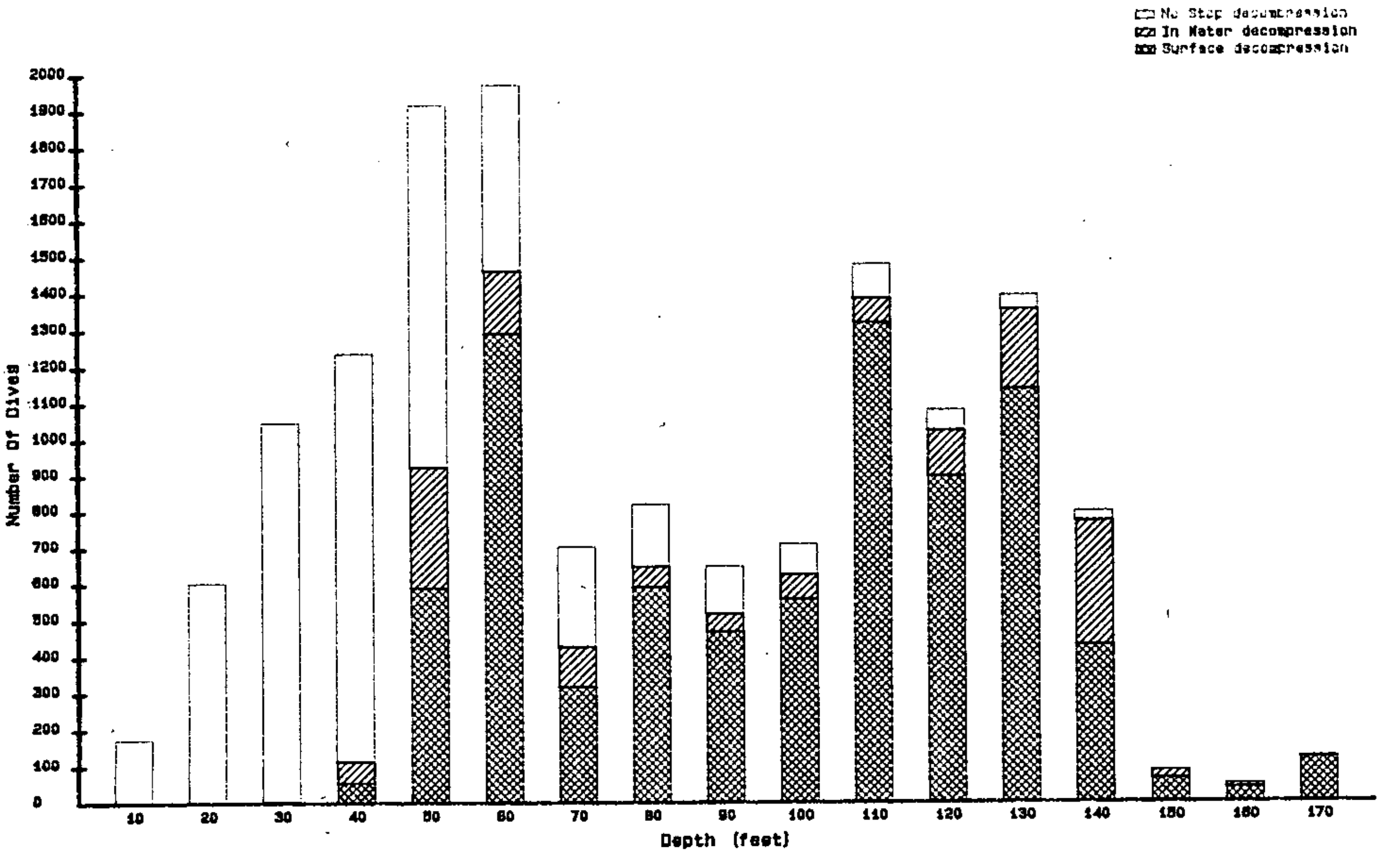

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FIGURE 5 a): DISTRIBUTION OF AIR DIVES BY BOTTOM TIME DURING 1982

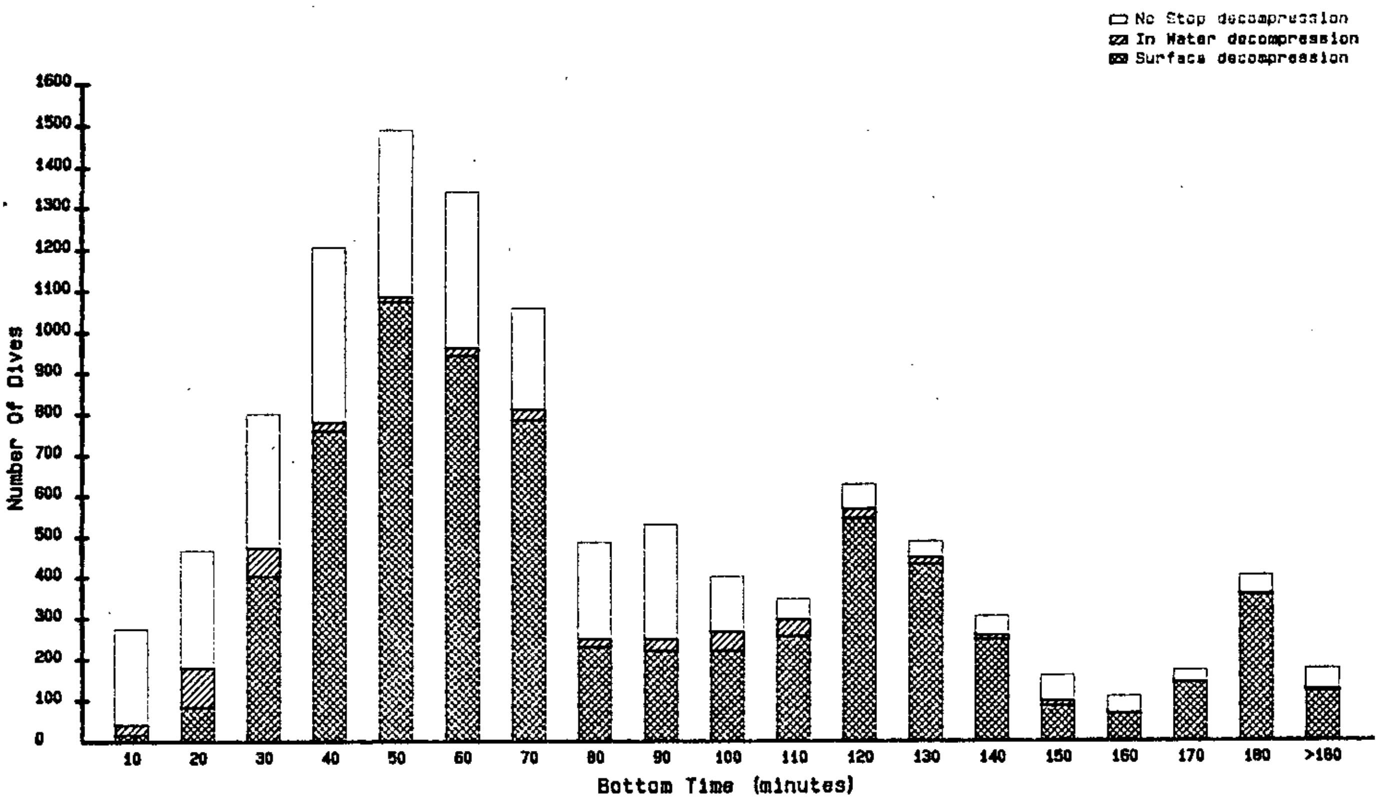
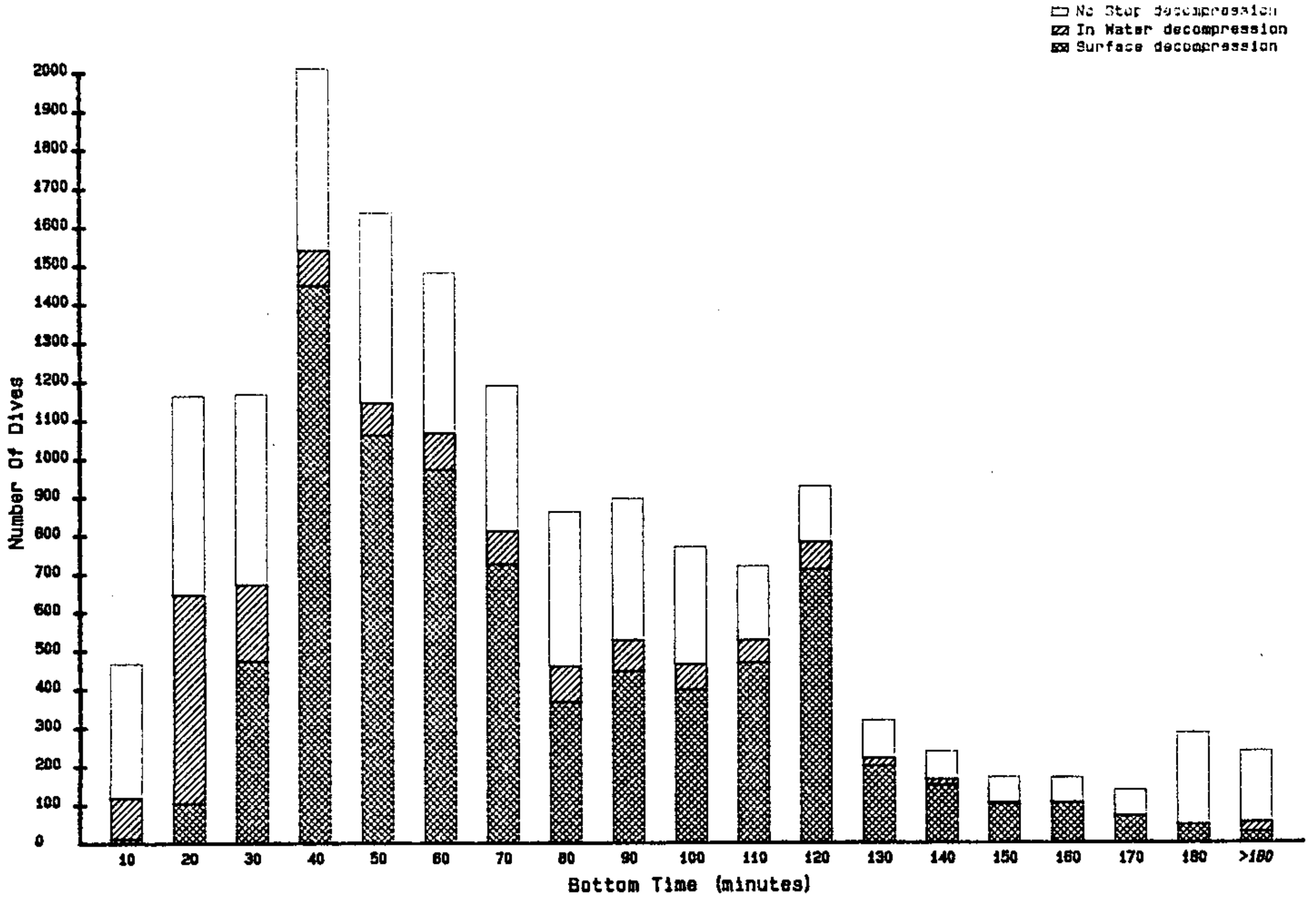


FIGURE 5 b): DISTRIBUTION OF AIR DIVES BY BOTTOM TIME DURING 1983



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5. Application of decompression "safety factors"

We are unable to make specific comment on the effect of any individual company's modifications to the tables. The main reason is that the number of variations on the "stem" table results in subsets with too small sample sizes for meaningful analysis. In addition, the anonymity of each company would not be preserved, as they could readily be identified from the modified tables. We are satisfied however, that although the numbers in the database are still too small to determine whether any one company's tables are better than any other's, there is no evidence that any company is using a dangerously bad set of tables.

We have made two attempts to quantify the extent of safety factors applied to the individual dives.

The first looks at the additional whole increments of depth or time added to the decompression schedule beyond that required by the dive - the "Jesus factor". For example, a 132 foot/27 minute dive might be decompressed on a 140 foot/40 minute table, providing 1 extra increment required beyond the 140 ft./30 minutes required "by the book". Interestingly, although the USN diving manual recognises this practice only in terms of additional time, it appears to be almost equally as common in commercial practice to apply an additional increment of depth as of time. Both, however, are frequently applied, and it is this circumstance, where the "factoring" has to be expressed in terms of two independent (but not unrelated) variables for each dive which makes the figures unmanageable and display impossible.

We have analysed the extent of the practice in terms of the number of increments of depth <u>OR</u> time applied to the tables, without any attempt to relate or integrate the two variables. A summary of these results is shown in Tables 3 and 4, with fuller details in Tables C5 and C6 in Appendix C.

Table 3

Application of a "Jesus-Factor" by Increment of Dive Depth
(values expressed as percentage of sample)

Decompression Procedure	Year	Sample Size	Increment of Table Depth beyond that "required"			
			0	+1	+2	>2
In-water	1982	469	72.7	26.2	0.9	0.0
	1983	1,647	54.6	44.3	0.7	0.1
Surface decompression	1982	6,996	67.5	32.0	0.4	0.1
	1983	7,887	61.6	36.2	1.9	0.2

Table 4

Application of a "Jesus-Factor" by Increment of Bottom Time
(values expressed as a percentage of sample)

Decompression Procedure	Year	Sample Size	Increment of Table Time beyond that "required"			
			0	+1	+2	>2
In-water	1982	465	60.6	29.7	7.7	1.9
	1983	1,639	68.0	28.4	3.0	0.7
Surface Decompression	1982	6,950	53.2	31.7	8.3	6.8
	1983	7,824	43.9	43.8	6.0	6.3

Our second attempt at quantifying the element of safety built in to each decompression, used an index which took into account both the "obligatory" safety element and the "Jesus-factor" applied. The numerical value of the index thus obtained (the "Safety-Factor Index"), is in fact the number of minutes of additional decompression time carried out on each dive in excess of that actually required by the dive, had the diver been decompressed using in-water stops (see page 12).

Values for the several types of dive are shown in Table 5.

Table 5
A comparison of the Safety Factor Index between In-Water and Surface Decompression techniques at various depth ranges

Dive Details		Safety Factor Index Mean ± SD (range)	
Type of Decompression	Depth Range	1982	1983
In-water	< 100ft	8.5 ± 5.4 (0-27.9)	8.2 ± 5.3 (0-41.3)
	100-130ft	8.5 ± 4.7 (2.5-38.1)	7.9 ± 7.1 (0-45.4)
	> 130ft	13.3 ± 14.3 (0.1-57.6)	6.5 ± 5.6 (0-48.3)
Surface Decompression	< 100ft	30.1 ± 15.7 (0-265.9)	30.0 ± 12.6 (0-106.3)
	100-130ft	29.7 ± 13.0 (0-80.4)	29.0 ± 12.9 (0-107.7)
	> 130ft	25.8 ± 11.7 (0-89.1)	28.2 ± 9.48 (0-66.4)

The most obvious feature of this table is the much greater magnitude of the Safety Factor Index being applied to Sur-D dives. There are two main elements to this.

The USN Sur-D tables as used by most companies do not have an entry shallower than 70 ft. and consequently all dives using Sur-D shallower than 70 ft. must be incremented up to that table entry.

The effect of this is a very large safety index in the "dives less than 100 ft." category. The second element is a reflection of the "Jesus-factoring" in terms of increments of time applied to Sur-D dives - see Table 4.

We have also looked at those dives which were carried out to a depth or time which by chance fell precisely on an increment of the tables (i.e. to a round number of tens of feet, or tens of minutes). Despite the prevalence of "Jesus-factoring", a remarkably large number of these dives were decompressed on a schedule exactly equal to the dive depth or time. Although this practice is legal, it reduces the element of safety, in terms of one of the variables, to zero.

The results are presented in Tables C7 (Depth) and C8 (Time) in Appendix C. An interesting observation is that, although there was in general no compensatory element applied in terms of the alternative variable for dives using in-water stops, the practice of such "Jesus factoring" was common where Sur-D was used. Three of these dives (Table A8) with a zero increment of time, resulted in DCS.

We have several records of dives having been decompressed with a zero safety margin in both variables (for example, a 140 foot/30 minutes dive decompressed on a 140 foot/30 minutes table). There were no cases of DCS arising from these dives.

6. Cases recorded

Following the adjustments described on Page 13, we have accepted 79 cases as being definite episodes of decompression sickness (DCS); 44 with Type 1 manifestations, and 35 Type 2. This information is displayed in Table 6.

Table 6

Episodes of DCS During The Survey Period

Year	Cases of Decompression Sickness		
	Type 1	Type 2	Total
1982	17	19	36
1983	27	16	43
Total	44	35	79

7. Identification of contributory factors

We have examined four major factors which might influence the incidence and type of DCS. These are:

1) the severity of the hyperbaric stress (i.e. the depth and time of the dive),

2) the decompression procedure used,

3) the extent of the decompression safety factor applied to the dive, and

4) the type of thermal protection used.

From the point of view of analysis, it is unfortunate that these variables do not act independently (see the statement on statistical analysis on Page 15). For example, Figure 3 shows that dives which were carried out using surface decompression procedures tended to have a more severe hyperbaric exposure than those which used in-water decompression. It could follow therefore that any increase in incidence of DCS following surface-decompression dives could be a function of the hyperbaric stress rather than the decompression procedure *per se*.

For the presentation of the results, we have chosen to demonstrate the influence of these four factors on the incidence of DCS as if they acted independently (Sections 8-11 below). In Sections 12 and 13, we have attempted to separate the individual factors by use of subsets of data which eliminate one or more variables. We fully recognise the difficulty which this creates in terms of small numbers.

8. Cases of DCS related to severity of hyperbaric stress

All 79 cases of DCS are plotted in terms of the depth and time of the dives in the scatter diagram in Figure 6. As in Figure 3, the curves representing DP Indices of 30 and 60 are superimposed as an indication of hyperbaric stress. Type 1 and Type 2 cases are identified, and those cases arising from in-water-stop dives are indicated by arrows. The single case arising from a no-stop dive is at the extreme right of the diagram (at 212 minutes).

The incidence of all cases of DCS relative to the hyperbaric stress is shown in Figure 7, with precise values presented in Table C9 in Appendix C.

Figures 8(a) and (b) show the distribution of all cases in 1982 and 1983 respectively.

We have been asked to determine the incidence of DCS in terms of 10-foot increments of depth of the contributory dives. This has been calculated, but is presented with the caveat that little can be drawn in conclusion because of the very small numbers in the various subsets of the tables. As only 6 cases of DCS have arisen from decompression techniques other than Sur-D, we have calculated results only for Sur-D dives. The precise values are given in Table C10 in Appendix C, with graphical presentation in Figure 9. Results have also been calculated in terms of increments of bottom time, and are given in Table C11 and Figure 10.

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FIGURE 6: DEPTHS AND TIMES AT WHICH D.C.S. OCCURS

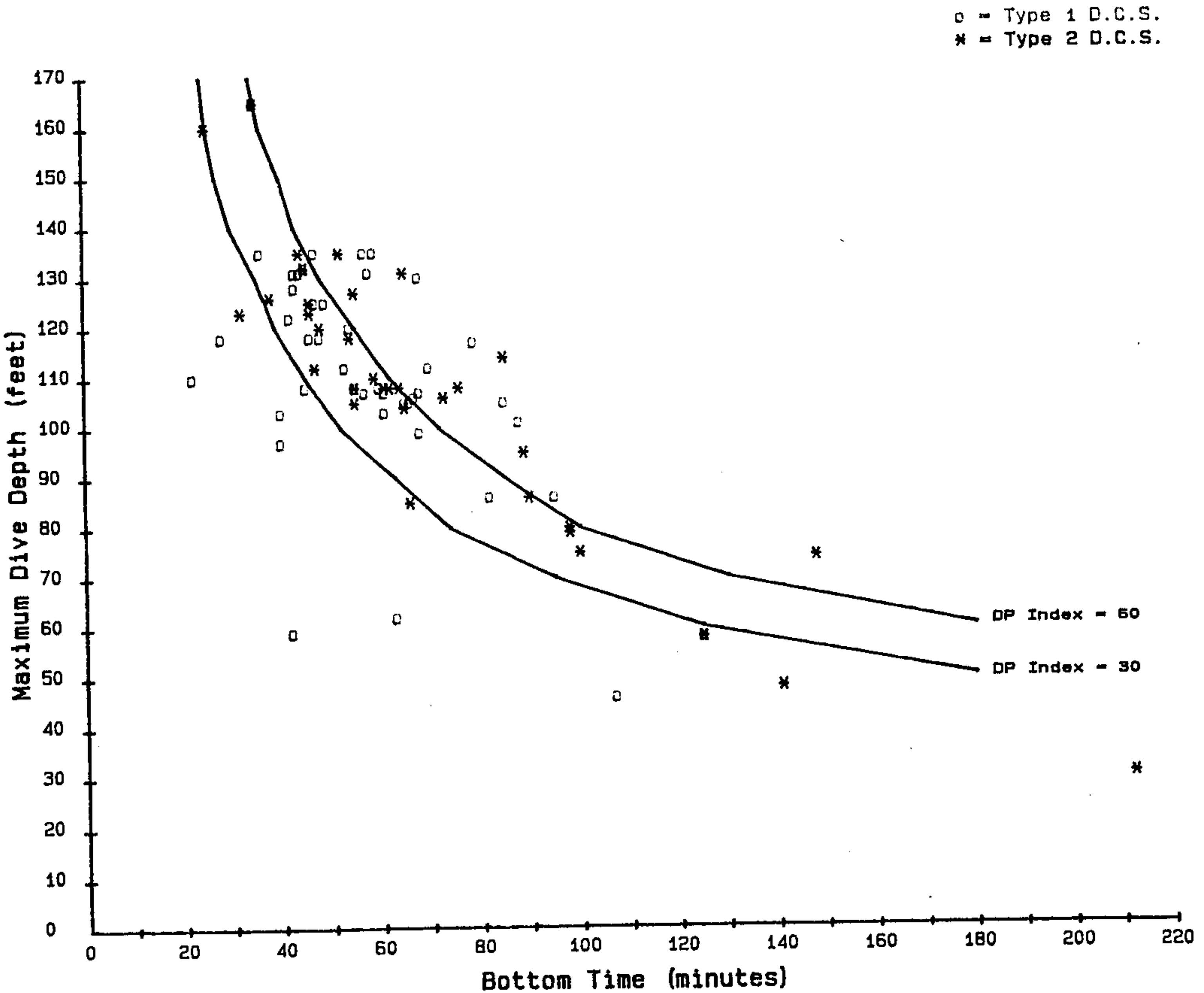

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FIGURE 7: INCIDENCE OF D.C.S. RELATIVE TO THE SEVERITY OF THE DIVE

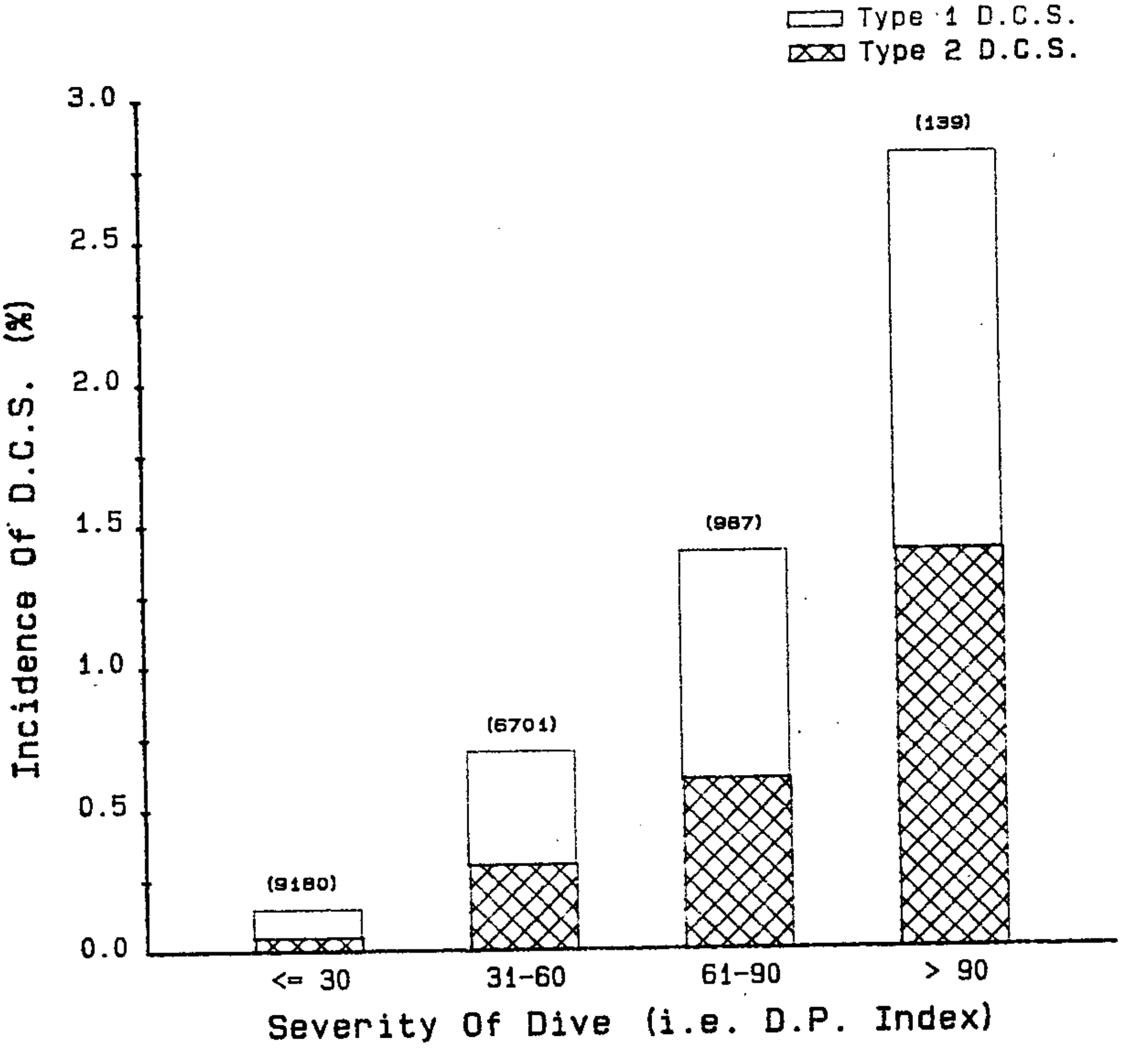

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FIGURE 8 a): DISTRIBUTION OF DECOMPRESSION SICKNESS BY MAXIMUM DEPTH DURING 1982

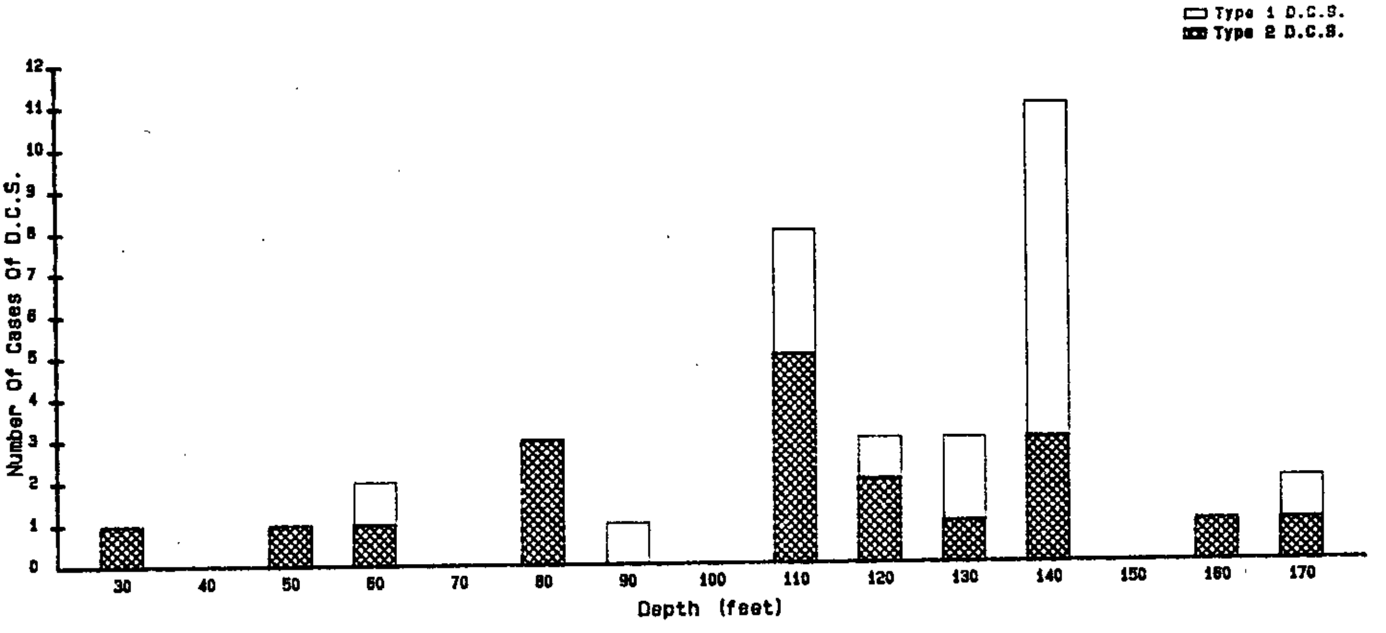

FIGURE 8 b): DISTRIBUTION OF DECOMPRESSION SICKNESS BY MAXIMUM DEPTH DURING 1983

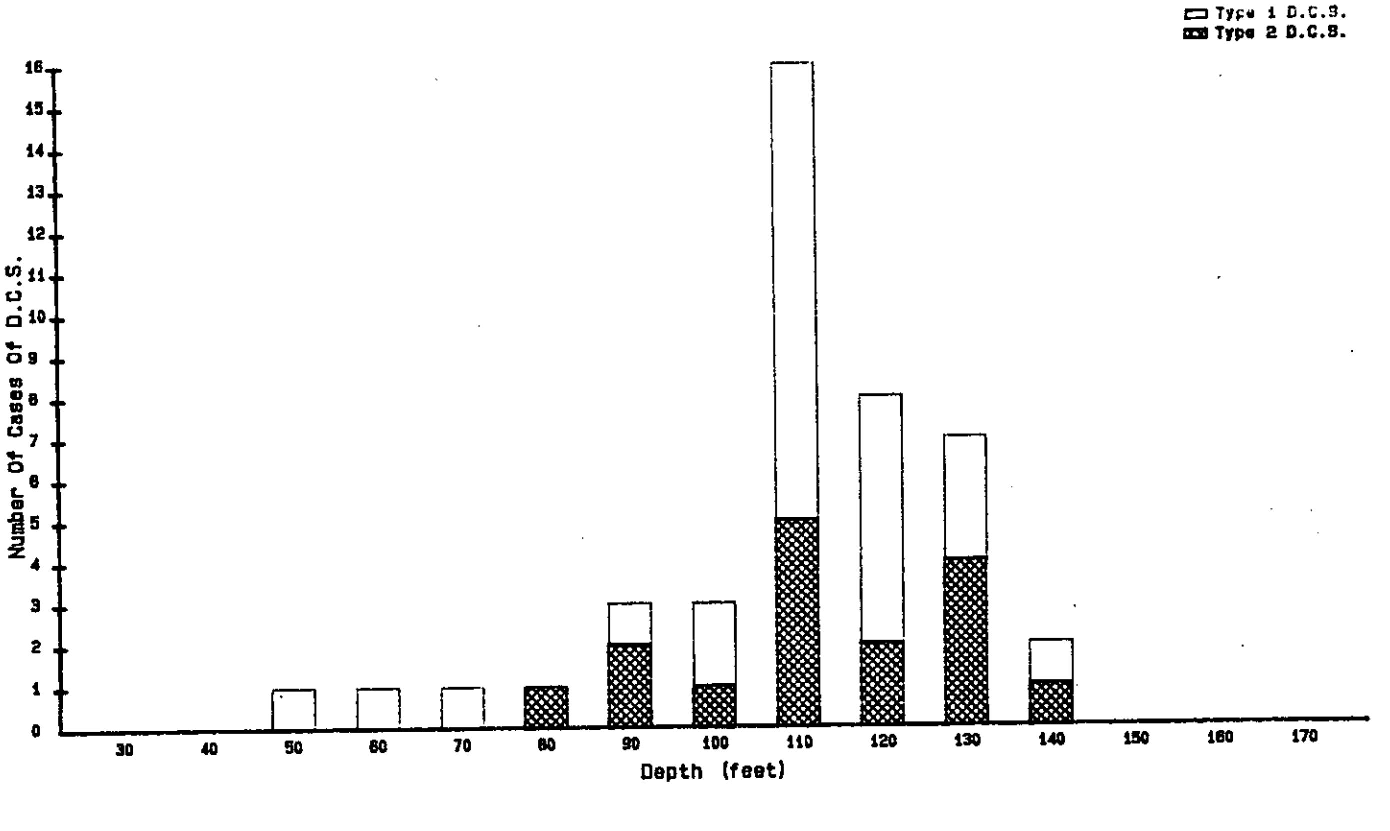

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FIGURE 9 a): INCIDENCE OF D.C.S. FOLLOWING SURFACE DECOMPRESSION DURING 1982

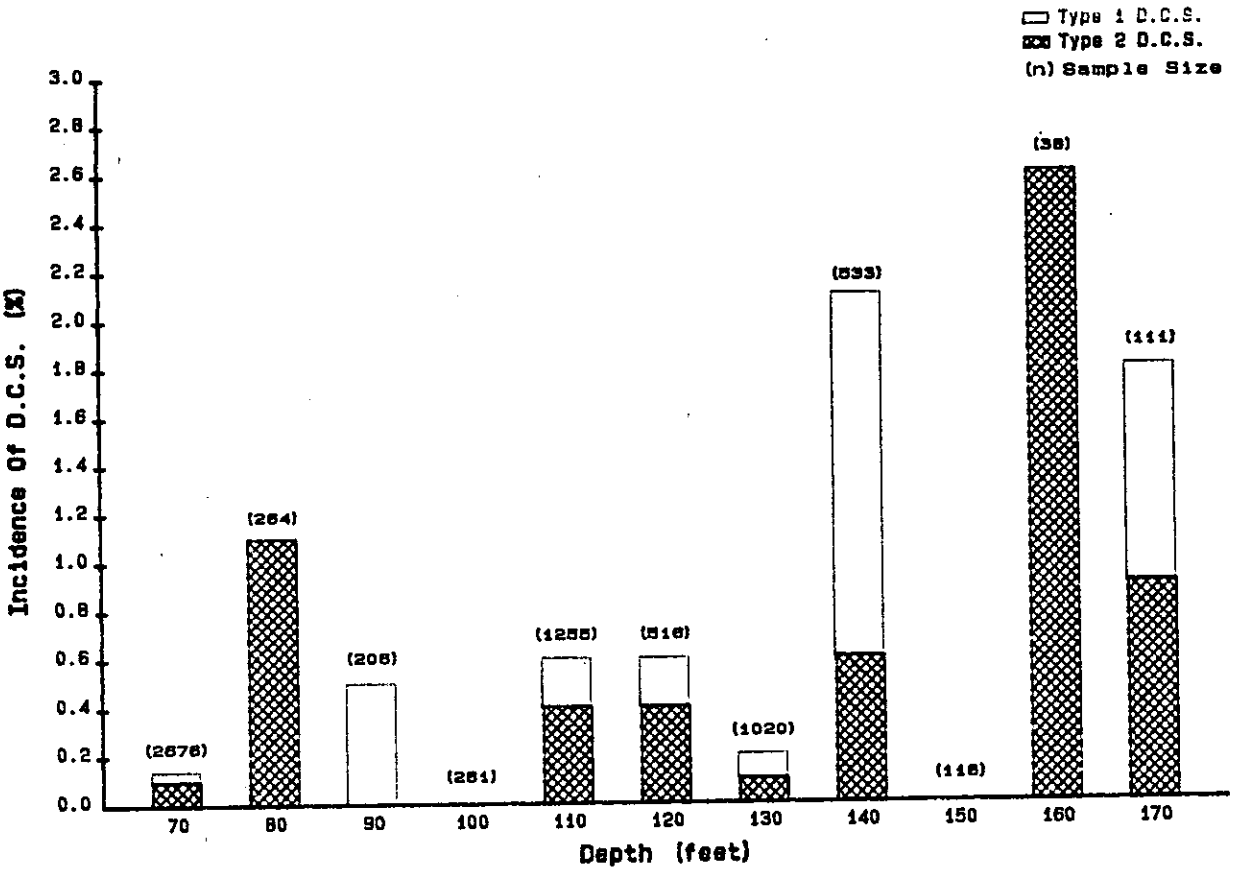


FIGURE 9 b): INCIDENCE OF D.C.S. FOLLOWING SURFACE DECOMPRESSION DURING 1983

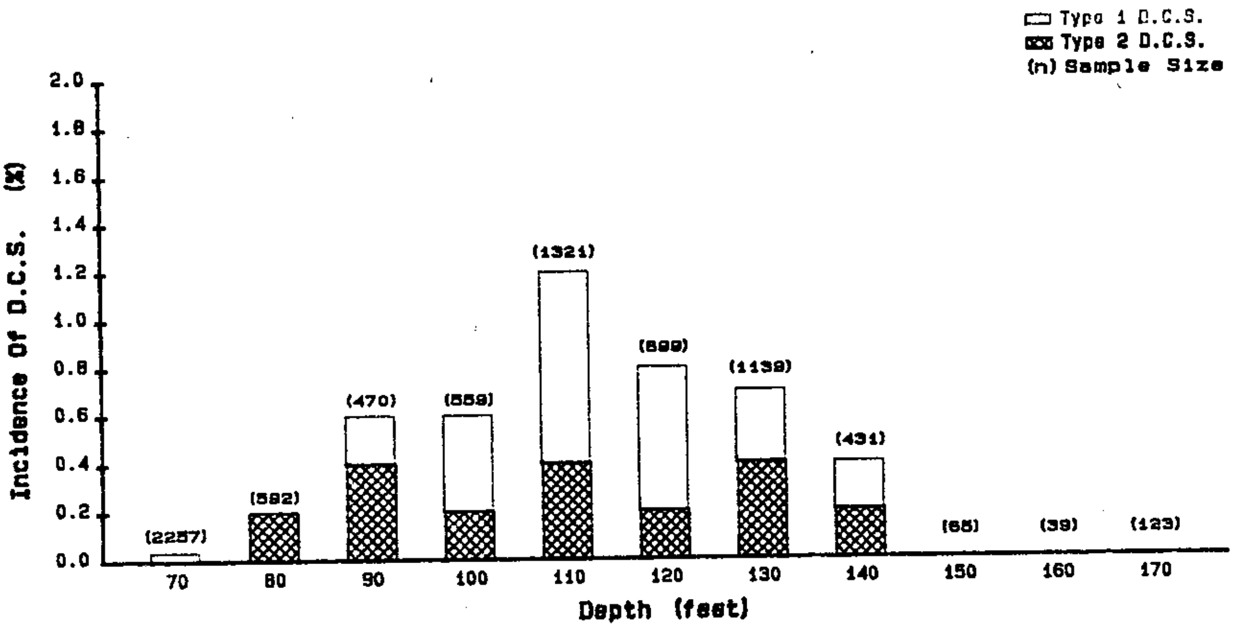


FIGURE 10 a): INCIDENCE OF D.C.S. FOLLOWING SURFACE DECOMPRESSION DURING 1982

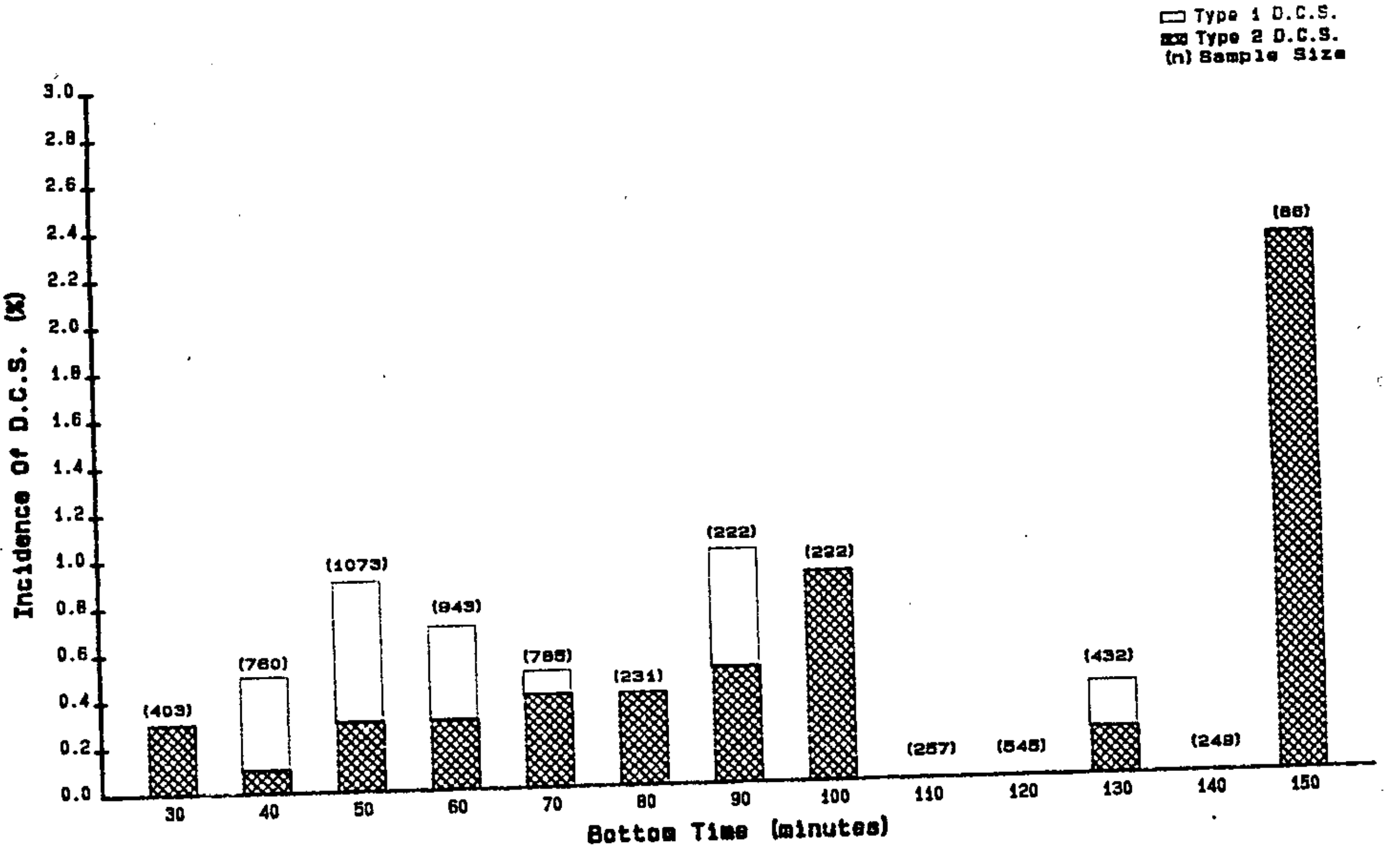
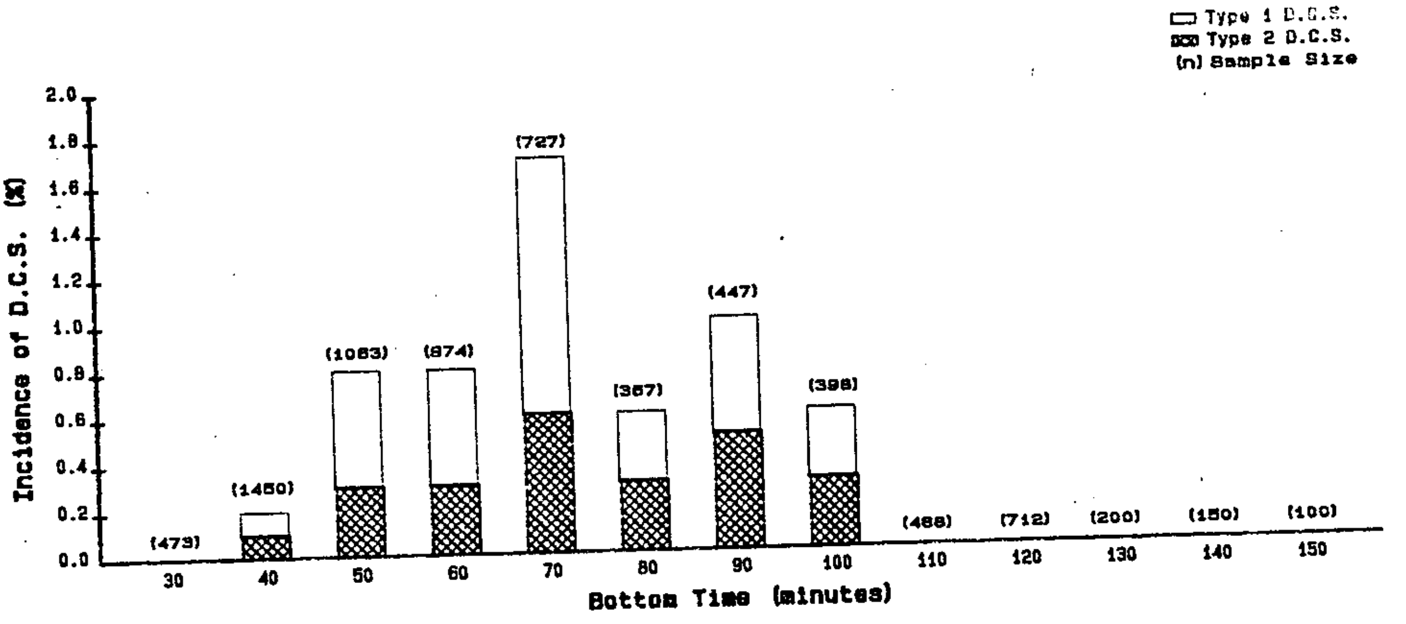


FIGURE 10 b): INCIDENCE OF D.C.S. FOLLOWING SURFACE DECOMPRESSION DURING 1983



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9. Incidence of DCS related to decompression procedure.

In Figure 6, the five Type 1 cases arising from in-water dives are identified by arrows, and the single case following a no-stop dive is seen at 212 minutes at the extreme right of the diagram.

All the cases, classified according to the decompression procedure used, are presented in Table 7, together with an indication of the hyperbaric stress involved.

To quote the single case of DCS arising from no-stop diving as an incidence is meaningless.

At first glance, it would appear that the incidence of DCS following Sur-D diving is twice as great as that following in-water stops. Table 7 however shows another variable, the DP Index. The DP index for all in-water stop dives is 5.9 ± 8.1, and for all Sur-D dives, 32.9 ± 19.0. For dives resulting in DCS, the DP Index for the relevant in-water stop dives was 14.2 ± 19.6 and for the Sur-D dives, 53.4 ± 21.1. The effect of this combination of variables is analysed further in Section 12.

Table 7

Incidence of DCS related to the decompression procedure

	No-stop			In-water Decompression			Surface Decompression		
	1982	1983	Total	1982	1983	Total	1982	1983	Total
Number of dives Mean DP Index±SD (range)	3,379 - -	5,326 - -	8,705 - -	469 6.4±9.9 (0-98.3)	1,647 5.7±7.5 (0-62.4)	2,116 5.9±8.1 (0-98.3)	6,996 33.9±18.2 (0-284.3)	7,895 31.9±19.6 (0-126.0)	14,891 32.9±19.0 (0-284.3)
Cases of DCS Mean DP Index±SD (range)	1 - -	0 - -	1 - -	1 - 48.4	4 5.7±5.2 (1.8-13.2)	5 14.2±19.6 (1.8-48.4)	34 52.5±19.4 (18.9-108.1)	39 54.2±22.8 (0-109.6)	73 53.4±21.1 (0-109.6)
Incidence (%)	0.03	0	0.01	0.21	0.24	0.24	0.49	0.49	0.49
Type 1 cases Mean DP Index±SD (range)	0 - -	0 - -	0 - -	1 - 48.4	4 5.7±5.2 (1.8-13.2)	5 14.2±19.6 (1.8-48.4)	16 51.2±19.1 (18.9-86.4)	23 56.5±25.4 (0-109.6)	39 54.3±22.9 (0-109.6)
Type 2 cases Mean DP Index±SD (range)	1 - -	0 - -	1 - -	0 - -	0 - -	0 - -	18 53.8±20.1 (21.8-108.1)	16 50.8±18.8 (21.6-97.1)	34 52.4±19.2 (21.6-108.1)

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10. Effect of applied decompression safety factors

The total decompression safety factor (i.e. the "SF Index", including both the safety element provided by the rounding up to the appropriate table increment, plus any added "Jesus-factor") was calculated as described on Page 12. The mean values obtained for dives resulting in DCS are shown in Table 8, where they may be compared with the mean for all the dives carried out using the same decompression procedure.

Table 8

A comparison of the Safety Factor indices of all In-Water and Surface decompression dives with those resulting in DCS.

	In-water Decompression		Surface Decompression		
	Dives resulting in DCS	All dives	Dives resulting in DCS		All dives
	(all Type 1)		Type 1	Type 2	
Number of Dives	5	2,116	39	34	14,891
Safety Factor Index mean ± SD (range)	10.7 ± 6.0 (3.8-18.1)	8.0 ± 6.0 (0-57.6)	21.7 ± 12.9 (2.3-70.7)	28.4 ± 15.1 (4.6-66.4)	29.4 ± 13.4 (0-265.9)

Surprisingly, (with the possible exception of Type 1 cases arising from Sur-D dives) it appears that in general, the dives which resulted in DCS had just as great a safety factor applied as those which did not.

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11. Effect of hot-water suits

Dives were carried out either with passive thermal protection (for example, dry suits, or Unisuits) or with active protection in the form of hot-water suits. The incidence and manifestations of DCS on dives using these procedures are shown on Table 9.

Again, it would appear at first glance that the use of hot water suits markedly affects the incidence, and also the manifestations of DCS. In the case of in-water stops however, the dive numbers are such that the difference between an incidence of 0.19% and 0.29% depends on one additional case of DCS - it is meaningless. In the 73 cases of DCS arising from Sur-D dives, the difference between 0.34% and 0.53% is more substantial, as is the apparent increase in Type 2 cases. Again however, other variables might be at work, and the effects of these are analysed further in Section 13.

Table 9

Incidence of DCS in relation to the type of thermal protection

	Type of Thermal Protection							
	Passive				Hot Water Suits			
	No-stop	In-water Decompression	Surface Decompression	Total	No-stop	In-water Decompression	Surface Decompression	Total
Number of Dives	4,460	1,073	3,229	8,762	4,245	1,043	11,662	16,950
Cases of DCS	0	2	11	13	1	3	62	66
Incidence (%)	0	0.19	0.34	0.15	0.02	0.29	0.53	0.39
Number of Type 1 cases	0	2	8	10	0	3	31	34
Number of Type 2 cases	0	0	3	3	1	0	31	32

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RESULTS

3: SEPARATION OF FACTORS

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SEPARATION OF FACTORS

In sections 8 to 11 we have described four factors which might influence the incidence of DCS: the severity of the hyperbaric stress; the decompression procedure used; the decompression safety factor applied; and the type of thermal protection used.

The decompression safety factor does not appear to be a contributory factor to the incidence of DCS.

12. DCS/Decompression Procedure/Severity of Hyperbaric Stress

In this section we look first at the combined effect of decompression procedure and severity of the hyperbaric stress on the incidence of DCS (Table 10), then, as in-water stop diving contributed only five cases to the total, we look closer at the effect of increasing dive severity on dives using Sur-D only (Table 11).

From Table 10, it can be seen that almost all of the dives using in-water stops had a DP Index of less than 30 and that no comment can therefore be made on more severe in-water dives. The great majority of in-water dives had in fact a very modest hyperbaric exposure, with a mean DP Index of 5.9 ± 8.1 (Table 7). The four cases of DCS which arose from these dives were all Type 1, and they had a spread of DP Indices typical of the whole group (mean DP index of 5.7 ± 5.2).

The numbers of Sur-D dives in each DP Index category are such that more meaningful comment can be made. The incidence of DCS undoubtedly increases with the severity of the dive, from 0.14% at a DP Index of less than 30 to 1.60 where the DP Index exceeds 60. Of even more concern is the proportion of Type 1 to Type 2 cases, which is approximately 50:50 at all degrees of severity of the dive.

This relationship is examined further in Table 11 which is a more detailed analysis of all Sur-D dives.

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Table 11

DCS related to hyperbaric stress for Surface decompression dives only

Severity of Dive (DP Index)	Cumulative Number Of Dives	Decompression Sickness			
		Type 1		Type 2	
		Number	%	Number	%
≤ 20	4,236	3	0.07	0	0.00
≤ 30	7,099	5	0.07	5	0.07
≤ 40	9,878	6	0.08	8	0.08
≤ 50	12,492	17	0.14	14	0.11
≤ 60	13,769	29	0.21	26	0.19
All Dives	14,891	39	0.26	34	0.23

The cut-off below which there were no Type 2 cases was a DP Index of 20, with a gradual increase in incidence up to a DP Index of 50, and a more pronounced increase thereafter. The crucial 5 cases of Type 2 DCS occurring from dives with DP values between 20 and 30, were 21.6, 21.8, 26.0, 28.9, and 29.3.

The DP Index is a device which integrates the hyperbaric stress imposed by the depth of the dive, and the length of the exposure. It is recognised that these two factors might not have equal effect on the proportion of Type 1 to Type 2 cases, and examination of Figure 6 shows that there is a difference in the distribution of Type 1 and Type 2 cases at the opposite ends of the depth/time spectrum. Thus, for all dives deeper than 130 ft, irrespective of time or DP Index, there were 10 Type 1 cases and 6 Type 2 cases of DCS. In comparison, for all dives with bottom times longer than 90 minutes irrespective of depth or DP Index, the proportions are reversed, with 3 Type 1, and 7 Type 2 cases.

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We have therefore examined, (in Sur-D dives only) the effect of increasing dive severity on DCS incidence,

1) for dives limited in depth to 130 ft. and with bottom time increments of less than 60 minutes, 60 to 90 minutes, and unlimited for time, and

2) for all dives, with no limitation for depth, in the same bottom time increments.

These results are displayed in Tables 12a and 12b, and are dealt with in the discussion.

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Table 12(a)

The effect of increasing dive severity on the number of cases of DCS arising from surface decompression procedures.

Depth Limit 0-130 ft

Severity of Dive (DP Index)	BOTTOM TIME								
	Up to 60 minutes			Up to 90 minutes			All Times		
	Cumulative Number of Dives	Type 1 *	Type 2 *	Cumulative Number of Dives	Type 1 *	Type 2 *	Cumulative Number of Dives	Type 1 *	Type 2 *
≤ 20	1,381	3 (0.22)	0 (0.00)	1,936	3 (0.16)	0 (0.00)	4,047	3 (0.07)	0 (0.00)
≤ 30	2,276	4 (0.18)	1 (0.04)	3,103	4 (0.13)	2 (0.06)	6,724	5 (0.07)	4 (0.06)
≤ 40	3,925	6 (0.15)	4 (0.10)	5,077	6 (0.12)	5 (0.10)	9,225	7 (0.08)	7 (0.08)
≤ 50	5,359	11 (0.21)	8 (0.15)	6,887	13 (0.19)	9 (0.13)	11,380	14 (0.13)	13 (0.11)
≤ 60	5,719	14 (0.25)	10 (0.18)	7,888	21 (0.27)	17 (0.22)	12,463	23 (0.19)	22 (0.18)
All Dives	5,905	14 (0.24)	11 (0.19)	8,681	27 (0.31)	22 (0.25)	13,435	29 (0.22)	28 (0.21)

* Incidence (%) in brackets.

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Table 12(b)

The effect of increasing dive severity on the number of cases of DCS arising from surface decompression procedures.

No Depth Limit

Severity of Dive (DP Index)	BOTTOM TIME								
	Up to 60 minutes			Up to 90 minutes			All Times		
	Cumulative Number of Dives	Type 1 *	Type 2 *	Cumulative Number of Dives	Type 1 *	Type 2 *	Cumulative Number of Dives	Type 1 *	Type 2 *
≤ 20	1,570	3 (0.19)	0 (0.00)	2,125	3 (0.14)	0 (0.00)	4,236	3 (0.07)	0 (0.00)
≤ 30	2,651	4 (0.15)	2 (0.08)	3,478	4 (0.12)	3 (0.09)	7,099	5 (0.07)	5 (0.07)
≤ 40	4,578	7 (0.15)	5 (0.11)	5,730	7 (0.12)	6 (0.11)	9,878	8 (0.08)	8 (0.08)
≤ 50	6,471	14 (0.22)	9 (0.14)	7,999	16 (0.20)	10 (0.13)	12,492	17 (0.14)	14 (0.11)
≤ 60	7,025	20 (0.29)	14 (0.20)	9,196	27 (0.29)	21 (0.23)	13,769	29 (0.21)	26 (0.19)
All Dives	7,358	24 (0.33)	16 (0.22)	10,137	37 (0.37)	28 (0.38)	14,891	39 (0.26)	34 (0.23)

* Incidence (%) in brackets.

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13. DCS/Severity of Hyperbaric Stress/Thermal Protection

It can been seen from Table 8 that no comment can be made on the influence of hot-water suits on the incidence of DCS arising from in-water stop dives.

Table 13 looks at the combined effect on DCS incidence of hot-water suits and severity of the dive for Sur-D dives only.

Table 13

Influence of the severity of hyperbaric stress and type of thermal protection on the incidence and type of DCS
(Surface decompression dives only.)

	Type of Thermal Protection					
	Passive			Hot Water		
	DP Index			DP Index		
	<30	31-60	>60	<30	31-60	>60
No of dives	1,514	1,273	442	5,585	5,397	680
No of cases of DCS	0	9	2	10	36	16
Incidence	0	0.7	0.5	0.2	0.7	2.4
No of Type 1	0	7	1	5	17	9
No of Type 2	0	2	1	5	19	7

The numbers in the various subsets, although small, are broadly comparable, and show that for severe dives (DP Index > 60) the use of a hot-water suit markedly increases the incidence of DCS. Of even greater concern is the effect that active thermal protection appears to have on the manifestation of DCS in dives of moderate severity - the proportion of Type 2 cases is greater where hot-water suits are used.

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It is noted that in all 10 cases of DCS arising from Sur-D dives with a DP Index of less than 30, a hot-water suit was used.

Figure 11 is a modification of Figure 6 with all dives using hot water suits (drawn in mauve) and using passive thermal protection (drawn in gold) clearly identified. The DP limit lines have been redrawn at 20 and 30.

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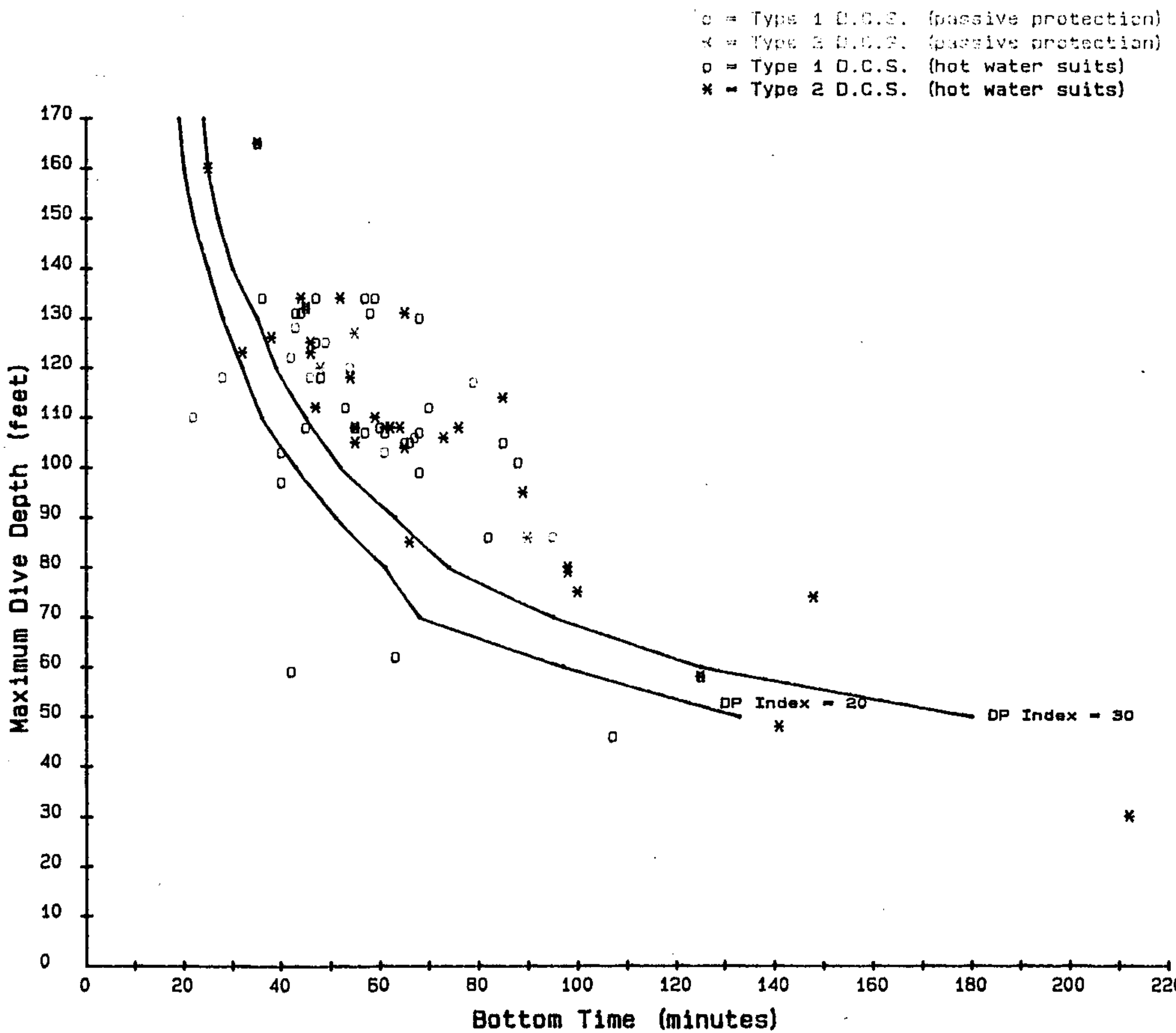
FIGURE 11: D.C.S. AND THERMAL PROTECTION



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DISCUSSION

In answer to the questions set in the terms of reference for the project:

a) there is a serious problem with regard to decompression sickness arising from diving schedules and practices currently used in North Sea operations, and

b) the principle factor involved is the severity of the hyperbaric stress of the dive, with a possible contribution from the use of active diver heating.

These points will be amplified later, following a general discussion of the project.

1. Quality of data

We have considered the circumstances which might have affected the accuracy and quality of the information given to us, and any resulting under- or over-estimating of the incidence of DCS.

The response of the diving companies has been such that we are reasonably confident of having included at least 95% of all dives in our survey.

We are less certain of the quality of data relating to cases of DCS as there are several potential sources of misinformation. Diving companies might use different criteria for the definition of DCS, with some companies regarding any symptoms (for example "niggles" or itching) arising after a dive as being DCS, and treating them as such, while other companies might disregard such minor and transient symptoms and only log as DCS those cases with more severe or persistent symptoms. In this regard, it is unfortunate that the more responsible companies who are prepared to treat on suspicion of DCS might appear as a result to have a poorer record, and this circumstance should be taken into account by the individual companies when they compare their performance with the overall incidence levels quoted in this report.

We have identified several cases which on retrospective analysis were quite clearly not DCS although they had (very properly) been treated as such offshore. These have been discarded from our results but, as we have not been able to review medical records for all cases (most episodes of Type 1 DCS being treated offshore without reference to medical advice), this factor might have caused an overestimate, particularly of Type 1 cases.

The current policy to treat all cases of DCS arising offshore on a long oxygen therapeutic table irrespective of the nature of the DCS might be expected to result in "wrong labelling" of some cases and an overestimate of Type 2 incidence. We do not think that this is a major source of inaccuracy, as this practice was not common in the period covered by the survey, and in addition we have been able to review clinical data in most alleged Type 2 cases.

The major source of inaccuracy, resulting in an underestimate of Type 2 incidence which would more than balance both the above factors is the undoubted practice of diver and/or supervisor concealment. We are clearly unable to put any figure to this, or even to demonstrate conclusively that it takes place, but from informal conversation with divers and diving supervisors, on social occasions and during diving medicine courses, we are in no doubt that it happens. The reasons for this are outlined on Page 14. The only means of tackling the problem is by educating the divers and supervisors of the possible long-term danger to health - as for example by the recent Department of Energy/Videotel Marine International videotapes on "Decompression Illness", - or by eliminating the practices which make Type 2 DCS a possibility.

We have concluded therefore that the 35 cases of Type 2 DCS which we have collected in this survey are probably an underestimate of the actual number of cases occurring.

2. Expression of results

The difficulties of statistical analysis of these types of data are described on Page 15. We have a related problem in expressing the results in terms of a meaningful incidence of the condition. The usual epidemiological calculation of rate, where the frequency of an observed condition is divided by the total number of people in whom the condition might arise, gives not only an expression of the proportion of the population who might be affected, but also an indication of the average risk of being affected to any individual member of the population. This assumes a reasonably constant denominator which in the offshore diving situation does not apply. Divers are a highly itinerant group, and an individual diver might have worked in the UK sector for only a small part, or for most of the time covered in the survey. In addition, even if present for the whole of the survey period, he may have been employed in activities other than air-diving for part of that time. Because of our assurance of anonymity, we are unable to follow the work history of individual divers, and can not therefore state a true incidence in the epidemiological sense, - that is, per head of population.

We had considered using "time in the water" as the denominator in the above calculation, and expressing incidence as "number of cases per x hours in the water". This however would be equally unsatisfactory, as a unit of time at, say, 50 metres has a different significance from the same unit at 20 metres.

It may however be useful to record an estimate of the number of air divers actually at work (that is, actually working offshore at the time, and not including those on leave or off sick) in the UK sector during a representative period (1st week in July) of the diving season in 1982 and 1983 (T Hollobone, personal communication). Approximate figures are 350 (1982) and 300 (1983). It should be noted also that in the latest complete year for which figures are available (1985), there is not only an increase in the total number of divers working offshore in the UK sector, but an increased proportion carrying out air-diving. An estimate over the same time period for 1985 suggests rather more than 500 air divers actually at work.

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3. Acceptable incidence of DCS

An overall incidence for DCS of less than 0.5% in those dives which required decompression is a matter for congratulation to the hyperbaric physiologist or mathematical modeller responsible for the generation of the decompression tables. It is a value which is better than that achieved by the world's navies, and must be seen to indicate that the diving companies are carrying out their business in a responsible manner. However, when a very large number of dives are carried out, even a very small incidence will produce a substantial number of cases, and the real problem to be considered is the type of DCS which results.

Type 1 DCS, although a painful condition, is one which is readily treated and, apart from some lingering concern about the possibility of bone necrosis, is not known to have any serious long-term effect. Neurological DCS is a much more serious condition which is likely to cause permanent damage to the spinal cord (Palmer *et al*, 1981) and which might leave the diver with permanent neurological deficits. Quite apart from the effect on general health, such residual neurological damage will render the diver permanently unfit to dive, and will thus deprive him of his livelihood. Most occupational physicians would be prepared to regard a small incidence of Type 1 DCS as an acceptable occupational hazard of diving. Few would be prepared to accept the chance of permanent neurological damage, and we think that none would accept such a chance if there were reasonable alternatives or means of avoiding the condition.

In our opinion, the occurrence of 35 cases of Type 2 decompression sickness over a 2-year period is completely unacceptable. Some of these cases have had to cease diving because of residual neurological damage. The main question for this report is whether the occurrence of such damage is an inevitable consequence of air diving - in which case there should be a ban on air-diving as an occupational procedure - or whether there is some factor responsible which if eliminated would reduce the incidence to zero.

4. Factors responsible

The bulk of air diving in the North Sea is carried out using surface decompression, a technique originally devised for relatively short exposures. With the introduction of oxygen breathing in the DDC in the van der Aue table, the very much shorter decompression time was seen as a bonus. Commercial practice however has been to translate this bonus into an increased bottom time for a given decompression time, and thus a more commercially-attractive dive. The technique is now used routinely for much more severe exposures than envisaged by its originators (Shilling, 1986). These longer dives are to some extent made possible by the use of hot-water suits, but this itself affects inert gas uptake and could contribute to an increased incidence of DCS.

It is clearly seen from Figure 6 that the great majority of DCS cases occurred in dives which imposed (in terms of depth and time of the dive) the greatest hyperbaric stress, and it is our opinion that this is the most powerful factor involved. This is in accordance with common sense, past experience and probabilistic analysis (Weathersby *et al*, 1985).

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It is not possible to make a comparison between Sur-D and in-water-stop dives across the whole range of exposure, as we know of only 35 in-water stop dives where the DP Index exceeded 30. We are therefore unable to say from this survey whether Sur-D dives are any more or less dangerous than in-water-stop dives for the more extreme exposures.

We can make a comparison between the two techniques for more modest dives (DP Index equal or less than 30). Fourteen cases of DCS occurred on these dives (ignoring for the moment the single case arising from a no-stop dive). The calculated incidence of DCS in this range is actually less for Sur D dives than for in-water-stop dives although the difference is not significant. What is important is that whereas all the 4 cases arising from in-water-stop dives were Type 1, the 10 cases from Sur-D dives included 5 Type 2.

There is little doubt that the use of active diver heating increases the overall incidence of DCS in Sur-D dives with severe hyperbaric exposure. The worst set of circumstances is a dive with a DP Index greater than 60 where a hot water suit is used; the incidence of DCS rises to 2.4% with probably an equal chance of suffering from a Type 2 hit. Where passive thermal protection is used, the incidence for similar dives is only 0.5%.

Unfortunately, we can not be so certain of the effect of hot-water suits on less severe dives, as the number of cases is smaller. We note however, that of the 4 cases of DCS (all Type 1) arising from in-water-stop dives with a DP Index of less than 30, 2 were using hot-water suits and 2 had passive protection only. In contrast, the 10 cases arising from similar Sur D dives were all wearing hot-water suits, and 5 of these cases were Type 2.

The single case of (Type 2) DCS arising from a very long no-stop dive was also wearing a hot-water suit.

We conclude therefore that the most powerful factor in the production of the observed cases of DCS is the severity of the hyperbaric stress of the dive. In dives of moderate exposure (DP Index equal or less than 30), we have no evidence that the surface decompression technique is any more hazardous than using in-water stops, where only passive thermal protection is used. We have some concern over the combination of Sur-D plus hot-water suits even on these moderate dives because of the appearance of Type 2 cases of DCS.

5. Basis of recommendations

We have been asked, should we identify that there is a problem, to advise on modifications and safe procedures.

An obvious move would be to put a limit on the severity of the dive exposure, using the DP Index as a convenient measure of hyperbaric stress.

Tables 12 a) and b) were calculated in an attempt to identify a limitation of depth, time, and DP Index which might result in an "acceptable" incidence of Type 2 DCS. The danger with this approach however is that we would force the replacement of a given number of relatively long air dives with a much larger number of short air

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dives. As our concern is with the absolute number of Type 2 cases arising, we would have to be certain that the incidence rate on these short dives was very low indeed, and that there was no additional factor involved which might increase the possibility of a Type 2 case.

We have chosen not to compromise on this issue, and take the stand that the only acceptable incidence for Type 2 DCS in an occupational situation (other than the exceedingly rare fortuitous event for which no decompression procedure can cater) is zero.

We have no record of Type 2 DCS on any dive, whether using Sur D or in-water-stops, where the DP Index was equal or less than 30, and where only passive thermal protection was used. Where hot-water suits were used, there were 5 cases of Type 2 DCS (all arising from Sur-D dives) on dives with a DP Index between 21 and 30. There were no cases arising on any dive where the DP Index was less than 20. These facts form the basis of our recommendations.

CONCLUSIONS

We conclude that;

1. although the overall incidence of DCS, given biological variability, is impressively low, there has been a totally unacceptable number of Type 2 cases.

2. the major factor involved in the occurrence of these cases is the severity of the hyperbaric exposure of the dive.

3. the use of hot-water suits is a contributory factor both to the overall incidence of DCS and to the proportion of Type 2 cases.

4. on the evidence available, there is no indication that for dives of moderate severity the technique of surface decompression results in any greater incidence of DCS than the use of in-water stops, and that when all other factors are taken into account, surface decompression is probably the safer technique.

RECOMMENDATIONS

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RECOMMENDATIONS

We recommend that:

1. the DP Index, as defined in this report, be applied to all air dives as a measure of the hyperbaric stress of the dive.

2. where passive thermal protection is used, all air-dives should be limited to a DP Index of not more than 30. (See Appendix D)

3. where hot-water suits are used, all air dives should be limited to a DP Index of not more than 20. (See Appendix D)

4. further consideration should be given to placing an absolute limit on the in-water time of all surface-orientated air dives, and perhaps also a shallower depth limit for no-stop dives.

Note well!!

It should be clearly understood that the DP Indices stated are nothing more nor less than an indication of the severity of the dive. Although based on USN standard air tables, they are just as applicable to dives decompressed on Sur-D schedules or on company tables which are not derived from any USN table. They must not be taken to mean that the USN tables should be used in preference to the company's own tables.

We had thought to publish tables of dives in 1 foot increments with DP Indices of exactly 20 and 30. To have done so however would have eliminated the safety element inherent in having to "round-up" to the appropriate table increments. As the time penalty involved is not great, we prefer to retain the incremental method. Examples of the maximum bottom times available for dives in 10 foot increments, within these DP limits are given in Appendix D.

It must also be emphasized that the use of a maximum DP Index to provide a limit to the actual severity of the dive does not preclude the addition of extra actual decompression time (by "Jesus-factoring") should the dive supervisor think such action appropriate.

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APPENDIX A

A sample computer record

DIVE LOG			
Company 7		Date 23.01.82	
Dive.Number 24016			
Max.Depth 106		Bottom.Time 73	
Type.Table USN1			
Table.Depth 110		Table.Time 80	
Type.Decompress SDO			
Surface.Interval 3		Repeat.Dive N	
D.P.Index 68.7	Table.D.P.Index 88.8		Safety.Index 20.1
D.C.S. 0		Suit H	
Time.Delay 0 : 0		Therapy.Table 0	

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Appendix B

Conversion of the USN standard air decompression table to a depth/time continuum

As published, the USN standard air decompression table provides a means of calculating the amount of time required to decompress using various increments of dive depth and time. To calculate the amount of decompression time required by a dive, the actual depth and bottom time are "rounded up" to an increment of table depth and time. To obtain a precise index of the severity of each dive (the DP Index) we required to be able to calculate the exact amount of decompression time required for the actual dive depth (to the nearest foot), and bottom time (to the nearest minute). In other words, we wished to convert the USN standard air decompression table from an incremental one, into a depth/time continuum.

Our solution to this problem was two fold. The first task was to expand the table time axis so that a decompression time could be calculated for every minute of bottom time (5-250 minutes) at each of the table depth increments. From the data obtained, it was then possible to complete the process by expanding the table depth axis so that a decompression time could be calculated for every foot of dive depth. Having done this, we were then in a position to tabulate the exact amount of decompression required for any combination of dive depth and time.

For a given table depth increment, a plot of "ascent time" versus "table time" produces a curve which can be mathematically described by a polynomial equation. Thus by taking each of the table depth increments in turn, and using the table times for that depth increment (with their corresponding "ascent times"), a polynomial equation can be computed which can be used to calculate the decompression time for any value of bottom time, at that depth.

Polynomials are equations that involve powers of the x variable. There are many levels of polynomial equations, but for our purposes, a second degree polynomial was all that was required. One method of fitting a second degree polynomial equation to a set of data is to first compute x squared, then simply regress the y on two predictor variables x, and x^2 (as if one were carrying out a multiple regression). In our case, the x variable is bottom time and the y variable is "ascent time" (taken from the USN standard air table for a specific table depth increment).

All data manipulation and statistical analysis (regression) were computed using the statistical package "Minitab" (Pennsylvania State University).

Having taken each of the table depth increments (40,50,... 170) in turn, and computed a second degree polynomial equation, we were furnished with set of equations, one for each of the table depth increments which could be used to calculate the exact decompression time required for any bottom time at the various table depth increments. For example, the equation which describes decompression time for dives at 110 foot was computed as:

$$\text{Decompression Time} = (0.9558 \times \text{Bottom Time}) + (0.005368 \times \text{Bottom Time}^2) - 22.156$$

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Thus if we wished to know what the decompression time was for a 110 foot dive lasting 45 minutes, then 45 would be substituted for "bottom time" in the above equation and the value 31.7 obtained.

Although we now had a set of equations which could be used to calculate the exact amount of decompression required for any bottom time, we could do so only for specific depths (corresponding to the USN table depth increments). The second task was to obtain a similar set of equations which could be used to calculate the decompression time at every foot of dive depth.

By plotting "ascent time" against "depth" for any value of bottom time (using the USN table depths as values) a curve is again produced which can be described by a polynomial equation. Thus by taking each minute of bottom time in the range 5-250 minutes in turn, and, using the table depth increments (with their corresponding "ascent times" calculated from the mathematical equations mentioned above) a polynomial equation could be computed which would give the decompression time necessary for any dive depth value, at that specific bottom time.

The end result of this was a series of equations - one for each minute of bottom time - which could be used to calculate the exact decompression time of any combination of dive depth and time. For example, using the above method, the polynomial equation which describes the decompression time for dives lasting 45 minutes is:

$$\text{Decompression Time} = (0.4606 \times \text{Depth}) + (0.0020552 \times \text{Depth}^2) - 44.779$$

From this equation we can calculate the decompression time for any dive having a bottom time of 45 minutes. Thus, if the dive depth was 115 ft. then by substituting 115 in the equation above we find that a decompression time of 35.4 is required for such a dive.

All 245 of these polynomial equations (together with several extra equations calculated for extremely long bottom times) were entered into a computer programme which generated the decompression time, or as we called it, the Decompression Penalty Index, for each of the man-dives logged in our computer files.

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Table C1

Diving Activity In Relation To Decompression Procedure

Decompression Procedure		Year		
		1982	1983	Total
No-stop	Number of Dives	3,379	5,326	8,705
	Bottom time (hours)	3,400	6,183	9,583
In-water stops	Number of Dives	469	1,647	2,116
	Bottom time (hours)	481	1,331	1,812
Surface Decompression using oxygen	Number of Dives	6,996	7,895	14,891
	Bottom time (hours)	9,345	9,253	18,598
* Surface Decompression using air	Number of Dives	9	19	28
	Bottom time (hours)	13	26	39

*It was clear from the logs of some of the Surface Decompression dives using air that this technique had been adopted as an abort procedure. (for example, where the oxygen supply had failed or was not available.) On the assumption this might have applied to all 28 such exposures, these dives are not considered further in our analyses.

Table C2

Diving Activity On A Monthly Basis

Month	Number of Dives					
	No-stop		In-water Decompression		Surface Decompression	
	1982	1983	1982	1983	1982	1983
Jan	20	62	3	11	25	61
Feb	37	86	3	38	140	340
March	51	152	9	53	373	209
April	245	588	15	177	941	936
May	666	726	107	239	1,288	1,096
June	627	998	109	217	1,003	1,753
July	748	1,051	75	287	1,044	1,390
Aug	403	973	53	201	920	1,422
Sept	298	324	33	172	661	368
Oct	170	142	58	93	380	135
Nov	90	164	3	90	115	124
Dec	24	60	1	69	106	61
Total	3,379	5,326	469	1,647	6,996	7,895

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Table C3 (a)

Pattern Of No Stop Diving Activity In 10 ft Increments Of Depth

Depth (feet)	1982			1983		
	No of Dives	Total Bottom Time (hours)	Average Dive Time (mins) [Range]	No of Dives	Total Bottom Time (hours)	Average Dive Time (mins) [Range]
0-10	109	148.0	81 [6-232]	176	292.4	99 [2-181]
11-20	419	666.5	95 [2-305]	604	936.2	93 [3-200]
21-30	557	736.3	79 [5-365]	1046	1487.7	85 [5-212]
31-40	522	594.3	68 [3-296]	1124	1941.3	103 [3-450]
41-50	712	748.5	63 [3-187]	990	927.6	56 [3-104]
51-60	388	251.8	38 [4-61]	509	305.6	36 [4-111]
61-70	187	103.2	33 [5-50]	276	128.4	27 [5-72]
71-80	183	84.2	27 [4-50]	171	63.4	22 [4-79]
81-90	70	24.3	20 [4-47]	133	41.0	18 [3-45]
91-100	72	20.2	16 [3-25]	84	20.9	14 [4-24]
101-110	70	10.4	8 [2-20]	93	21.2	13 [4-20]
111-120	49	8.0	9 [3-15]	56	9.3	9 [4-16]
121-130	27	3.4	7 [5-10]	38	4.9	7 [3-14]
131-140	6	0.5	5 [4-7]	26	3.3	7 [4-12]
141-150	4	0.3	4 [3-5]	0	-	-
151-160	4	0.3	4 [4-5]	0	-	-
161-170	0	-	-	0	-	-
171-180	0	-	-	0	-	-

Table C3 (b)

Pattern Of In-Water Decompression Diving Activity In 10 ft Increments Of Depth

Depth (feet)	1982			1983		
	No of Dives	Total Bottom Time (hours)	Average Dive Time (mins) [Range]	No of Dives	Total Bottom Time (hours)	Average Dive Time (mins) [Range]
0-10	0	-	-	0	-	-
11-20	0	-	-	0	-	-
21-30	1	4.2	250	0	-	-
31-40	7	15.2	130 [84-215]	60	152.6	152 [77-310]
41-50	147	265.3	108 [47-157]	337	539.4	96 [35-96]
51-60	69	91.9	79 [39-180]	172	189.2	66 [29-112]
61-70	12	12.1	60 [33-88]	112	104.9	56 [13-127]
71-80	21	17.6	50 [28-104]	58	40.9	42 [21-81]
81-90	28	15.7	33 [22-60]	48	29.7	37 [20-53]
91-100	21	9.9	28 [18-88]	69	29.8	25 [13-58]
101-110	28	12.1	25 [12-61]	66	25.8	23 [12-48]
111-120	24	6.5	16 [10-29]	126	39.6	18 [4-49]
121-130	80	19.7	14 [6-70]	217	69.0	19 [5-51]
131-140	28	9.7	20 [7-39]	342	102.9	18 [4-49]
141-150	0	-	-	23	5.1	13 [7-36]
151-160	3	0.8	16 [8-20]	11	1.7	9 [5-12]
161-170	0	-	-	2	0.3	10 [10-10]
171-180	0	-	-	4	0.4	7 [5-9]

Table C3 (c)

Pattern Of Surface Decompression Diving Activity In 10 ft Increments Of Depth

Depth (feet)	1982			1983		
	No of Dives	Total Bottom Time (hours)	Average Dive Time (mins) [Range]	No of Dives	Total Bottom Time (hours)	Average Dive Time (mins) [Range]
0-10	0	-	-	0	-	-
11-20	0	-	-	0	-	-
21-30	1	3.9	235	3	10.0	200 [185-211]
31-40	59	164.9	167 [104-225]	55	130.1	141 [86-195]
41-50	759	1842.3	145 [12-203]	590	1254.2	127 [34-227]
51-60	1348	2825.2	125 [38-180]	1292	2412.8	112 [13-227]
61-70	509	880.0	103 [33-184]	317	507.1	95 [35-144]
71-80	264	334.2	75 [25-158]	592	765.8	77 [23-133]
81-90	206	228.7	66 [18-119]	470	557.9	71 [4-116]
91-100	261	246.1	56 [10-100]	559	603.4	64 [3-112]
101-110	1255	1210.7	57 [11-115]	1321	1222.5	55 [13-106]
111-120	516	409.2	47 [5-85]	899	656.5	43 [5-90]
121-130	1020	720.4	42 [9-125]	1139	750.2	39 [11-70]
131-140	533	345.1	38 [11-69]	431	276.5	38 [9-65]
141-150	116	64.4	33 [10-48]	65	32.3	29 [4-44]
151-160	38	16.2	25 [8-40]	39	16.2	24 [9-36]
161-170	111	53.6	28 [7-35]	123	57.2	27 [6-39]
171-180	0	-	-	0	-	-

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Table C4 (a)

Pattern Of No Stop Diving Activity In 10 min. Increments Of Bottom Time

No-Stop Procedure				
	1982		1983	
Bottom Time (mins)	Number of Dives	Average Depth (ft) [Range]	Number of Dives	Average Depth (ft) [Range]
0-10	233	87 [10-160]	348	80 [10-140]
11-20	286	67 [10-118]	518	69 [10-131]
21-30	327	58 [10-100]	496	54 [10-100]
31-40	425	51 [6-80]	471	47 [5-84]
41-50	404	42 [5-90]	490	43 [3-87]
51-60	378	38 [6-60]	414	37 [2-79]
61-70	246	32 [8-60]	378	32 [8-59]
71-80	237	34 [1-50]	404	32 [8-72]
81-90	280	36 [6-49]	369	32 [3-49]
91-100	135	36 [10-50]	307	33 [10-56]
101-110	50	27 [10-39]	193	27 [10-45]
111-120	60	26 [10-50]	146	26 [10-54]
121-130	40	23 [10-42]	98	25 [10-40]
131-140	45	23 [7-38]	73	26 [2-40]
141-150	62	20 [10-40]	66	27 [10-40]
151-160	42	18 [9-40]	65	27 [10-39]
161-170	31	19 [1-36]	67	28 [10-40]
171-180	46	24 [10-42]	239	21 [7-40]
181-190	17	31 [15-46]	71	31 [10-38]
191-200	12	24 [10-39]	105	33 [18-39]
> 200	23	23 [10-39]	8	32 [26-39]

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Table C4 (b)

Pattern Of In Water Decompression Diving Activity In 10 min. Increments Of Time

In-Water Procedure				
	1982		1983	
Bottom Time (mins)	Number of Dives	Average Depth (ft) [Range]	Number of Dives	Average Depth (ft) [Range]
0-10	25	128 [119-154]	106	135 [116-175]
11-20	97	123 [91-157]	542	128 [62-157]
21-30	71	103 [75-134]	201	107 [59-138]
31-40	21	90 [59-138]	91	79 [46-141]
41-50	12	80 [43-125]	85	80 [45-134]
51-60	18	64 [49-85]	95	61 [43-128]
61-70	26	60 [42-125]	87	55 [43-75]
71-80	19	54 [50-69]	93	53 [39-75]
81-90	28	52 [40-95]	82	48 [33-72]
91-100	45	47 [39-59]	67	46 [33-59]
101-110	40	47 [42-72]	60	45 [40-45]
111-120	23	45 [43-59]	72	46 [39-63]
121-130	17	43 [39-46]	21	43 [39-67]
131-140	10	44 [43-49]	14	44 [42-46]
141-150	12	44 [42-49]	4	42 [39-43]
151-160	1	46	1	43
161-170	0	-	0	-
171-180	1	55	0	-
181-190	0	-	0	-
191-200	0	-	0	-
> 200	3	33 [29-36]	26	33 [33-34]

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Table C4 (C)

Pattern Of Surface Decompression Diving Activity In 10 min. Increments OF Time

SDO2 Procedure				
Bottom Time (mins)	1982		1983	
	Number of Dives	Average Depth (ft) [Range]	Number of Dives	Average Depth (ft) [Range]
0-10	17	134 [100-166]	13	129 [86-165]
11-20	84	126 [48-165]	105	128 [51-170]
21-30	403	135 [73-165]	473	131 [72-170]
31-40	760	124 [58-165]	1450	121 [48-170]
41-50	1073	121 [48-149]	1063	112 [48-150]
51-60	943	108 [49-138]	974	103 [43-140]
61-70	785	100 [42-131]	727	94 [44-134]
71-80	231	81 [44-122]	367	83 [46-120]
81-90	222	74 [44-125]	447	79 [38-115]
91-100	222	64 [42-110]	398	73 [40-106]
101-110	257	59 [37-90]	468	61 [38-105]
111-120	545	57 [35-108]	712	56 [35-98]
121-130	432	56 [35-128]	200	52 [38-76]
131-140	249	49 [40-62]	150	49 [38-72]
141-150	86	53 [42-74]	100	49 [33-70]
151-160	66	51 [35-78]	103	49 [33-55]
161-170	142	52 [36-70]	70	49 [40-58]
171-180	358	49 [33-70]	47	44 [35-57]
181-190	73	43 [40-64]	10	42 [25-49]
191-200	45	43 [35-45]	4	47 [40-54]
> 200	3	35 [30-44]	14	43 [25-54]

Table C5 (a)

Number of In-water decompression dives which were decompressed with between 0 - 2 increments of table depth beyond that required.

Depth feet	1982				1983			
	Increment of Table Depth beyond that "required"				Increment of Table Depth beyond that "required"			
	0	+1	+2	>2	0	+1	+2	>2
0-40	3	5	0	0	26	32	2	0
41-50	140	7	0	0	242	92	2	1
51-60	46	22	0	0	81	89	1	1
61-70	8	4	0	0	90	21	1	0
71-80	15	6	0	0	36	20	2	0
81-90	11	13	4	0	37	8	0	0
91-100	16	5	0	0	36	33	0	0
101-110	24	4	0	0	27	38	1	0
111-120	6	18	0	0	53	70	3	0
121-130	47	33	0	0	92	125	0	0
131-140	25	3	0	0	144	197	0	0
141-150	0	0	0	0	20	3	0	0
151-160	0	3	0	0	10	1	0	0
161-170	0	0	0	0	2	0	0	0
>170	0	0	0	0	4	0	0	0

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Table C5 (b)

Number of Surface decompression dives which were decompressed with between 0 - 2 increments of table depth beyond that required.

Depth feet	1982				1983			
	Increment of Table Depth beyond that "required"				Increment of Table Depth beyond that "required"			
	0	+1	+2	>2	0	+1	+2	>2
0-70	2,517	146	9	4	2,126	112	12	7
71-80	139	123	2	0	189	376	22	2
81-90	116	83	4	2	209	249	8	2
91-100	144	113	4	0	250	291	17	1
101-110	553	698	3	1	827	452	42	0
111-120	236	276	4	0	297	574	21	5
121-130	372	645	3	0	434	680	25	0
131-140	425	108	0	0	351	80	0	0
141-150	100	16	0	0	44	18	2	0
151-160	9	29	0	0	18	21	0	0
161-170	111	0	0	0	121	2	0	0
>170	0	0	0	0	0	0	0	0

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Table C6 (a)

Number of In-water decompression dives which were decompressed with between 0 - 2 increments of table time beyond that required.

Time	1982				1983			
	Increment of Table Time beyond that "required"				Increment of Table Time beyond that "required"			
	0	+1	+2	>2	0	+1	+2	>2
1-10	2	10	12	1	18	74	12	2
11-20	35	51	10	1	416	114	8	2
21-30	53	18	0	0	134	60	5	1
31-40	16	5	0	0	74	14	2	0
41-50	10	1	0	1	54	27	2	0
51-60	8	7	0	3	62	28	1	4
61-70	19	6	1	0	60	23	2	1
71-80	19	0	0	0	64	27	2	0
81-90	22	4	0	2	58	20	4	0
91-100	23	14	8	0	35	27	5	0
101-110	24	13	1	1	26	29	4	1
111-120	12	6	4	0	62	10	0	0
121-130	15	1	0	0	15	6	0	0
131-140	9	1	0	0	8	4	2	0
141-150	11	0	0	0	3	1	0	0
151-160	1	0	0	0	0	0	0	0
161-170	0	0	0	0	0	0	0	0
171-180	0	1	0	0	0	0	0	0
181-190	0	0	0	0	0	0	0	0
191-200	0	0	0	0	0	0	0	0
>200	3	0	0	0	25	1	0	0

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Table C6 (b)

Number of Surface decompression dives which were decompressed with between 0 - 2 increments of table time beyond that required.

Time	1982				1983			
	Increment of Table Time beyond that "required"				Increment of Table Time beyond that "required"			
	0	+1	+2	>2	0	+1	+2	>2
1-10	4	10	0	3	6	2	4	1
11-20	20	40	19	5	26	51	19	9
21-30	124	223	56	2	104	285	68	16
31-40	251	359	104	44	386	886	111	69
41-50	626	309	18	117	543	259	38	182
51-60	419	298	48	178	263	574	35	97
61-70	506	230	17	30	395	283	20	28
71-80	134	82	8	5	183	146	13	17
81-90	121	63	21	15	236	174	32	5
91-100	80	76	26	38	172	192	26	4
101-110	109	86	46	16	237	182	10	36
111-120	304	125	92	19	381	259	40	31
121-130	270	45	111	0	137	34	25	0
131-140	121	118	2	0	91	45	11	0
141-150	62	23	0	0	78	5	16	0
151-160	58	2	1	0	94	8	0	0
161-170	136	5	0	0	65	4	0	0
171-180	248	94	10	0	15	30	2	0
181-190	68	3	0	0	8	2	0	0
191-200	32	11	0	1	4	0	0	0
>200	3	0	0	0	8	6	0	0

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Table C7

Analysis of dives which were decompressed on a table depth exactly equal to the dive depth.

Exact Depth of Dive (feet)	1982				1983			
	In-water Decompression		Surface Decompression		In-water Decompression		Surface Decompression	
	Number of Dives	mean *SF Index	Number of Dives	mean *SF Index	Number of Dives	mean *SF Index	Number of Dives	mean *SF Index
80	1	6.0	2	14.5	2	0.8	2	19.9
90	0	-	0	-	2	4.4	3	12.1
100	0	-	3	24.1	1	7.9	35	14.8
110	1	8.3	10	11.5	0	-	8	23.2
120	0	-	3	3.5	1	0.0	7	26.1
130	1	12.7	1	58.5	0	-	6	16.0
140	0	-	0	-	0	-	1	0.0
150	0	-	1	19.8	0	-	0	-
160	0	-	0	-	0	-	0	-
170	0	-	0	-	0	-	4	22.4
TOTAL	3	9.0	20	22.0	6	3.3	66	16.8

* In these dives, the SF Index is derived from the additional <u>time</u> element only.

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Table C8

Analysis of dives which were decompressed on a table time exactly equal to the dive time.

Exact Time of Dive (mins)	1982				1983			
	In-water Decompression		Surface Decompression		In-water Decompression		Surface Decompression	
	Number of dives	mean *SF Index	Number of dives	mean *SF Index	Number of dives	mean *SF Index	Number of dives	mean *SF Index
10	0	-	1	1.4	3	2.6	0	-
20	2	4.6	1	3.5	289	4.2	0	-
30	7	6.8	3	4.7	1	5.7	3	2.5
40	1	3.5	4	6.7	2	4.2	11	6.0
50	0	-	2	8.1	3	3.5	12	10.1
60	1	5.4	4	6.4	2	1.8	11	12.3
70	1	3.5	4	5.2	4	9.3	6	17.7
80	0	-	3	16.5	4	4.6	3	26.7
90	0	-	5	15.3	2	4.6	4	21.9
100	1	2.2	4	12.3	1	10.3	7	12.2
110	1	5.4	0	-	2	3.5	0	-
120	0	-	7	23.1	2	5.3	10	31.2
130	1	3.2	0	-	0	-	0	-
140	0	-	1	3.5	1	3.5	0	-
150	1	0.8	5	29.2	0	-	0	-
160	0	-	0	-	0	-	0	-
170	0	-	0	-	0	-	0	-
180	0	-	17	42.7	0	-	1	9.1

* In these dives, the SF Index is derived from the additional <u>depth</u> element only.

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Table C9

Incidence of DCS relative to the hyperbaric stress

	DECOMPRESSION PENALTY INDEX											
	82				83				TOTAL 82 & 83			
	≤ 30	30-60	60-90	>90	≤ 30	30-60	60-90	>90	≤ 30	30-60	60-90	>90
Number of Dives	3,600	3,359	474	32	5,580	3,342	513	107	9,180	6,701	987	139
Cases of DCS	5	22	7	1	9	24	7	3	14	46	14	4
Incidence	0.1	0.7	1.5	3.1	0.2	0.7	1.4	2.8	0.2	0.7	1.4	2.9
Number of Type I	2	12	3	0	7	13	5	2	9	25	8	2
Number of Type II	3	10	4	1	2	11	2	1	5	21	6	2

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Table C10

Incidence of DCS following Surface Decompression by increment of depth

Depth (feet)	Incidence of DCS			
	Type I		Type II	
	1982	1983	1982	1983
0-70	0.04	0.04	0.1	0.0
71-80	0.0	0.0	1.1	0.2
81-90	0.5	0.2	0.0	0.4
91-100	0.0	0.4	0.0	0.2
101-110	0.2	0.8	0.4	0.4
111-120	0.2	0.6	0.4	0.2
121-130	0.1	0.3	0.1	0.4
131-140	1.5	0.2	0.6	0.2
141-150	0.0	0.0	0.0	0.0
151-160	0.0	0.0	2.6	0.0
161-170	0.9	0.0	0.9	0.0

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Table C11

Incidence of DCS following Surface Decompression by increment of bottom time

Bottom Time (minutes)	Incidence of DCS			
	Type I		Type II	
	1982	1983	1982	1983
21-30	0.0	0.0	0.3	0.0
31-40	0.4	0.1	0.1	0.1
41-50	0.6	0.5	0.3	0.3
51-60	0.4	0.5	0.3	0.3
61-70	0.1	1.1	0.4	0.6
71-80	0.0	0.3	0.4	0.3
81-90	0.5	0.5	0.5	0.5
91-100	0.0	0.3	0.9	0.3
101-110	0.0	0.0	0.0	0.0
111-120	0.0	0.0	0.0	0.0
121-130	0.2	0.0	0.2	0.0
131-140	0.0	0.0	0.0	0.0
141-150	0.0	0.0	2.3	0.0

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APPENDIX D

Maximum bottom times for dives within DP Limits stated

Depth (feet)	Bottom Time (minutes)	
	DP limit of 30	DP limit of 20
40	360*	300*
50	180*	150*
60	120	100
70	90	80
80	70	60
90	60	50
100	50	40
110	40	35
120	35	30
130	30	25
140	30	25
150	25	20
160	25	20
170	20	15

* Note that these dives might exceed a maximum bottom-time limit.

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Table 10

DCS related to hyperbaric stress and decompression procedure

	Decompression Penalty Index					
	< 30		30 - 60		> 60	
	In-water Decompression	Surface Decompression	In-water Decompression	Surface Decompression	In-water Decompression	Surface Decompression
Number of Dives	2,081	7,099	31	6,670	4	1,122
Number of cases of DCS	4	10	1	45	0	18
Incidence	0.19	0.14	3.22	0.67	0	1.60
Number of Type 1 cases	4	5	1	24	-	10
Number of Type 2 cases	0	5	0	21	-	8

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