and whose exposure at any one time has not exceeded four hours."

Do you want me to go on? You can get the gist. On the whole it is annual, but for young guys and people who dive at less than 30 metres, and do not stay under for more than four hours, they will be about every three years.

COMMERCIAL HELIUM-OXYGEN DIVING

David Elliott

Diving is a subject in which you are all obviously interested, so having given you some fairly serious papers, I thought that it was time to give you one which is really of interest value only. But, nevertheless, as doctors involved in diving, it is worth your while knowing what is going on in the commercial diving field, if only to appreciate the fact that diving is a very important part of occupational medicine and applied physiology.

Pressure affects every ceil of the body. In fact there is hardly a system that is not affected by pressure. I would remind you that many bio-chemical reactions in the body are not iso-volumetric, which means that they will either be inhibited or accelerated by pressure. This means that literally every cell of the body is affected. There are various rather subtle enzyme changes that can go on in man when he is at very great depth. Pressure is used as a research tool, as an additional variable to basic physiology. There are a number of physiologists who are interested in the effects of pressure, who study various uni-cell preparations and other systems in order to test how pressure affects physiology. I think that it is worthwhile appreciating that there is a lot more to diving applied physiology than the somewhat easy version which we teach in the courses for divers and so forth. I feel very strongly that diving should be part of applied physiology training, because it is a very useful academic subject in the area of altered physiology. I also believe that more occupational medicine should be taught in medical schools. I think as diving doctors and as hospital consultants this is something that you can influence in the future.

Having finished my little sermon, let me now get on to the diving which I am working in myself. Diving is indeed a limiting factor for the future of the offshore gas and oil industry. This talk will not be diving medicine, it will be about practical diving and diving physiology.

The diver is regarded as nothing more than a versatile, effective and relatively cheap underwater tool. If the job could be done by some mechanical device the engineers would prefer it. So far as they are concerned the diver is just a damned nuisance, because he is a biological specimen. Things can go wrong and when they do everything else on the platform can come to a stop. Divers are cheap, and they are versatile, but they are not very popular. But with good diving procedures and well maintained equipment accidents are quite rare. Our problem is that as divers go to deeper and deeper depths, as the world needs oil from deeper water, so the margins of safety for divers associated with the oil industry are getting less and less. Also the cost of supporting a diving system at great depth increases enormously.

This has stimulated a number of developments such as JIM, which is a one-atmosphere suit. I imagine that most people in Australia are familiar with this because it has been used extensively, both in Bass Strait and on the North-west Shelf. The thing about JIM and the other one-atmosphere systems is that the man is totally protected from the high pressure environment. Therefore there are no physiological problems of any significance. The difficulty is that JIM, although pressure rated now to 2,000 feet, is cumbersome. For instance, if he gets his foot caught in something he can not reach down below his knees so another JIM would have to have to be used to rescue him. It is so big that if you design an underwater manifold system for the pipeline you have to design it three to four times as large as you would have to do if you had a diver to do the same job. That costs a lot more money than employing a diver in the first place. Sometimes it is cheaper to employ a diver to do the job because it is so cumbersome. JIM and remote controlled unmanned robots were supposed to virtually replace divers from the off-shore scene. Like most predictions this one was considerably premature. In fact the only place where JIM really works is on the exploration side. Here the drill ship is just testing a well in some remote part of the sea and occasionally may need to send JIM down to do something at the sea bed. For the construction phase of the oil field and later for the life of that oilfield, when there has to be maintenance inspection and occasional repair, there are a lost of tasks for which JIM is quite unsuitable.

Welding underwater is often required. One uses a thing called a pipe alignment frame. The pipe alignment frame links up the bits of an underwater pipeline that have to be joined. The frame is quite a big piece of engineering. The bell will come down and the divers will either get out of the bell and do some sort of job in the water, or they will blow down the little inverted habitat inside the frame and work in a dry environment to weld the two ends of the pipe together.

Divers are essential to the kind of work which the gas industry and the oil industry will need in the future. Therefore the priorities are to try to determine how deep man can go in the open sea to work both effectively and safely, because that is the limit for what we can get back out of the sea in the way of oil and gas. That is my primary job for a particular oil company. Rather surprisingly, there is no other oil company that does this sort of thing. I think they are hoping that we will do it for them. But in the meanwhile we have got a head start on them and are far better able to bid on offshore contracts, because we know as much about commercial diving as any diving concern.

What I would like to do next, is to give you a synoptic history of helium diving. Although I am tempted to go back to the year 1906, when there was a record air dive to 310 feet, I think I had better begin in the early 1960's, which is when it all began to take off. At that time the world record was held by the Royal Navy. It was 600 feet with a bottom time of about 6 minutes. Commercial deep diving at that time was limited to bounce dives to about 450 feet with about 30 minutes bottom time, sometimes stretching to 60 minutes. The divers were normally ex-USN divers using ex-USN hard hat equipment and US tables. I can well remember the way that they treated their bends. They did entirely in-water stops and they would shout over the intercom "Hey, Bill, let out a bit of slack". That is the way they treated any bends on the way up. It was a pretty dodgy game and that is as recently as 1960.

At the same time and at very much shallower depths, only about 30 feet to 100 feet, the USN Sealab 1, with George Bond and the Con-Shelf One with Cousteau were beginning to gain some public attention. They were pioneering the idea that divers might like to live in an underwater city. I have yet to meet a commercial diver who agreed with that particular idea. So it was a bit of a red herring, although some of the research has indeed been relevant.

Against this dominantly naval background, the Royal Navy doing bounce diving and the US Navy doing saturation diving in a habitat, we began to get stories of some crazy Swiss mathematician doing impossible dives and coming up in a time that should surely kill him. This chap, Hans Keller, and his medical advisor, Professor Buhlmamn from Zurich University, were thought to be using secret gas mixtures in order to do decompressions which were just so rapid as to be potentially lethal from our point of view. Nevertheless, they managed to do a 1,000 foot dive under the eyes of the French Navy, in their chamber in Toulon. Next they got US Navy support and did a dive, using a Shell platform, off California, to 1,000 feet. There is some doubt as to just how much Hans Keller managed to do in the water at 1,000 feet, but he certainly got out of the bell, because it was his fin that stopped the lower door from closing after that. But he was very short of gas because there had been a leak overnight and they were using the last bottles to do their dive. So it was not done in a particularly efficient, good diving manner. The result was that his buddy died on the way up from decompression sickness. The standby diver sent down from the surface to try and close the bottom door was swept away and never seen again. So you can understand that the Americans who witnessed that, both the Navy and Shell, really thought that there was no future in deep diving. The USN then continued their saturation diving in shallow depths while Shell proceeded to develop a thing called the Lockheed system.

The Lockheed system is a one-atmosphere system. One has a typical open sea workboat with an A-frame containing what looks like a diving bell. That is a one-atmosphere bell and it is an absolute dream to go in for a diver because it is so comfortable. This bell is lowered onto a sea bed habitat which is also one-atmosphere. Engineers can go down and do any maintenance and then shut the door and come back to the surface. That sounds like a jolly good system because you do not have to use divers. But there are a number of problems which we need not bother to go into. One is the vast expense of maintaining the surface support. Another is that Lockheed rather oversold it by saying that it was a "shirt-sleeve" environment. For an engineer who has never left the surface before it could be quite terrifying. But for anyone who has been diving in a bell it is an absolute breeze. So the Lockheed system was born. That was the basis of most American commercial developments in the next few years, with one notable exception, which I shall come to later.

Shell formed a diving company and commissioned Professor Buhlmann and Hans Keller to do research. We only got rid of that company two years ago. He had been working for us for 18 years and had done a lot of good work in that time.

So in Europe we began to feel that Keller had done, in spite of those fatalities, a lot of good work. It was a tremendous breakthrough. Immediately, the Royal Navy resumed its bounce diving. This is where I came in. A 600 foot, one hour bottom time dive done in the 1964-65 season, off the south coast of France.

What we are talking about, whether it is a saturation system or a bounce dive system is a deck decompression chamber and a diving bell. The bell goes down and gets to the bottom. It equalises with ambient pressure so that the divers can get out. They return to the bell and shut the bottom door. The bell is hoisted to the surface kept at the pressure of the bottom. It is then locked on to the deck chamber at the same pressure. After they have transferred the divers can do their decompression, if it is a bounce dive, comfortably in the chamber. If it is a saturation dive they can stay there and live at that depth, going down later as required.

The most significant commercial development at that time, 1965, was the first commercial saturation dive, for the hydroelectric scheme on the Swiss Mountain Dam.

What has been happening since then? We have just been trying to make the divers go deeper, longer, and do it more safely.

Saturation Diving

A bounce dive with 15 minutes bottom time at 450 feet requires approximately 5 1/2 hours of decompression. So if you get an hour's working time, of which a lot will be taken up in getting out of the bell and all that sort of thing, you have got to have more than a 24 hour availability of men. Gas uptake reaches equilibrium after about 6-12 hours, the precise time is neither agreed nor known. If you stay longer than that and become equilibrated, then there is no further uptake. Since there is no further uptake the decompression penalty will not increase any further. So after you have been down at the bottom for nearly 24 hours the decompression profile will be identical even if you were to stay there a month. That is exactly what is done.

The concept of saturation diving is, you go down, you stay there, achieve equilibrium and then it does not matter when you come up. You may just as well get the job finished and then come up slowly. The only difference now is that we tend to saturate at a depth somewhat shallower than the working depth, and then make little bounce dives each day to the working level. That means that if one has to use a hyperbaric lifeboat the divers may be 150 feet nearer to safety than they would otherwise be. It is also something of a bother because we think that may be what is causing bone necrosis. But we really do not know.

I would like to show you a pressure chamber which was actually built, welded together, stressed, in the basement of a hospital. There is a ward immediately above it. So the engineering, the airconditioning system, the great heat stress, was quite a challenge. It is a 1,000 metre system, and it was designed by the same man who designed that little one man chamber that was in the Swiss helicopter. One can go down at a rate of 500 metres in 50 minutes, maintaining ambient temperature at 32°, which is what the diver requires, and also maintaining the noise level at less than 20 decibels. It is beautifully designed.

You were shown a film of JANUS IV in Singapore. It was a combined dive by the French Navy and the Comex diving organisation, off the south coast of France. My slide picture was taken at 450 metres in the open sea. They actually did 10 minutes at 510 metres, which is the deepest that man has been in the open sea. But unfortunately a piece of Comex breathing apparatus packed up, so it was not really a working dive. Nevertheless, it shows that man can get in the water and do beautiful work at those depths.

Perhaps the world's best deep-diving unit is in Panama City in Florida. Unfortunately, I have absolutely no say in its management because it belongs to the USN. It has got a saturation living system at the top and underneath there is a floodable chamber that can take a 32 feet submersible. The whole thing will go down to 2,000 feet. They employ four doctors, twelve medics, and sixty divers. Their research effort is as great as the rest of the world put together.

We are not very interested to find the maximum depth that man can work. Really what we are interested in is, how well can man work in cold water and in breathing apparatus. One needs a decent breathing apparatus with good communication to the surface and heating of the inspiratory gas. The other thing which bothers us a little bit is whether there are any long term consequences to the health of the diver. The answer, at the moment, is that although we have found various changes and enzyme changes at depth, it all appears to be transient. But by transient I mean that they go within a few months of surfacing.

Last year you had John Miller on the Duke University dive in 1980. Shell put $50,000 into Duke University's dive in January this year (1981).

One needs a little bit more gas for a deep chamber dive than one does for sports diving. The oxygen content of the gas has to be monitored very closely. It is 0.72% at maximum depth, so that has to be kept within about O.05%. They were doing pulmonary physiology, including breath by breath 0_2 and CO_2. So the standard of gas calibration had to be absolutely superb. They had two technicians working for one year just to calibrate all the gases they needed for that dive. They went doom to 2,165 feet in the first instance, which is the depth that they just achieved last year. John Miller was once again responsible for the medical aspects of the dive. I was just a visitor. They performed all the normal sorts of cyclometric tests. There were three professional divers inside and each one did an arterial puncture on one of the other divers and had no trouble in doing it. I consider that is a major measure of their mental and physical ability at depth.

At that depth one diver did 240 watts for 5 minutes. I think that effort on the exercise bicycle is best compared to running a 5 minute mile in mud with Wellington boots on. He was a little bit knackered afterwards, but his $PaCO_2$ remained pretty good. It did not go up very much. So that shows that man can work very hard at very great depths. It shows too that we can hope that man will perhaps one day get to those depths in the sea. Then they went deeper and did 24 hours at 2,250 feet. They had more than eleven days deeper than 2,000 feet. That is the deepest that man has ever been to in high pressure chambers.

The deepest and longest that man has ever worked in the sea commercially is half that depth. That is the bottom bit of the Cognac Platform, at a depth of 1,025 feet. To place it, two derrick barges were used with a saturation system on each. This was for Shell, and I was quite heavily involved.

The saturation system on one of those barges has an entry lock to the deck chamber and a mating diving bell, which is hoisted by an A-frame. There is the saturation shack where they monitor the gases and pressures and generally look after the men who are living in the chamber. There is the dive control shack where they look after the bell. There is also the most important thing in diving monitoring, the little mobile eyeball known to the divers as "Harvey". If he did not come and watch them they used to beckon him over and pat him on the head. It is very useful because they position the work basket and the bell right next to the job, which has been pre-planned. The diver would not come out until all was ready, and topside were able to see everything the diver was doing. That diving was over a period of two years. The divers worked more than 14,000 man hours at more than 900 feet. There is a great gulf at present between what can be done commercially and what can be done in a University laboratory.

So the next emphasis is how we are going to bring them together, because commercially we do not have the equipment of the USN Experimental Diving Unit. I mentioned when I was dealing with contingency planning both the Lost Bell and Polar Bear project, which is what was done at the Norwegian Underwater Institute in Bergen. The chamber only started work in February 1980. It is rated to 650 metres and has two living chambers, a transfer lock, and a wet lock, rather like the one at Panama City, but a quarter of the size. They have got a bell which theoretically can take divers from the living chambers and lock them onto the wet part. But they do not do that, because they only have a second-hand bell. The Polar Bear Project, which Shell sponsored and ran, had help from the by Department of Energy and the Norwegian Training Directorate. When we were running the Shell doctor's course in Bergen last year I was pleased that the Norwegian Shell Company came along and said that they would sponsor this complex, as Shell's contribution to Norwegian Research, because oil companies have to make a contribution in Norway if they want to have any hope of getting a contract for development.

Last November we did a 300 metre dive in this chamber. The purpose of that really was to weld the two together, I think they made every mistake in the book, but they came out of it very well indeed. They are now so confident that we are going to do a 500 metre dive in that chamber. You can actually have a dry compartment and then a wet compartment in a horizontal chamber. We are going to send one team of men down to 500 metres on oxy-helium rather like the USN has done and Zurich University has done, and Professor Lambertson has done. In the other chamber we will take the divers down on the Duke University profile with added 10% nitrogen. We will then compare the two groups of divers when they hit maximum depth. The emphasis is not on the academic as much as on the practical. Our real objective is to simulate open sea conditions in cold water and test breathing apparatus, heating systems and communications systems.

DISCUSSION

Question:

Is there any move to try hydrogen in deep diving or can we expect to go from Trimix to yet a more complicated mixture?

Dr David Elliott

Hydrogen is a very good diving gas. It is less narcotic and lighter than helium. It does have a tendency to explode on contact with air, but if the oxygen content is less than 4% it is non-combustible. The Swedish Navy, many years ago did some very successful dives on hydrogen, but unfortunately a diver died due to a simple procedural error. He was pulled to the surface, when they should have given him a few stops, which was rather tragic. But that death killed the Swedish Navy's interest in deep diving. But it was not the fault of the hydrogen.

The USN has commissioned research on hydrogen. There have been some rather horrendous explosions during this research. It is a very good diving gas and the difficulty is how to use it safely. In about 1967 Comex did a hydrogen dive. They went to about 200 feet on helium. The hydrogen was stored outside the diving bell and there was a little air lock outside the diving bell. They went into that little lock and switched gases when outside in the water. That is safe and I think that is the only safe way it can be done. Otherwise the hydrogen must at some time get back to the surface and be an explosion risk. Peter Bennett would far rather use hydrogen instead of nitrogen and helium as his diving gas but, needless to say, the hospital will not allow him to do so. Although it is safe to use at great depth, it is not safe to have it near the surface, so far, commercially.

Question:

What are the oxygen partial pressures used in deep diving?

Dr David Elliott

I will talk in fractions of an atmosphere. You have not much margin to play with as far as gas mixing is concerned. You have got to keep the oxygen partial pressure between 0.21 and 0.6. Above 0.6 you are liable to get pulmonary toxicity. Keeping it about 0.4 or 0.5 is about halfway between the two. In fact it has been shown that man is slightly physically more effective on 40% oxygen than he is on 20%.

Question:

In experimental diving do you have to continually monitor and adjust oxygen levels?

Dr David Elliott

Yes. This is a problem with very deep diving. You virtually need a complete university department to do a dive like Peter Bennett's. How are you going to translate that into commerce for practical diving? That is my problem.

Question:

How can you have wet and dry compartments in a horizontal chamber?

Dr David Elliott

One has two transparent vertical partitions, one from the roof (A) and one from the floor (B). They overlap by a couple of feet. (Figure 1). Water is put in the chamber on the side of the floor partition (B) that has the roof partition (A) coming down. Once the water reaches between the two partitions the pressure on the water surface at (C) will stop water getting into the rest of the chamber. Then more water is added while gas is vented from the water filled section. Then one has a water filled section, in a horizontal chamber, for divers to work in.

FIGURE 1

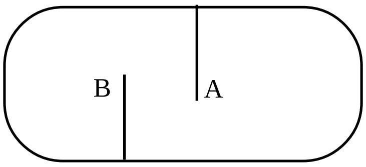
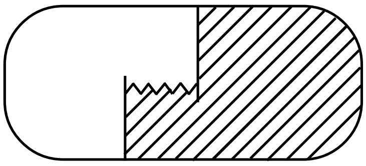


FIGURE 2



AIR WATER

Question:

Is it very difficult to measure oxygen partial pressures accurately. Do they just work it out by the amount they are adding to the chamber?

Dr David Elliott

No, it is all calibrated. The people who are doing it are university physiologists. They are talking about measuring 0.001% accurately. I see no way at the moment that we can ever translate that to the offshore scene. However I think there are a lot of university things that we can convert for practical purposes. You can convert achievements into commercial diving operations. Helium is indeed very expensive, and this is the reason why we are now having these so-called push/pull systems, where the helium is returned either to the bell or to the surface, for re-processing.

There is no doubt that in man some of the respiratory limitations which were thought to be mechanical, are in fact a consequence of High Pressure Neurological Syndrome. But basically, if I can give you a grossly over-simplified hypothesis, here is an explanation. You can imagine that the fatty tissues and the watery tissues of the body compress at different rates. Then at very great depths the myelin sheath, on which conduction is dependant, is actually thinner, relative to the axon, than usual. As a result, and I repeat that this is grossly simplified, you get a whole stack of things due to High Pressure Neurological Syndrome. In order to restore that neurilemmal layer to its relatively correct thickness so that conduction can be carried on as it was, you have to add an anaesthetic agent, This acts by being fat soluble and expanding the neurilemmal sheath. The anaesthetic agent which you add is in fact nitrogen, because nitrogen is an inert gas. The mechanism of inert gas narcosis is the same as alcohol and anaesthesia. So we try to find a balance between the effects of helium and pressure which cause the neurilemmal sheath to go thin and adding nitrogen as an anaesthetic agent to re-expand it to its normal value. It is amazing that it works as well as it does. There are a few bits of the syndrome which it does not manage to deal with. We are not sure what causes the ultimate problem, that of convulsions.

If you produce alcohol at great depth the effect of pressure would, as it were, reverse the anaesthetic effects of the alcohol so that the yeast would be more productive. Although it does not work with drinking alcohol, it does work with some commercial alcohols. So fermentation at pressure, and the pressure reversal of anaesthesia, was one of the things that prompted Peter Bennett to write the paper in Undersea Biomedical Research in which he predicted that of the percentages 5, 10, 15, 10% would be the right theoretical percentage of nitrogen, which would exactly balance out the effects of pressure at any depth. The depth is independent of the absolute pressure, it is the percentage that counts.

Question:

You may have observed some rather sleepy people around at various times and I have heard the expression a long time ago describing an individual as being a “bubble-head”, which was the diving equivalent of a punch drunk. Have you any experience of this sort of person, other than those you may have met locally and recently?

Dr David Elliott

Actually, your question is very important and it will lead me off on a rather long tangent if I am not careful. What you are really implying is, are there long term effects on the central nervous system from diving? This was a scare which was created by a Hungarian worker, who was looking at compressed air workers. It was written up in Ian McCallum’s book “Compressed Air Work”. It has been quite impossible ever to confirm in any other autopsy material. He claimed to have found cysts in the brains of compressed air workers and said it was all due to their diving. But the very careful autopsy examinations of compressed air workers in Britain and the United States, completely failed to support that. There have been papers written by a group from Galveston, Texas, in which they claim to have done various psychometric tests and found that a few divers were deficient. We had John Hallenbeck come to a meeting in Luxembourg to give a review from the point of view of neurologists with diving experience, as to the likelihood of brain damage following diving. Without going into the arguments his conclusion was that one would not expect permanent damage to be done to any diver unless it was due to untreated decompression sickness. That one does have to accept, but certainly not all these other problems.