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NITROX & TECHNICAL RECREATIONAL DIVING: CURRENT SITUATION IN EUROPE, ADVANTAGES AND HAZARDS

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多くのレクリエーショントレーニング団体はこれまで圧縮空気のみを使って、停止不要限界内でダイビングすることをダイバーに教えてきました。そしてまた、受講生達に、安全に、かつ深く行きすぎないようにダイビングするよう勧めてきました。ここ数年の間に、スクーバ器材で高酸素濃度空気（“ナイトロックス”、EANx）を使うものが導入されました。かなり前から、ヨーロッパのスポーツダイビング団体の中にはこれに先行して、参加した人に減圧を計画したダイビングを教えているものがありました。こうした講習は必ずしもすべて十分に検討されているわけではありませんが、すべてのことは安全ということを強く強調して教えられていました。

こうしたスキルがマスターされると、こうした限界を越えて水中環境を探索したいとか、もっと深くに行きたいとか、ケーブやレックなどの探検までも望む人があらわれます。こうしたことを実現するのに、空気以外のガスや高酸素濃度空気（ナイトロックス）、それに特殊な器材を使うことを選ぶ場合もあります。こうしたダイバー達は、“テクニカルダイバー”と言われてきましたが、これは定義が不明確ですが、“テクニカル登攀家”のアナロジーで言われたものでしょう。

彼らは、そのダイビングでプロの器材を使うでしょうが、彼らが作業ダイバーでないことは認めなければなりません。

ここで検討するのに、既存のアドバンスト（上級）ダイビングとテクニカルダイビングの間の境界線を引くために、テクニカルダイバーは一回のダイビングの間に二種類以上のガスを吸うレクリエーションダイバーであるという定義を適用することにしましょう。こうして、この定義によって、当該潜水（酸素減圧停止を含む）で異なるプレミックス（前もって混合してある呼吸ガス：訳注）でレギュレータを替えるダイバーも、リブリーザーすなわち閉鎖式および半閉鎖式の呼吸器を使うダイバーもカバーできることになります。また、このアドバンスト（上級）ダイビングの検討においては、このテクニカルダイビングの定義に外れるいくつかのテクニックにも触れますが、それはそのテクニックではダイビング中に一つのガスしか使わないためです。

PART Ⅰ: CURRENT SITUATION EUROPE

Many recreational trainig agencies have taught divers to make dives only on compressed air, within the no-stop limits and have encouraged trainees to dive safely and not too deeply. In the past year the use of oxygen-enriched air (“nitrox” , EANx) in scuba apparatus been introduced. For many years a number of the European sport diving organisations have gone somewhat further than this and have taught planned decompression to all comers. Although these lessons are not always well remembered, everything has been taught with a great emphasis on safety.

Once these skills have been mastered, there are some individuals who want to explore the undersea environment beyond these limits, to go deeper, maybe for the exploration of cave systems or wrecks. To achieve this they may choose to use gases other than air or oxygen-enriched air (nitrox) and to use special equipment. These persons

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have been lemed "technical divers", a term which is ill-defined but said to be analogous to "technical mountain climbers". They may use professional equipment in their dives, but it must be appreciated that they are not working divers. They are still recreational divers with all the freedoms which that implies.

For the purposes of having a boundary between conventional, advanced and technical diving for this review, the definition will be adopted that a technical diver is a recreational diver who breathes more than one gas mixture during a single dive. Thus this definition covers both those divers who change regulators for different pre-mixes in the dive (including oxygen decompression stops) and those who use rebreathers', i.e., closed and semi-closed versions of breathing apparatus. Also in this review of advanced diving are some techniques which fall outside this definition of technical diving because they use only one breathing gas throughout the dive.

NITROX OR TEK-DIVE AND THE HAZARDS OF DEEP AIR DIVING

"How deep do you dive?" is one of the commonest questions any diver is asked. The questioner is likely to be unimpressed with a reply that the best photographs are taken only just below the surface. They are satisfied with only a large numerical answer. So, for reasons that seem obscure to some other divers, compressed air scuba has been used successfully to reach 156 m.

The hazards include nitrogen narcosis, oxygen neurotoxicity, carbon dioxide retention and "deep water blackout" which may be a particular combination of the first three. At 156 m the inspired pO_2 exceeds 3 bar. The number is not known, but it could be large, of the recreational divers who have exceeded that depth, or who merely have attempted to do so, but who have not returned.

Deep Water Blackout is part of an ill-defined and fortunately rare group of incidents which are usually reported as "Loss of Consciousness of Unknown Aetiology". These incidents are quite distinct from the identifiable causes of impaired consciousness at depth such as carbon monoxide poisoning and myocardial infarction. This phenomenon appears to be a hazard for only those compressed air divers who swim deeper than the limits recommended by the conventional recreational training agencies. Loss of consciousness underwater is a serious event, particularly for a diver wearing a half-mask and using a mouthpiece, simply because the most likely outcome is drowning.

Nitrogen effects

As is well known, the manifestations of nitrogen narcosis are proportionate to the partial pressure of the inspired nitrogen and, subject to individual variability. begin to be noticed during descent from around 30 m. Before codes of safe diving practice advised against colmpressed-air diving deeper than some. 50 m, experience demonstrated that only very few divers could accomplish useful work at depths greater than 90 m. Narcosis increases to the extent that early reports described a "semi-loss of consciousness" on air at depths as great 107 m, though this may have been associated with some CO_2 retention. Although compressed air has been breathed at depths as great as 180 m in submarine escape procedures, the duration of this exposure was deliberately kept within the latent period of onset of narcosis, a few seconds. One of the deepest recorded experiences of compressed air is that of Goodman (1973) who describes the glassy appearance of a diver's eyes at 144 m as suggesting those of the "firmly plastered drinker" and adds that after some 45 s the simple task of assembling pegs had deteriorated to mere fumbling. "Bending forward ever more closely over his precious' pegboard, with intermittent bursts of inappropriate laughter and hearty, self-satisfied chuckling, the subject has, after 90 s of air breathing, effectively retreated into a private world." What quality of judgement about safety procedures would one expect the average diver to make when in the water at around 150 m ?

The mechanism of narcosis is the same as that of the gaseous anaesthetics and that of alcohol intoxication: the individual passes through similar stages in each, from excitation to sleep. The biophysical basis for narcosis is well reviewed elsewhere (Bennett, 1993). Of interest here, in the practical situation, is the interaction and possible potentiation at depth of the effects of other respiratory gases, oxygen and carbon dioxide.

Oxygen effects

The pulmonary and neurological features of oxygen toxicity are reasonably well known (eg Donald, 1992) but oxygen as an "inert" (i.e. narcotic) gas has received less attention (Paton, 1967). The greater the depth of the oxygen exposure the greater the relevance of its other propertics and oxygen, not surprisingly, also potentiates nitrogen narcosis (Bennett, 1993).

Carbon dioxide effects

It was proposed that nitrogen narcosis is enhanced by carbon dioxide retention by Case & Haldane (1941) and this has been demonstrated by Hesser et al (1971). However carbon dioxide retention is not the cause of depth narcosis (Bennett & Blenkarn, 1969) and, indeed, the symptoms of depth narcosis and of carbon dioxide at depth are quite different. The CO_2 factor is likely to be worse in those air divers who may be "CO_2 rctainers" (Lanphier 1955).

The effecsts of high concentrations of carbon dioxide in the absence of oxygen lack were examined in an investigation of "Shallow water blackout" incidents among those diving on pure oxygen (Barlow & Meintosh, 1944). This showed an impairment or loss of consciousness when cxercising hard on pure oxygen breathed through 800 ml external dead space.

"Deep Watler Blackout"

Given the interaction between CO_2, oxygen and nitrogen at raised pressure, the concept of Deep Water Blackout was based on a few well-observed cases (Elliott 1996a). A special team of naval divers used to practise their 76 m air diving procedures in the controlled environment of the wet pot of a large chamber complex. One could watch on television screens how well divers performed hard physical exercise in the water at depth. Often the individuals were obviously narcotic, attempting to dissemble their equipment or responding to commands in an aimless mauner. On surfacing, "that was a good dive", they would have no memory of this and when shown the video of their errors, each would assert "not me, must be somebody else".

More worrying were the occasional lapses of several divers into unconsciousness. The divers were, of course, wearing a full face mask, so there was never any risk of drowning, and the unconsciousness was over in less than a minute but, for anyone using a half-mask and a mouthpiece, that would have been long enough to get into serious trouble.

Using the definition of "Technical Diving", which is a change of breathing mixture during the dive, deep air diving is not technical diving. Extreme scuba diving on air seems just stupid.

RECREATIONAL NITROX DIVING

In the last years PADI, SSI, IANTD, TDI and other agencies have commenced training with oxygen-enriched compressed air, nitrox (EANx). The nitrox is used with conventional scuba equipment dedicated to nitrox and some parts, particularly of the charging system, have to be "oxygen clean" to avoid combustion. The use of only one gas mix in the tank for the duration of each dive means that this type of diving, though more advanced than conventional recrcational diving, is not "technical diving". Diving with pre-mixed nitrox in open-circuit scuba is a variety of regular recrcational diving and must be distinguished from the use of premixed nitrox in semi-closed circuit rebreathing apparatus. The gas composition breathed in such apparatus changes during the dive which makes them a part of technical diving.

Any oxygen level greater than 21% can be used for open-circuit nitrox but in common use are premixed 28%, 32% and 36% oxygen in nitrogen. In a two tank boat trip a leaner mixture would be used for the fist (deeper) dive and a richer mixture for the second and shallower dive. The advantages to the user of nitrox are either a prolonged no-stop time on the basis of the "equivalent air depth" (EAD) or, if one sticks to the air tables, a safer decompression. One cannot have not both at the same time.

For the purposes of calculating decompression one can ignore the oxygen content of a breathing gas (even though oxygen certainly influences vasomotion and thus perfusion). When breathing an oxygen-enriched air mixture, the nitrogen uptake at depth is reduced and can be considered the same as that when breathing air at some shallower depth, the "equivalent air depth" (EAD). The EAD can be calculated for any percentage oxygen level:-

$$\frac{\text{EAD} = (\text{Actual Depth} + 10)\text{x}N2\% - 10 \quad \text{Metres}}{79\%}$$

The prolonged no-stop time when using the EAD is somewhat illusory, at least on a first dive, because at depths shallwer than 25 m the dive duration will be limited by the capacity of the tank, not by no-stop time. Oxygen safety limits maximum nitrox depths to around 36 m.

The calculations needed to predict the safe duration of a repetitive dive on nitrox are fairly straightforward even if the shallower second dive is on a richer oxygen mixture. But some divers do get their repetitive calculations wrong even on air and, using nitrox, there are simply more opportunities for error.

By ignoring the Equivalent Air Depth when breathing nitrox and using the air decompression tables for the actual depth dived, the risks of decompression sickness are reduced. As there is already a very low incidence of decompression sickness when using air it would be very difficult to see any improvement in a large population when using nitrox (Hamilton, 1995).

However it might be worthwhile in those over 40 years old in whom spinal decoompression sickness appears to be more prevalent.

THE REBREATHERS

Recreational divers are exposed to numerous articles in the magazines about rebreathers. There are many types of rebreathers from the closed circuit designs with sensor controlled sslf-mixing of oxygen and diluent for deep cave and wreck exploration to the semi-closed rebreathers without sensors for use with pre-mixed oxy-nitrogen at shallower depths. It is Important to clarify the different categories of rebreathers and to consider for different uses the merits and disadvantages of their different gas flow systems (Elliott, 1996b).

Semi-closed Rebreathers

Unlike open-circuit systems, in which the composition of the supply gas should be constant, and unlike closed-circuit systems, in which the composition of the inspiratory gases is capable of being provided precisely, the semi-closed system is a dynamic system. The breathing bag provides the diver with gas the composition of which changes during the dive.

The designs now being introduced to recreational diving are derived from those of military origin using an oxygen-rich nitrox pre-mix but first there are some other types of semi-closed rebreather which need to be mentioned briefly to avoid ambiguity. The first semi-closed rebreather was the deep standard divers' open-circuit helmet and was supplied by a hose. Within the large semi-rigid system of the helmet and the upper portion of the associatcd dry suit there was no need to have a countterlung in the circuit. Rebreathing occurred within the helmet which was supplied from the surface at a predetermined flow rate, sufficient to minimise the carbon dioxide build-up. In the deeper versions of the helmet, the constant flow of fresh oxy-helium to the diver was fed through a venturi which caused a proportion of the gas in the helmet to be recirculated through a soda-lime canister. This apparalus was used up till the early 1970's.

To save expensive helium, there is a commercial breathing apparatus which uses a hose to provide oxy-helium to a semi-closed set with a counterlung or breathing bag. This oxy-helium semi-closed set necessarily uses oxygen percentages of less than 21% and so is used only from a diving bell. To allow for the varying levels of oxygen consumption within a specific depth range, the flow rates have to be relatively high. This means that, at around 150 to 200 metres, these semi-closed sets no longer provided helium savings over open-circuit demand breathing apparatus. Nevertheleoss there are several locations where these units are still operational.

There is a semi-closed set which was developed for the Royal Swedish Navy and which is a "self-mix" unit. It has a constant oxygen flow rate and a separate helium supply which is increased with depth. With such a breathing apparatus the potential problems again relate to the varying need for oxygen during a dive.

Equally ingenious, but slightly more complex to use, is the constant ratio semi-closed circuit principle (Williams, 1969). This devie was first used by the French Navy and is based on degning the breathing bag as a bellows system. Within the counterlung is a separate smaller (1:11) concertina bellows, the slave, which follows the movements of the main breathing bag precisely. Thus each of the bellows are filled from the lungs at the same time when the diver exhales but, when he inhales from the main compartment, the slave (one eleventh of the previous exhalation) is discharged into the sea. The larger of the bellows is fed on demand from the pre-mix gas supply.

There is also a Canadian semi-closed breathing apparatus which is said to deliver a constant partial pressure of oxygen to a depth of 95 m but, as with any new apparatus, one would want to see rigorous manned testing at high work levels with oxygen monitoring before accepting iL. The majority of the nitrox semi-closed breathing apparatus now being marketed to the recreational diver is based on a pre-mixed gas delivered by constant mass fiow.

PART II : HAZARDS

HAZARDS OF VSING NITROX

Besides the benefits of using nitrox there are also disadvantages. These include explosive risks associated with the use of oxygen and the possibility that mistakes can be made in mixing the oxygen and air to make one of the appropriate percentage mixtures. "Top-ups" and other home brews can be lethal and the diver must always get the tanks filled by a reputable nitrox agency and each tank needs to be analysed for oxygen content and labelling the presence of the user. Serious mistakes can also be made if the tank which is selected on a boat for the next dive is of a mixture inappropriate for that particular depth of a dive. Perhaps the greatest concern is the risk of drowning, especially when using a standard regulator with a mouthpiece, if an epileptic fit due to acute oxygen neurotoxicity occurs underwater.

There is no safe maximum cut-off value for oxygen, one is dealing with the probabilities for which the data are scarce. One recreational agency puts pO_2 1.4 forward as the maximum advised; BSAC, PADI, IANTD and TDI use pO_2 1.44 bar. Only for exceptional tasks, such as diver rescue, would they go as far as 1.6. Nitrox diving with a maximum pO_2 1.5 bar is used regularly by the commercial diving industry but only with much greater control of the diver and his or her safety. The gas is supplied by hose and is analysed accurately to determine the maximum safe depth for that percentage oxygen while the depth of the diver is monitored continuously on-line. The diver uses an open-circuit demand regulator and usually wears an oro-nasal mask within a band-mask or helmet which is not likely to be lost during an epileptic fit.

HAZARDS OF USING NITROX REBREATHERS

Counter-lung theory

In most of the semi-closed oxy-nitrogen rebreathers now made for the recreational diver, a pre-mixed gas is supplied at a pre-determined flow rate to a counterlung or breathing bag. The fresh gas is mixed there with the gas already present, much of which has just been exhaled and scrubbed of CO_2. Thus the diver breathes in from the counterlung and exhales through the scrubber back to the counterlung from which excess gas is vented at virtually the same rate that fresh gas is being supplied Calculation of the oxygen percentage in the counterlung is based on a simple formula which is independent of depth. In the steady state the percentage of oxygen in the breathing bag may be given quite simply by:

$$\frac{O_2\%= (O_2\text{flow}- O_2\text{ consumed}) \times 100}{(\text{Mixture flow} - O_2\text{ consumed})}$$

As can be seen, this percentage is independent of depth and, once the supply flow rate bas been set for a particular prernix, the only variable is that of oxygen consumption. The oxygen percentage is also independent of the volume of the breathing bag. The volume of the counterlung, or more strictly that of the whole breathing circuit including the lungs, will affect only the rate of change flom one steady state of oxygen consumption to the next. The rate of change of oxygen content in the cunterlung when the diver's work level changes can also be calculated (Loncar & Omhagen. 1996) but, with a small circuit volume in relation to a raspiratory minute volume for divers of around 20 I.min-1, this transient. phase is brief in relation to the ability to sustain hard work.

Given a pre-determined flow rate to the breathing bag of premix gas with a known composition, the formula above can be used in maintaining the oxygen range within predictable upper and lower limits. Thus the dolminant variable during the dive is that of oxygen consumption and will be detertmined by activities ranging from minimal muscular effort (perhaps when composing a photograph) to maximum sustainable breathing capacity (in some life-threatening situation).

An oxygen consumption of around only 0.25

l.min-1 is widely accepted as a lower limit. This value is therefore used to determine the highest percentage of oxygen that could be found in the counterlung, a percentage approaching that of the premix gas. The maximum allowable pO_2 can then be used to calculate the maximum depth permitted for that flow rate and mixture.

The other extreme, the maximun sustainable oxygen consumption, is more difficult to predict. For a diver of average size and reasonable fitness', a O_2 max of at least 3 l.min-1 can usually be expected and is almost universally accepted (Lanphier & Camporesi, 1993). For the elite athlete performing out of the water an oxygen consumption exceeding 7 l.min-1 can be sustained (Whipp & Ward, 1994; Harries 1996). It is also known that maximum voluntary ventilation (MVV) and maximum breathing capacity (MBC) are significantly reduced at raised environmental pressure, and by as much as around 50% at. 45 m. Nevertheless, for counterlung calculations the Royal Navy and the Royal Ausrtralian Navy use O_2 3 l.min-1 and the U.S. Navy and at least one manufacturer use 2.5 l.min-1. Given also that apparatus for sport diving is not denied to exceptional athletes, the figure of at least 3 l.min-1 for maximum sustainable O_2 should be used as the value appropriate for semi-closed apparatus at all depths.

An implication for the diver using apparatus setup in accordance with calculations based on oxygen consumptions lower than these extremes is that, when maxinmally exercising, the diver could well sustain an oxygen consumption greater than the volume of oxygen provided. One semi-closed rebreather currently available provides the diver with only 5 l.min-1 of 40% oxygen according to figures which have recently been confirmed with that manufacturer. At a possible O_2 1.75 l.min-1, with a constant mass flow of 5 l.min-1 40%· oxygen, this apparatus will supply the diver with pO_2 0.3 bar at its advertised maximum depth of 30 m.. However, this would be achieved with only around 8% oxygen in the breathing bag which would mean not only an equivalent air depth of 36 m but also that it would not be a safe mixture for making the ascent. The procedure of flushing through the breathing bag with fresh gas before leaving maximum depth is a wise routine and, if no gas is left, a mini-bottle of air or nitrox with a demand regulator could be life-saving.

That example of 5 l.min-1 is particularly extreme because other manufacturers and several training agencies recommend double that flow rate for 40% oxygen. Yet even these higher flows do not solve all the potential problems. An oxygen consumption of 2.5 l.min-1 can be sufficient with a 40% oxygen premix at the manufacturer's constant flow setting of 9.2 l.min-1 to bring counterlung oxygen content down to 17.6% oxygen and so reverse the advantages of using an "equivalent air depth" for decompression.

Because decompression tables require to be entered at the deepest, depth of the dive, how can one estimate the deepest EAD of the dive? Is it valid to make an estimate based on an average oxygen consumption? In particular, as the actual EAD varies during a dive and sometimes may tend towards being deeper that the actual depth, how can a safe decompression ever be planned?

It is possible that there is sufficient padding in the decompression tables that these questions about unpredictable EADs and decompression are relatively academic, but the data needs to be collected and published. In the meanwhile, the active diver using semi-closed apparatus might prefer to plan on using the air dcecompression tables for the actual depth dived.

A request to a particular manufacturer for basic data from manned testing on actual levels of oxygen in the breathing bag during hard work revealed that no such data was available. Gas samples for both O_2 and CO_2 from breathing bags at the O_2 extremes during shallow manned trials by exceptionally fit divers need to be taken at a laboratory experienced in diving physiology and analysed, preferably before settings such as flow rates are decided.

Wisely perhaps, some of the training agencies using one particular semi-closed set have increased the recommended flows and reduced the recommended maximum depths for some mixtures. It is not known if such decisions are based on measurement or, more probably, intelligent guesswork, nor is it known if the same safety factors are likely to be introduced worldwide by all the specialist training agencies.

Thus diving with semi-closed rebreathers introduces several hazards which are not encountered by those diving on open-circuit compressed air scuba. The potential consequences include dilution hypoxia, hyperoxia, hypercarbia and soda-lime cocktail'. Members of this and associated organisations need to be aware of these problems and be prepared to educate if and when the agencies and manufacturers provide misleading or exaggerated statements.

FURTHR NOTES ON ADVANCED RECREATIONAL DIVING

THE PRACTICE OF OXYGEN DECOMPRESSION

The use of oxygen breathing during decompression is routine in naval and commercial air diving. It is also used by some mixed-gas recreational divers, sometimes supplemented by EAN at deeper decompression stops. The supply of oxygen to the diver on an air hose by switching it at the surface provides a risk of breathing oxygen at the wrong depth but so also does the practice of changing from the regulator of one tank to that of another at depth. The safest procedure seems to be when the oxygen bottle and regulator is suspended from the surface and awaits the diver at a known depth.

The use of oxygen breathing during a surface interval between dives is probably beneficial as a prophylactic and has a sensible basis in theory. However any quantitative prediction of its efect upon the reducing the need for decompression in a subsequent dive is unteseted.

CLOSED CIRCUIT OXYGEN

This type of apparatus has a carbon dioxide scrubber and a simple counterlung or breathing bag which is full of oxygen from which the diver breathes. As the oxygen is consumed so more oxygen needs to be released into the breathing bag from the cylinder carried by the diver. This can be done "on demand" when the diver thinks that the rebreathing bag is getting low. This is a potentially dangerous procedure because, during the dive, dissolved nitrogen is being washed out of the body into the rebreather's closed system. As the bag diminishes in volume with the consumption of its oxygen, nitrogen comprises an increasing percentage of the bag's content. Unless more oxygen is released into it in good time, the point can be reacbed when the counterlung provides the diver with a hypoxic mix. Hypoxia is usually associated with a CO_2 build up but, with a CO_2 scrubber in the circut, the diver is likely to be totally unaware of the diminution or oxygen. Then diver may pass gently into unconsciousness due to "dilution hypoxia" and death is likely to follow. This may happen at depth but, if not there, could be precipitated by the subsequent fell of pO_2 occurring during ascent. To avoid this, an oxygen diver breathes for 2 minutes from the breathing bag while at the surface and then empties it and its contained nitrogen before recharging the counterhing with pure oxygen. Then the descent can begin. This one "nitrogen wash out" is sufficient for a 90-minute dive in a typical naval rebreather.

Because breathing "on demand" can be particularly hazardous, the diver is usually provided with a constant mass (i.e., a constant surface equivalent volume) of 1.5 litres of oxygen per minute into his breathing bag. In spite of this constant mass flow, dilution hypoxia can still be a hazard. If, for instance, the oxygen bottles have perhaps leaked or they empty earlier than expected, the diver may be unaware that his counterlung contains an diminishing percentage of oxygen as he heads towards an anoxic death. Another problem can occur if the working or swimming diver exceeds 1.5 l.min-1 O_2 without noticing that the bag is getting smaller. The diver is "beating the flow" and could be heading for hypoxa.

MIXED GAS DIVING

The technical diver is usually in one of two categories: the wreck diver or the cave diver. The wreck divers tend to be solo and carry all their gas on them: oxy-helium or trirmix (air-helium) for maximum depth, nitrox and oxygen for their drift decompressious. The cave divers use the same kind of mixes but tend to work in teams, laying out their tanks along the route of their explorations in a number of earlier dives. For maintaining thermal balance, dry suits are inflated with argon. Whether oxy-helium or air-helium (trimix') is breathed for the deep phases of a dive the hazard of the High Pressure Neurological Syndrome (HPNS; Bennett & Rostain 1993) will be present. The actual dives and decompressions are planned together with estimated gas consumptions of each of the gas mixes provided to give an additional 30% or so gas redundancy for safety. The tachnical dtver also seems to possess a faith in the mathematical accuracy of decompression theory which is difficult to share.

Should decompression illness arise, there is probably no treatment immediately available to them other than oxygen by mask.

CLOSED-CIRCUIT MIXED-GAS

The self-contained and the hose-supplied closed-circuit mixed-gas apparams are both closed circuit bur are totally different designs. The diver breathing from a hose-supplied closed-circuit apparatus is supplied by hose from the bell to the diver and, after exbalation, the gas is returned by a parallel hose to the bell or to the surface -where the CO_2 is scrubbed and the O_2 replenished. An advantage of these extended closedcircuit systems is that the diver breathes from a conventional demand valve during the dive and, provided the technology does not fail, shouid not be at risk from hypoxia, hyperoxia or hypercarbia.

Many versions of self-coniained closed-circuit mixed-gas rebreathers been developed in the past 25 years. They "self-mix" the respiratory gas from two gas bottles, one of inert gas, usually helium, and the other of pure oxygen with a remarkable reliability-A constant partial pressure of oxygen, around 0.7 bar, can be monitored by sensors and maintained at any depth. Duration is limited only by the capacities of the gas supply bottles and the duration of the scrubbing system. This type of apparatus has good breathing characteristics in the water and shoud maintain the inspired gas within defined physiological limits.

For the recreational diver a closed-circut apparatus provides extended duration at any depth withoul the need to carry large volumes of gas. Reliable sets should provide reasonably warm breathing gas and few problems. These sets should be physiologically as safe as one could wish and only if the technology fails would the diver be exposed to the hazards of hypoxia, hyperoxia or hypercarbia. Only other problems like HPNS and safe decompression, which are unconnected with the breathing apparatus, will limit their potential at the deeper recreational depths.

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