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Oceans 2000

Third World Congress of Underwater Activities

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BUCKINGHAM PALACE

All human progress depends on communication and world conferences are a most effective modern method of exchanging information and ideas. I deeply regret not being able to attend 'Oceans 2000', the Third World Congress of Underwater Activities. It is a fascinating subject which is still only on the threshold of discovery in the deep waters.

I hope all the delegates attending the Congress, and particularly those who have come from overseas, will find much to interest them and will have much to contribute to this rapidly developing area of study and exploration. But no congress can be entirely devoted to business and I hope everyone will find the time to enjoy themselves, to meet old friends and to make new ones.

Philip

1973.

Arthur C. Clarke

Arthur C. Clarke is probably best known for his collaboration on the screenplay of the film *2001: A Space Odyssey,* and for his novel of that name.

But this was just one of the stories that this famous science fiction writer, formerly a chairman of the *British Interplanetary Society,* has turned out over the years.

His greatest achievement, however, was to invent the communications satellite, for his knowledge of space science and engineering is soundly based.

A lesser known speciality of Arthur Clarke's is diving, and he was one of the first to suggest that astronauts should use diving to simulate the weightless conditions of space.

The Future of man in the Sea

The purpose of this talk is to stretch your minds by thinking about the use of the oceans during the next century — which is less than thirty years away. Much that is now planned will affect the seas for all times to come. I would like first to make a criticism of those short-sighted people who have been grumbling that too much money has been wasted on space as opposed to oceanography. I don't want to steal any of Scott Carpenter's thunder, but I would like to stress this point: that much that is now being done in the seas is only possible thanks to space technology, and this is going to be even more so in the future.

Weather forecasting and communications are rapidly becoming dependent on satellites and, of course, communications and the weather are basic to all marine operations. Oceanographic ships and drilling rigs already depend on navigation satellites to pinpoint them in the open sea, something that has never been possible before. Satellites are also the only effective means of keeping contact with the thousands of automatic data-gathering buoys which will soon be distributed over the world's oceans.

Incidentally, I am particularly glad to welcome Captain Cousteau through the airlock — even though he is not personally here today. He has become one of the most enthusiastic converts to satellite oceanography for, as you may know, early in 1973 a handful of satellites probably saved the *Calypso* from disaster in the Antarctic when she was trapped in the ice with one broken propeller and the other damaged. Satellites were able to radio back a picture showing just where the ice was and to give accurate weather forecasts. In another generation I am quite sure we will wonder how we were able to do anything on the sea without satellites.

I have here a press release from the Navy's fleet weather facility reporting that satellite imagery is becoming indispensable for shipping operations in the Arctic and Antarctic. The satellite pictures showing the location of ice masses have already extended shipping operations by several months, perhaps ultimately through the whole polar night. The economic consequence of this could be enormous because some of these satellites can show the ice even in darkness, because they can see it by its temperature gradients and map its position accurately.

As a matter of fact, my own interest in underwater activities was a direct result of my interplanetary enthusiasms. In the late Forties I realised that the skin diving equipment which was becoming popular then would give me a chance of experiencing something like weightlessness. When, with some difficulty, I had broken through the two-metre barrier in the Seymour Baths just round the corner, I used to close my eyes, spin round in the water and deliberately try to disorientate myself — so that I would know what an astronaut would feel like when there is no up or down. Incidentally, exactly the same disorientation hit me involuntarily last April when I was snorkelling off the Virgin Islands and for some reason the gyros in my inner ear suddenly uncaged and I was doing about 30r.p.m. (or at least it seemed like it) a couple of metres down. I couldn't do a thing about it. If the quick release on my weight belt hadn't lived up to its name there would have been a change of programme today. I don't know why it happened, but from now on I'm being ultra-cautious in every department. You see before you the only diver who has decompression Tables pinned up in his bathroom!

My underwater Odyssey, which led me to the Great Barrier Reef and not only to Ceylon, had some rather interesting by-products. In 1954, during a weekend in Washington, I convinced Dr. Wernher Von Braun that he too could find weightlessness underwater. He promptly went out and bought an aqualung and arranged for the construction of a perfectly enormous tank at Huntsville, to test the space vehicles he hoped he would be building one day. For this extravagance he was roundly chastised by the General Accounting Office, yet that test facility paid for itself a hundred times over. Today it holds a complete Syklab mock-up. In its crystal clear depths Russell Schweikart and the other astronauts tried out the hastily improvised equipment which enabled them to save that mission, so Wernher's swimming pool probably saved the United States about two billion dollars.

It has always seemed to me that the feeling of well-being, even ecstasy, that one can experience underwater during a really enjoyable dive is a by-product of weightlessness. You can't take your worries with you when you go underwater; you can be scared stiff — but that is quite different. Those who have been lucky enough to enjoy extended space missions have had much the same reaction, they even refer to the danger of becoming addicted to weightlessness. This has led me to speculate that we do not really belong here on the surface of the earth; our first natural environment is the sea where all terrestrial life began and where, to a close chemical approximation, everyone of us spends the first nine months of his life.

We have paid a great biological price for the conquest of the land and the fight against gravity; the price is to be measured not only in fallen arches and slipped discs and backache, but probably in heart diseases and the shortening of our life-span.

Some years ago I wrote that we creatures of the land are exiles, displaced organisms on the way from one element to another. We are still in the transit camp waiting for our visas to come through, and when they do and we go on out into space, where I suspect most of the human race will live for most of its history, we will regain most of the freedom we lost when we left the sea — a freedom which we try to recapture every time we sink beneath the waves. But we are still in the oceans what we were on all the continents ten thousand years ago — primitive hunters.

If you want to imagine what we may one day be doing on and in the sea, try this mental exercise: pretend you are a typical representative of the Middle Stone Age. The men of that time were as human and intelligent as we are; if you had caught one early enough you could have turned him into a computer programmer or an airline pilot, and we know that many of them were artists as good as any we have now. But could those men have imagined what their descendants — us — would do, for better or for worse, to the land over which they hunted for the mammoth or the aurochs. Could they have pictured the grain fields in North America? Could they have imagined the chequer boards of rice fields in the East where every generation feeds more millions than lived through the whole of the Stone Age? What would they have thought of a Jersey cow, or a Percheron carthorse, or any of our farm animals — the products of centuries of breeding?

Now you will note that I have only mentioned technologies which are so old-fashioned that many people don't consider them technology at all, but part of a natural way of life. Agriculture is a quite recent invention, probably now nearing the end of its history, and this is not to mention all the other things we have done on the land — mines, bridges, motorways, dams, cities, airports — the whole fabric of modern civilisation. So when we contemplate our future in the sea, we may do no better than the most brilliant genius in the Early Neolithic Age, so please bear that in mind.

I want to be a little more specific about the uses of the sea. I am aware that many of these points will be touched on by later speakers; I apologise to any whose views I inadvertently contradict.

Harvesting the Sea's Resources: Everyone has seen those tantalising lists showing how many tons of gold and so forth there is in each cubic mile of seawater. So far we have been pretty slow at mining these riches, simply because they are so dilute and such immense amounts of crude ore have to be treated to get at them. Apart from salt, the only materials so far won directly from the sea are magnesium and bromide. Nature has been much cleverer at this game than we are. We found to our surprise, sometimes to our discomforture in the case of radio-active fallout — DDT — that lowly marine organisms can extract incredibly minute quantities of selected elements from seawater and concentrate them to an extraordinary degree. So why should we not train them to do an even better job? In a primitive way we have already begun to use this technique. For a long time the main source of iodine was kelp, which extracts it from seawater where it is present in one part in ten million. Even today a major source of lime is coral — either living or dead. I speak with much feeling on the subject because I am battling to save the reefs of Ceylon from the local lime kilns. They drive bullock carts out over the coral reef to smash up the coral so that they can harvest it and bring it back to be burnt for lime.

Perhaps we can genetically design seaweeds or other marine organisms to selectively concentrate any element we like and harvest them when the crop is ready. We had better not be too clever — can you imagine a coral sitting there year after year, slowly extracting uranium 235 until, suddenly — bang!

Sea Mining: What makes sea mining suddenly look much more exciting is the recent discovery of hot brines like those in the Red Sea, in which heavy metals are present in many times the normal concentrations, just waiting to be pumped to the surface. These hot brines seem to be oozing out of the cracks between the continents where the plates on which the world's land masses float are slowly drifting apart. They may thus give us access to the almost unlimited wealth miles down in the earth's crust. If this is so, we can forget any shortage of raw materials for the next few thousand years, in fact we may even abandon mining on the land, because liquid ores are rather more easy to handle.

I have not mentioned manganese nodules and other fairly readily exploitable sources because you know all about them and I am sure they will be discussed at this conference. But I would like to mention one problem which will be associated with any form of submarine mining, as in mining on land, and that is the unholy mess it can make. I don't want to exaggerate at this point for I imagine that an undersea avalanche or a turbidity current can dump about as much mud on the Abyssal Plain as we are likely to stir up there in a century. But I do know we may make a pretty bad mess.

Incidentally, I am reminded of a story I heard recently which may not be familiar to you, but it is rather appropriate:

When Moses reached the edge of the Red Sea with the enemy hot on his heels, he communed with the Almighty and presented his problem. The Lord listened carefully and said "Yes, yes. I have two pieces of news for you, one good, one bad. The good news is that I can part the Red Sea and you can go through on dry land and then I'll close it and drown all the enemy. The bad news is that first you will have to file an Environmental Impact Statement."

There is one form of sea mining that does not produce any pollution. It involves hundreds and thousands times more tonnage than all the metals, chemicals and oil we would ever extract: the most important substance we get from the sea is water. There has been some discussion about towing icebergs by nuclear tug — people are surprised that this can be done, that we lose so little ice in the course of towing an iceberg even through the Tropics.

There are problems in cutting up and transporting millions of tons of ice, but why should we not let the sun do the job for us? If we stranded a really big iceberg in the right place off some tropical desert area in a prevailing wind, it would perhaps produce major climate changes, cooling the area off as well as producing rain in the right place.

Energy: People have been talking for years about extracting energy from the sea, but no one has done a great deal about it. The rise and fall of the tides is one of the obvious sources, but geographic problems limit its application. As far as I know only the French have built a full-scale tidal power plant with an output of about a quarter of a million kilowatts.

Some years ago Ed Link pointed out to me that there is another way of tapping the energy of moving seawater. There are rivers in the ocean mightier than any on land but they are usually rather slow moving. However, there may be regions of the seabed where narrow canyons can produce a venturi effect, so that the submarine currents flow at many knots. At what price could we build underwater windmills or submerged turbines to take advantage of this? One suitable situation, Ed said, might be under the Gulf Stream where there is a powerful counter-current. I am not sure whether this would be an altogether good idea. I have a feeling that extracting energy from the Gulf Stream would make the British Isles wholly, instead of partially, uninhabitable! Perhaps we should reverse the process and pump energy into the ocean currents at strategic points — perhaps a modest injection might have a many times greater consequence.

But there is another source of energy in the sea still untapped: the temperature difference between the water of the Abyssal Plain and that at the surface. In 1881 a French physicist made this astonishing prediction: "The world will one day mine the sea for energy". Early this year an American scientist wrote a paper calculating that we could provide energy for six billion people — twice today's population at the 1970 American level — for a one degree temperature drop of the tropical seas. This might even be a good thing. You know it is very strange to stand on a tropical beach with the water around your ankles perhaps too hot for comfort, and to realise that a few miles away — down from the equator — the water is only a few degrees above freezing point.

There are many ways of devising a heat engine to take advantage of this differential, which could be as much as 80°C (150°F), if we use certain well-known tricks to help the surface layers trap sunlight. In the 1930's George Claud tried to run a type of steam engine off the West coast of Africa, but was defeated by the mechanical problems of anchoring 1000 metre-long tubes in the sea to circulate his working fluid. I am sure the job could be done much more easily today with modern diving techniques and better materials. Perhaps we might have a static method of converting energy using thermal couples so that we don't have any moving parts at all. The efficiency might be very low but there is plenty of energy there, so the efficiency does not really matter if the capital and running costs are low. I proposed this scheme — thermal couples in the ocean — about ten years ago in the journal in which I publish all my scientific papers — *Playboy Magazine*. Some of you may have read the resulting short story — 'The Shining Ones'.

Now, if we ever do try to use the thermal energy of the sea there will be an interesting by-product if we set about matters in the right way. By the laws of thermodynamics, if you pump power out of the sea you flatten the temperature grade. In other words, you heat up the lower levels and that will start an underwater fountain, an upwelling. We know that the fertility of the sea depends on the chemicals which are trapped down there — the nitrates and phosphates — and that if we could store them up we could make many of the desert regions of the sea into fertile oases. I suggested this about sixteen years ago in a novel called *The Deep Range*, which some of you may know, and experiments on these lines using heat to stir up the trapped nutrients are now beginning. It would, of course, have the same kind of effect on the sea that fertilizers have had on the land — and we all know the agricultural consequences of that.

Whale Farming: Whale farming has often been suggested as a practical possibility, yet, for all their technical sophistication, our whaling fleets are still like Indian hunters pursuing the wild buffalo over the plains — and we know what happened to both sides of that particular equation. Imagine what we could do to whales with selective breeding. With the meat shortage that lies ahead of us, a couple of hundred tons of beef on the fin should appeal to any farmer. And if you think it is morally repugnant, as I do, to slaughter such magnificent animals even by humane methods, there *is* another alternative: a cow that produces a ton of milk a day is an interesting economic proposition.

Since I have touched on the subject of whales, I should say a few words about cetacean intelligence. It was a beautiful idea, a beautiful dream, that there might be another form of life on this planet with which we might be able to communicate. But, although dolphins are certainly charming creatures and are a delight to know, I am beginning to have grave doubts about their intelligence. For a very basic reason — they seem much too friendly to man. Yet there may be other intelligent creatures in the sea. I would like to remind you of the question once asked of a Greek philosopher and of his answer — "What is the most cunning of all the animals?" Answer: "That which no man has yet seen."

I am sure there are a lot of surprises lurking in the oceans. Remember the excitement of the discovery of that living fossil, coelacanth? And it is about time we settled the unfinished business of the Great Sea Serpent (I suspect that name is misleading; 'the' is certainly wrong — there are several different types of creature and none of them are serpents and may not even be particularly great). For example, I have read what sounds exactly like a straight forward description of Steller's sea cow, the last of which was supposed to have been slaughtered about two hundred years ago. These relatives of the Dugong grew up to twenty-five feet in length, and if one of them popped up on a dark night and looked at you when you were in a small boat, I think you would probably settle for that as a pretty good sea serpent. If the coelacanth survived for a couple of hundred million years, I do not see why a few sea cows could not survive for two centuries.

I would like to put in a claim for my particular pet, the giant squid. As a boy I came across Frank Bullen's book *Cruise of the Cachalot* which had a vivid description of a fight between a sperm whale and a giant squid. Years later, I came across the famous and mysterious chapter in *Moby Dick* entitled simply 'Squid'. I would like to read now this description; I am sure it was pretty accurate, except for one point:

"*In the distance a great white mass lazily rose and, rising higher and higher, at last leaned before our prow like a snow slide newly slid from the hills. Thus, listening for a moment as slowly it subsided and sank, then once more arose and silently gleamed, almost forgetting for a moment all thoughts of Moby Dick, we now gazed at the most wonderous phenomenon which the secret seas have hitherto revealed to mankind. A vast pulpy mass, furlongs in length and breadth, of a gleaming cream colour, lay floating on the water, innumerable long arms radiating from its centre, curling and twisting like a nest of anocondas as if blindly to clutch at any hapless object within reach. No perceptible face or front did it have, no conceivable token of either sensation or instinct, but undulated there on the billows, an unearthly, formless, chancelike, apparition of life.*"

The only error is that he refers to 'furlongs in length' which, I think, must be a mistake for fathoms, for a furlong is an eighth of a mile, and that would be some squid! However, maybe it isn't such an exaggeration . . .

Both Frank Bullen's encounter and Herman Melville's half a century later, took place in the Indian Ocean, and so did an even more remarkable one, if we can trust *The London Times* for 4th July, 1874:

In May 1874 a 150 ton schooner, *The Pearl*, set out from the port of Galle (just two miles from my own bungalow on the South Coast of Ceylon) and on May 10th was becalmed in the Bay of Bengal. Shortly before sunset, passengers on the P. & O. liner, *Strathowen*, observed a giant squid attack the schooner which, admittedly, had fired at it first. The squid wrapped its arms around the schooner and overturned it! Five survivors were picked up.

You can draw one law from this — don't use giant squids for target practice! Is this story fact or fantasy? We may never know, but something has now turned up which makes it a little less improbable.

In 1896 a sea monster, about six tons of material/flesh, (it was never fully identified) was cast ashore at St. Augustine, Florida. A few years ago, F.G. Wood discovered a bit of it in the Natural History Museum, and it has now been identified as, not a giant squid as was first thought, but an octopus. Now this fragment weighed six tons; the largest known octopus is about 60 kilograms. It is estimated that this one must have had a tentacle span of about 200 feet. So there may be quite a few things in the sea that haven't come out of it — yet.

In the long run we all know what is the most terrifying, most dangerous, most destructive creature in the sea, right here in this hall, that's why we at this Congress have a great responsibility. The question which this generation has to answer is 'Can we exploit the sea without destroying it?' One can find plenty of grounds for pessimism. Look at the record of the International Whaling Commission — a classic example of greed and stupidity. Even more depressing, look at the current *U.N. Law of the Sea Conference*. To quote from a recent issue of the *New York Times*: 'It offers a singularly striking example of narrow self-serving nationalism, a greedy rush by individual states to usurp the common heritage under conditions of anarchy that threaten imminent conflict.' The tragi-comedy of the cod war is just a small example of the conflicts that will develop on or under the sea unless we realise that it is utterly ludicrous to talk of national sovereignties on the ocean, just as it is in space.

I see that I have come back to the subject of the links between space and sea. Let me mention another one in conclusion. Only a few years ago it seemed that this planet of ours was the only world in the solar system upon which liquid water could exist, hence the only one which could have oceans. The truth now turns out to be more complicated and more exciting.

Observations of Mars from *Mariner 9* show that quite recently there was an immense quantity of running water there; dried up river beds and what might very well be dried up ocean beds. There is one very flat area a couple of thousand miles across, almost featureless, and at a level where the pressure is high enough for liquid water to exist. The discovery of giant volcanoes such as *Nix Olympica*, which is more than twice the height of Everest and 500 kilometres across, is also relevant because volcanoes are a prime source of water.

So, there may have been water on Mars in the fairly recent past, and when we study the effects of it, we will learn a lot more about the trajectories of our own planet; any study of the hydrology of Mars will contribute to an understanding of the forces that have sculptured our earth. However, there are those who think that Mars is still evolving, so its oceans may lie in the future, not in the past, and when the seas on Earth are gone they may still be forming on Mars.

Of course, we must not forget Jupiter — the greatest of all the planets. If you flattened out our earth on the face of Jupiter it would look about as big as the Mediterranean on the globe of the Earth. Jupiter is King-size, and its immensely deep atmosphere contains gigantic quantities of free hydrogen getting denser and denser. So, somewhere as you go down through that quite warm atmosphere, you come to a level at which there will be a liquid and, conceivably, this might be water. We just do not know. If this is so, there may be oceans on Jupiter that will make ours look like duck ponds, the exploration of which will present quite a technological challenge — indeed, a combination of spaceship and bathyscope. I would not dare to bet on that particular possibility just at the moment because, if all goes well, we are going to get our first close-ups of Jupiter on 3rd December.

Lastly, here is a thought I would like to leave you with this morning; a comment from my good friend Dr. Isaac Azimov: "*If there are seas on Jupiter, just think of the fishing*"!

Hannes Keller

Hannes Keller from Switzerland was the first man successfully to dive to the record depth of 1000ft., and he did it as far back as 1962. Sadly, this achievement was marred by the tragic death of his diving companion, Peter Small.

Since then, he has concentrated on the technical development of safe and efficient underwater equipment for industrial deep diving, principally producing a professional suit and new chamber systems. He has also produced two-man and five-man portable recompression chambers.

Diving 2001

It is a great privilege and pleasure for me to run through some of the problems of the future of man in the sea. I will concentrate on three topics: the scuba diver, the underwater sea quest, and homo aquaticus.

Many of us are now chiselling at the limiting factors of diving; we dream of extended no-decompression diving. The problem of decompression lies in the fact that one cannot dive deep with oxygen alone because it is a very poisonous gas that men can only support in small quantities. In diving, one must mix this powerful oxygen with harmless gases such as nitrogen, helium, and so on. These gases diffuse into the body, stay there like blind passengers accompanying one on the dive, and do not react with the body chemically. But, when one returns to the surface, these slow-witted non-reacting gases come out of the body, and if one is not making a slow and tiresome decompression, form dangerous bubbles in the body. This very much limits the freedom of the diver.

There are four hypothetical methods of getting rid of the need for decompression: drugs preventing bubble formation; non-inert breathing gas mixtures which are chemically absorbed by the body; liquid breathing mixtures instead of gases, and extra-corporal blood circuits (the lungs being filled with a liquid).

Drugs Preventing Bubble Formation: When the gas pressure in the body tissues versus ambient pressure exceeds a ratio of approximately 2:1, we get bubbles. This limits diving with scuba to between 100 and 200ft. For greater depths one needs industrial diving techniques such as decompression chambers and submarines but drugs may now change the critical ratio. Today, I believe that some 20 per cent improvement could be realised, and in the future, super-effective drugs might double or treble the ratio, but at this point one certainly reaches the limits of what chemistry can do for you.

Depths for scuba diving could be doubled or trebled, but one would be forced to use helium instead of nitrogen for breathing. However, helium saturates the body 2.64 times faster than nitrogen, and this would again take us back to short decompression diving at shallow depths.

We can estimate, therefore, that a suitable drug applied to a helium-nitrogen mixture would allow the scuba diver to go to depths of between 200 and 400ft. This does not sound terrific for the magical year 2001, but it would mean that really black depths would be open to everyone, and that certainly would be a moving experience.

However, if there were a gas that would mix with oxygen and which could be absorbed by the body without poisoning it, it would give us diving without decompression. Very hypothetically, such a thing would look like this: at 300ft. we would have a mixture of 5 per cent oxy, 45 per cent xx, 45 per cent *vv* plus 5 per cent corrector-catalyzer mixture (whatever that means!). The oxy would feed the body normally; I imagine the xx plus blood plasma would form an xx plasma, and *vv* plus tissue fat would make *v* fat. Then the xx plasma plus the *vv* fat would form a green liquid! The green liquid would dissolve in the blood, be filtered by the liver and leave the body with the urine.

The 5 per cent corrector–catalizer mixture would do some very odd jobs indeed.

When it came to ascending to the surface, all the gases would have disappeared; nothing would be left for bubble formation and no decompression would be needed. We could expect the gases like xx and *vv*, being non-toxic, to have molecular weights of 60 or more. Such gases have critical points of 500 p.s.i. maximum, therefore, we cannot expect to be at depths greater than 1000ft.

Breathing Liquid: This has been discovered by Professor Kylstra. It is fantastically simple: One just drowns in physiological salt water which is saturated with oxy, but instead of saying "Farewell beautiful world", one stays alive. It must be done at depths in excess of 300ft. or the farewell would be final, since the liquid cannot hold sufficient oxygen at a lesser depth. Maybe new liquids will overcome this, but for anybody who can beat his psychological barriers against it, it is a great way to solve all diving problems!

Extra-corporal Blood Circuit: The technique for this is, in a way, similar to the liquid breathing method. One fills the lungs with a suitable liquid and one may or may not continue to breathe. An artery or vein is cut and interrupted, the blood being guided through an apparatus which one may carry under the arm. The apparatus does the lungs' work by getting oxygen into the blood and carbon dioxide out of it. So, after joining a diving club, the diver sees his surgeon, gets his plugs installed and has no further diving problems. Whenever he feels like going underwater he just pays his electricity bill, connects the apparatus and drowns a little bit! The diver could now reach the absolute limits of diving; the depths could be as much as 5000ft. But then the body chemistry could become upset — under the extreme pressure the metabolism would change delicate equilibriums with fatal results. Such changes of metabolism occur when one changes body temperature. Very roughly, one can say that each 1000ft. is equivalent to a degree Fahrenheit body temperature change. The effect is much too complicated to be compensated by drugs, so I believe that the limit of diving is between 3000 and 7000ft. Naturally, one day some crazy chap will make it 7043ft!

For the scuba diver, descent and ascent rates will be a big problem. (I once made a descent from 300 to 1000ft. in two minutes, but I admit that I did not feel too great). Today, one understands that pressure changes cause specific problems that limit ascent and descent rates to between 100 and 300ft. per hour at depth.

For the properly equipped sports scuba diver of the future, I would expect dive durations of six to eight hours, the one big problem being that of opening the energy gap. To heat a swimming diver, a suit must generate approximately 500 watts; with propulsion and rapid water velocity cooling him, the diver needs 1000 watts. Propulsion, (if only we could think of a small torpedo that could be carried on the belt or between the legs) requires another 1000 watts. We want about eight hours duration — and here we have a tremendous battery problem. We can manage with 1000 lbs. of lead acid battery, or with 200 lbs. of silver zinc battery, or with 40 lbs. of liquid oxygen and hydrogen plus a fuel cell, or with atomic power — if atomic power can be provided and if the small isotope battery is ever constructed.

A diving suit must give protection without hindrance; thermal, mechanical, optical and logistical protection. The materials of the future will be strong enough to make you laugh very loudly when a white shark tries to chew you, but the point is that the suits will be strong enough to be blown under pressure if you surface accidentally and need pressure for the prevention of a decompression accident. Then, naturally, the suits will allow efficient buoyancy control in conjunction with the breathing apparatus and electronic black box.

At present I am working on a suit which completely protects a diver from the hazards of drowning: if the diver loses consciousness, he will continue to breathe and automatically drift to the surface instead of being lost at depth. Rescue will then be easy. Such dry suits will even beat the wet suit for comfort.

Electronics: Today, *Hewlett Packard* markets a pocket computer which has forty thousand transistors, taking care of all basic mathematical functions of trigonometry and so on. Very soon somebody will make such a thing for divers and your dive will become almost automatically controlled. The box will provide a continuous dive plan, including return to base, control of vital body functions, supervision of overall safety and precautions, computation of optimal procedures in case of failure and trouble, control of breathing apparatus, automatic control of ascent in case of unconsciousness, communication to other divers and base, and navigation relative to base, divers, target, surface and bottom. Some of this data will be received by the diver via the apparatus.

A laser beam projected on to the faceplate will give a three-dimensional holographic display of the navigational situation, including one's own path underwater, the positions and movements of other divers and the position of base, surface, bottom and target.

Maybe ultra violet light will penetrate depth and dirty water, and provide visibility. The navigation system will be provided by means of ultra sonics, maybe electromagnetic waves, and probably inertia systems as those in submarines and jumbo and fighter planes, only much less precise and costly.

The future belongs to a variety of breathing apparatus, and although nothing will ever beat the simple aqualung, we will have miniature compressors silently filling our cylinders over-night, and a small scuba set filled with 8 lbs. of air will weigh approximately 20 lbs., including the air vaporizer.

In the closed-circuit deep-diving apparatus, CO_2 and other contaminants will be frozen out of the circuit; no filters will be needed, and buoyancy will be easily controlled.

So, what I predict is this. The oceans are not dead. In 2001 I hope still to have the choice of jumping nude into the water and playing with the mask, fins and snorkel I bought in 1960, but the military divers will swim around silently with an extra-corporal blood circuit, and some enthusiasts will breathe liquid far down at 3000ft. Naturally, it will be great to be able to move hundreds of feet up and down, with propulsion, navigation, communications and, last but not least, liquid gases.

Living Underwater: The earth is becoming somewhat crowded; there is a tremendous energy-gap, and there is a contamination problem. In the 19th century, people had great problems in protecting themselves from contamination inside the house — outside, nature was healthy. Today it is different. Last week I was in New York — I am told that breathing air in a New York street is equivalent to smoking 40 cigarettes a day, and that one cigarette shortens life by 15 minutes; one day in New York therefore shortens my life by half a day. However, I was in a hotel which advertised filtered air, so I spent as much time as possible in my hotel room so that I was safe from contamination!

I believe that the future belongs to three-dimensional structures, towns which are completely closed shells. Inside such shells one would be able to keep the air conditioned and to filter out all contaminants.

A sociologist told me that the ideal city has one million inhabitants. Such a city could be designed as a cube, as a sphere, or other three-dimensional shape. A 0.6 x 0.6 x 0.6 mile cube would give each person — child or adult — one thousand cubic metres of space, which amounts to about twice the volume of a complete six-roomed apartment, including a garage. In such a cube people would live and work and communicate.

The first advantage — elimination of the energy gap: whatever energy the industry in the centre would use would heat the apartments. Secondly, people could commute easily with elevators and mechanical stairs — everyone could walk anywhere in 15 minutes. Thirdly, climate and contamination would be under control, with minimum technology needed. Fourthly, Nature would be within 10 minutes walking distance and could be kept intact for agriculture and recreation and joy — no more fences and houses anywhere — all would be one really nice big garden. Fifthly, it would be economical. Lastly, social contact would be optimal: one would have all the human contact one wanted, plus rooms for privacy for, naturally, to be happy, one needs a room in which to be alone — without acoustical or optical contact with the outside.

It has been proposed that we build such structures underwater. I am afraid this is not possible. It would be economic nonsense because of a simple physical law: A city underwater has to be of the same density and weight as the water it displaces.

If a structure is made of concrete, then 40 per cent of its volume would have to be of solid concrete; a room 21ft. wide would have concrete walls 3ft. thick. If made of steel, 13 per cent of the entire volume would have to be of steel: a room 25ft. wide would need solid steel walls 1ft. thick. For buoyancy reasons alone, an underwater city would require several times more building material than a sky-scraper structure on land, which makes a nonsense of the whole idea. If one thinks of heavier materials, of the costs and quality of this magnitude, it is impossible.

Floating cities — Yes! If one needs cooling, the water under a city would inevitably carry away heat energy. In a hot climate this is wanted, not so in a cold climate. So, certainly, Miami 2001 will float, while Oslo 2001 will be on solid ground where minimum heat is lost.

To Swiss people, the thought of a three-dimensional city filling a little valley with lots of people, all with their little bank accounts in the country, appeals very much. Actually, such structures have already been tried. The Egyptians once made big three-dimensional structures, but the architects only dared to move the dead inside. In Babylon, an architect tried, and when he failed because of an error in the calculations, found the greatest excuse I have ever heard. Since Babylon all architects have had their splendid excuses.

If underwater cities are impracticable, perhaps there is even less need for humans to acquire gills and cold blood and become homo aquaticus. Cousteau has predicted that selection and mutation will create new forms of human beings, capable of living fish-like underwater, for instance. But the human and his domestic animals have escaped the selection process from Nature — it is known, for example, that Eskimos are not hairier than Africans.

When trying to predict the future of mankind, we can certainly analyse some trends. One will try to permit the maximum number of individuals the experience of life. That means a big crowd! This crowd will certainly have to live in three-dimensional structures; the cities of the future. There is no need for humans to fly like birds as homo aeronauticus, or swim under the sea as homo aquaticus; if a city has 500 levels, its three dimensions are enough. The factors limiting life will therefore be the energy-gap; waste of prime materials, and contamination.

Other Trends: Each individual will seek maximum 'life fulfilment' which means a maximum of brain stimuli. Brain stimuli can be realities making an impression on nerves which then act on the brain, for instance, London Tower, or drugs, or electrical impulses — a computer could be connected to the brain to make it 'see' the Tower. But humans want not only a maximum of stimuli on the brain but also a maximum variety of stimuli. The brain wants to be able to choose its stimuli; it wants the freedom to choose and change. But the concept of homo aquaticus is profoundly opposed to these needs; aquaticus would have a very dull and one-sided animal life.

Another strong argument against aquaticus is the difficulty of maintaining body heat. The human metabolism is set at a very precise constant temperature, and homo aquaticus would need highly complicated chemical mechanisms to compensate for such temperature effects. The metabolism would need to be at least three times more complicated than it is already, and would probably be three times more prone to illness and malfunction. Nature dislikes such impracticable constructions.

If humans really want the maximum number of individuals surviving for the maximum time, then something else is needed.

Humans will not live in the sea, but they must become smaller — very much smaller. People only 3ft. tall could be as intelligent, sensitive, beautiful and as sexy to each other as people who are 6ft. tall. If humans could stop growing when eight years old, they would be easier to feed and to transport; less energy and prime materials would be used up, and more people could find a place on earth. Muscular effort could be implemented with tools. It could already be done today with hormones.

Finally, if by 2001 all the big fish have been shot, then at least a 3in. fish will be a great experience for a 3in. diver!

Question time

Question: Is anyone conducting research currently on hydrogen/oxygen mixtures for deep diving, and is the mixture explosive when you are down at, say, 30 atmospheres pressure?

Hannes Keller: One could use hydrogen; it is non-explosive when one is deeper than about 130ft. Experiments at approximately 600ft. were carried out in 1948. These experiments were successful, but unfortunately Zetterstrom was killed because of an error committed by his crew.

On the other hand, hydrogen is a very active and poisonous gas. Experiments up to now have been somewhat successful and I would expect that long deep exposure would cause ill effects to humans. That is my personal hypothesis; I have no experiments or technical background on this. But helium solves all the problems hydrogen makes. Maybe one needs something else at very extreme depths.

Question: How can the problem of breathing water — with the poor diaphragm that the body has at the moment — be overcome? Surely, it would get very tired pumping water?

Hannes Keller: No, not really, because the diaphragm would float in the water. The osmotic pressure of the liquid in the lungs should correspond exactly to the osmotic pressure of the body fluids, which is done, for instance, with physiological salt water. Professor Kylstra has tried this on a man: one lung was filled with water and other with air and the man claimed that both his lungs felt perfectly comfortable. So, liquid in the lungs presents no problem to the diaphragm.

Question: I would like to ask a question of Professor Clarke. At the beginning of this century, oil was going to provide all our energy sources — and now we are running short of it. Do you not see the same problem arising out of the energy sources from the sea and, if so, should we not be careful of starting experiments that we cannot control?

Arthur Clarke: Yes, obviously we must always be careful not to start experiments that we cannot control. Certainly, if we do tap the sea, it should keep us provided with energy for a good many centuries to come — long enough to get to the real energy source by tapping the sun *at* the sun. That will keep us going for a few billion years.

Question: Having overcome the problem of dying a little, how does Mr. Keller feel we should live a little by coming nearer the surface again?

Hannes Keller: Oh, I enjoy the surface perfectly. I believe that occasional diving is lots of fun — but the surface gives much more to life than the world underwater. Ask the dolphins!

Questions: Dr. Keller, you mentioned aids to vision underwater and you mentioned the use of ultra violet light. Would you like to expand on that a little please?

Hannes Keller: The problem of light underwater is, very briefly, this: Red light is absorbed very easily by water and the bluer the light, the more easily it penetrates, which means that long wavelengths get through. Now, I imagine that we could have a device that transforms ultra violet light into visible light, but this is very hypothetical. I have heard that a green laser beam was used very successfully to penetrate dirty water, and something along these lines certainly will be constructed. It has also been suggested that as sound waves are reflected by objects in water, this reflection could be made visible with special devices. Such a device could even be constructed for divers — I am very sure that we will find ways to see in dirty water.

Question: You have talked hypothetically of filling the lungs with water; that one lung on a man had actually been filled with water: how does one get rid of this? Why I ask is that recently we had a diver who 'died a little' by taking in water; he was in hospital for over three weeks while they tried to get rid of it, but eventually he 'died a lot' because they had no way of removing the small quantity of water that was there.

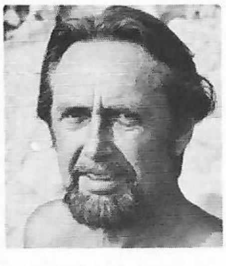
Hannes Keller: I think the problem arises only when the lungs are wet at the surface: they cannot hold sufficient oxygen. At depth it is completely different: so long as you are at 300ft. or more, you can drain the water out. Some water stays in and the lungs will still be wet, but that damp will be saturated with oxygen — you can get sufficient oxygen at depth, but it cannot be done at surface pressure. Another idea is that of the extra-corporal blood circuit, with which you would have no problems with lungs; you would not need lungs anymore, as long as the apparatus was connected.

Question: Could I ask either of you: With the development of these self-contained environments, what kind of fail-safe devices, or provisions against any accidents, would either of you envisage — keeping in mind that some of the disasters that we may have read about recently could have been avoided?

Hannes Keller: I think we know quite a lot about failure probability. Naturally, whenever an apparatus is contructed so, according to certain mathematical laws, it will fail one day. One can multiply the improbability by having several systems working in parallel — fail-safe systems. Let us assume that we have one apparatus that is bound to fail once in a thousand years; if a second, similar apparatus was connected when the first one failed, it would run for another thousand years, thus giving you enough time to repair the first one.

Now, in the case of a city, you could have three complete systems, but it *will* happen that all three systems fail together. That is one of those things that we have to accept — everything can fail. There is no absolute safety.

Arthur Clarke: Thank you very much Hannes. We all enjoyed that talk and the answers, and now we switch from Hannes to Hans. I'm afraid we are going to keep saying 'who needs no introduction' about pretty well every speaker here, but surely this is truer of Dr. Hans Hass than almost anybody else.



Dr. Hans Hass

Dr. Hans Hass is, of course, one of the pioneers of underwater exploration, and is known to millions through his books, TV and cinema films, many of which starred his wife, Lotte.

His ventures into the underwater world started in 1937 and he had his first encounter with sharks in 1939 while filming in the Caribbean.

After the war he toured the world diving from his yacht *Xarifa*. In 1960 he abandoned underwater work for a while, sold the *Xarifa*, and instead of studying marine life, devoted himself to a different scientific study — that of human behaviour.

Stop the slaughter

In 1960 I sold my ship the *Xarifa* and discontinued diving because, as a biologist, I had become interested in other fields of evolution: in how evolution started in the sea, especially climaxing in man; in human organisation; in governmental and business patterns.

I did not dive for 10 years but, having published the result of my work, I felt the urge to go back to diving and, with my family, re-visited Tahiti, Jamaica, the Great Barrier Reef in Australia, and various other places.

I must say that I was shocked by what I saw: reefs which before I had known very well were terribly different. Fish were suddenly missing and in Tahiti and Jamaica, the larger of them were only 10cms. It was like a desert. I began to realise what had happened during those 10 years and, moreover, to feel personally responsible because many must have been incited to the sport of skin diving and, more especially, to spearfishing, through reading my books. With this in mind, I felt that I had to do something to rectify the situation. The result was a Manifesto which I wrote in June 1971, and which I am going to read now:

"Underwater hunting has offered many exciting and fascinating experiences to many of us but has, unfortunately, also resulted in serious damage to the underwater world. The perfected weapons and the ever increasing number of underwater hunters have lead to a decimation of the fish populations. In fact, in many areas, fish have been practically exterminated. This is dramatically demonstrated to anyone who was diving along the Mediterranean coast some 20 years ago and who re-visits the same area today. But many tropical coral reefs too are bare and desolate. What is to be done?

We can, of course, stick to the view that the only thing that matters is present enjoyment: let tomorrow take care of itself. But those who really love underwater sport must feel differently. If we destroy underwater life, we destroy the oceans' main attraction to divers; however beautiful reefs may be, if they are bare of fish they lose their charm. What is to be done?

Since I was one of those who popularised this sport, perhaps my opinion should be heard. I am profoundly convinced that only drastic measures will help. Protected zones and underwater parks are an excellent idea and certainly important — but they are not sufficient. Fishing licences do not really help either, because efficient controls are practically impossible.

The only way to eradicate this evil at its roots is a world-wide ban on all mechanical underwater weapons. At first glance, such an undertaking would seem impracticable and hopeless: for manufacturers and retail shops this would mean a loss of business. But would it really be a loss in the long run? I think the contrary is true. If the fish populations are being destroyed, then diving loses much of its appeal, and the sale of diving equipment, cameras, and other accessories will be reduced accordingly.

We who love underwater sport must have one guiding principle — regardless of sacrifice and financial losses — to maintain and further our sport. Therefore, I invite all sport divers to join me in this attempt to save our sport.

Firstly, let us influence all diving organisations to ban the use of underwater mechanical weapons. Secondly, let us try to persuade the manufacturers, distributors and vendors to phase-out the manufacture and sale of mechanical underwater weapons. Thirdly, let us use our influence on legislators throughout the world to bring about laws prohibiting the manufacture, sale and use of mechanical underwater weapons.

For the time being, hunting with hand spears could still be permitted. This type of hunting requires considerable skill and is fair, since it gives fish a good chance of escape. But the use of rubber spring-loaded guns, to say nothing of explosives, gives man an unfair and excessive advantage over marine animals. This perversion of the original concept of underwater hunting must come to an end. It must be spontaneously abandoned; legally suppressed."

In the Autumn of 1971 I attended an Underwater Film Festival in Berlin at which I was asked to launch the Manifesto, and on this occasion we formed an association — the V.B.M.U. — which, translated, means Association to Fight Against Mechanical Underwater Sport Weapons. We felt that our first aim must be to do something about Spearfishing Championships, which may have been alright years ago, but which now, in our days of conservation, have become a wrong symbol: to give first prize to a man who has killed the maximum weight of fish has become both ridiculous and impossible.

We felt that our first move should be to contact Cousteau and try and win him over to our cause. So, two years ago we sent him this telegram:

"Dear Commandant Cousteau,

In your function as President of the C.M.A.S., I ask you to dis-associate yourself from the World Spearfishing Championships and to induce C.M.A.S. to withdraw its sponsorship of these and further similar activities.

I invite you to join a Committee which has the aim of achieving a total ban on the production and use of all technical weapons for underwater sport, with the exception of the simple hand spear. We are not guided by sentiment or economics, but feel that the underwater sport that we all love is undermining its own base. If immediate action is not taken, fish life along the coast and reefs will be destroyed everywhere — just as it has already been destroyed in many areas.

With the expression of my sincere appreciation, I send you my best regards."

Cousteau did not reply.

Professor Grzimek, a leader in the field of conservation in Germany, wrote a further three letters on the same subject to Cousteau, and also received no reply.

The Director of the *World Wild Life Fund*, Dr. Vollmar, wrote another letter — and did not receive a reply.

I am mentioning all this because a few weeks ago we heard that Cousteau had changed his opinion and is now against spearfishing; that *U.S. Divers* — the largest firm in America producing underwater gear and underwater sport weapons — of which Cousteau is the President, has officially announced its discontinuance in the production of underwater sport weapons.

I am very happy about this development because support from Cousteau — a man with great popularity — will certainly help our cause.

Many of the world's most prominent divers have spontaneously joined our Association; I am just going to read out a few names — you must excuse me if I should omit some important ones:

First, the Founder Committee (apart from myself) was: Dr. Hermann Heberlein — well-known in Switzerland for his efforts in conservation; Professor Eibl-Eibesfeldt — my old friend, and animal behaviour specialist; Jens Peter Paulsen — leader of the *German Underwater Association;* Ludwig Sillner and Horst Laskovsky. Unfortunately, Ludwig Sillner was killed in a car accident and he has been replaced by Dr. Peter Vine, who was so successful in getting legislation in the Seychelles and the Sudan totally or partly prohibiting spearfishing there.

Then joined Jacques Piccard; Hannes Keller; Professor Bini; Henri Broussard; Jacques Mayol; Dr. Frank Shipsey; Ben and Eva Cropp; Douglas Faulkner; Dr. Robert Dietz; Ron Taylor — the World Champion in Spearfishing; Valerie Taylor; John Harding; Walt Deas; Irvin Rockman; Dr. Lee Tepley; Stanton Waterman; Al Giddings; Paul Tzimoulis — *Skin Diver* magazine; Jack McKenney — Editor of *Skin Diver*: Henry Bruce; Ron Church; Victor de Sanctis; Peter Gimbel; Philippe Diolé, and many others.

Personally, I know quite well that it is not just spearfishing that is depleting the fish populations, and that underwater parks are a very important idea — but I would like to suggest that if we create underwater parks, they should be for spearfishermen — not fish!

It seems very arrogant of mankind always to think in terms of putting animals in a zoo; after all, the sea is *their* territory, so let us make underwater parks where spearfishing is permitted; not underwater parks where the poor fish can hide.

I sent my Manifesto to Jack McKenney, for publication in *Skin Diver*, and he replied to the effect that the American diver had a right to be able to spear fish for consumption. I felt that I should reply to this and wrote him a letter on the subject of rights (which he did not in fact publish). I said:

"As you know, it is the firm belief of many religions that the human being was placed on earth by Divine Power and that Nature was created for him, to supply him with what he needs. Today this belief can no longer be supported; instead we know, beyond reasonable doubt, that man is part of a process which we call 'Evolution'.

Let us first consider the time before man. In this period there existed no right for food because there was nobody who was either apt, or willing to enforce such a 'right'. Those animals and plants that were able to obtain food in a given surrounding survived; others starved in limitless numbers. Further, many species were either directly or indirectly exterminated by other species: as Darwin so correctly put it, the fittest survived, and this was the only 'right' that existed.

Then man originated and turned out to be more powerful than any other species. What we call our 'intelligence' enabled us to extend our genetic body artificially and to form specialised entities of superior power. I dealt with this development in one of my last books 'The Human Animal'. Let us look at the relationship between these new entities formed by man, and the rest of Nature, animals and plants.

If we consider all we know about the flow of evolution we can only state that no other organism has acted as efficiently and ruthlessly as man. We encourage the growth of those plants we eat; those that impede our interest, we delete. We do the same with animals. In this man-to-Nature relationship there still exists no 'right', because there is nobody apt or willing to enforce it — it is still the fittest that survive.

Only within the realm of the man/man relationship have criteria come about which constitute 'rights' and 'wrongs'. These criteria are not universal, but vary to a certain extent: what an American considers right does not necessarily tally with what is considered right in the U.S.S.R. or Red China. However, certain rights are fairly universal because they are necessities — functional necessities for community formation: for instance, not to kill or rob. Such rights necessarily limit individual liberty. On one side we gain, on the other we lose: we gain safety but lose the right to kill someone we do not like.

Today our technical advance has led us to the point that we must consider our 'rights' within the man/Nature relationship. If we go too far in destroying Nature we harm our own interests. For this reason we now begin to grant 'rights' to plants and animals, and are willing to enforce them. Today, the movement for conservation is again not guided by friendliness — a feeling pretty contrary to our tendencies within evolution — but by selfishness, and a striving to remain the fittest. If, therefore, someone speaks of the individual right of every diver to hunt for food, I cannot quite agree.

When we started spearfishing years ago, we certainly felt that we were in the right, just as in every other quest to conquer Nature. Meanwhile, however, this has lead to a development which is harming our interests. I do not know the situation along the California coast, but fish along some European and many Tropical coasts are being exterminated. Certainly, dynamiting and modern methods of fishing play an important part, but it cannot be denied that technically advanced spearguns are primarily responsible. That is why I feel that they must be banned. I am certainly aware of how ridiculous a diver must feel using a hand spear when he is surrounded by others still using spearguns, but I feel that this is a necessary sacrifice. We must limit our 'rights' in order to preserve and thereby gain. We must give in order to take!"

Meanwhile, there have been several other successes for our cause: several retail shops in Holland and Germany have discontinued selling underwater weapons. We are very happy too about developments at this Congress: that the *British Sub-Aqua Club* Motions were accepted. Among them I find especially important that the practice of spearfishing while wearing an aqualung be prohibited, and that the spearing of certain territorial species be banned. I think this is a very good start.

Apart from spearfishing, a lot of harm is done by the ever-increasing number of underwater tourists who swarm all over the world — now even to the most remote reefs. On the one hand we should be happy that with improved communications so many people can now go to the Maldives or anywhere in the world to dive and see the true beauty of Nature. On the other hand, it is terrifying to realise that by this movement the environment may be destroyed.

We have been thinking about what could be done; whether perhaps one could influence underwater tourism through underwater tourism — perhaps a kind of symbiosis between biology, diving and tourism could be achieved.

The first practical effort in this direction will be started next year in the South of Spain at Almeria. It is called *Club La Parra,* and will comprise a very fashionable hotel, with apartment complex, a modern diving school with small biology laboratory attached and, as a special attraction, a four-room underwater house in which 12 tourists can spend the night, have discussions, watch films, shower, change and eat 10 metres down.

From this underwater perspective we want them to look at the everyday world above; at today's invasion of man into the sea. There will be nightly excursions on to the reefs; we will create artificial structures around the house and are even thinking of torch-lit underwater concerts. It is a fantastic experience to listen to music underwater: you 'hear' with your whole body; you float in music.

We are doing all this because we want to shock. A German paper, *Der Spiegel,* reporting on this project, put it in these simple words: "*Hans Hass says that once you have spent the night with fish you cannot do them any harm any more.*" This is expressed quite well because I really do think that perhaps by shocking in this way we can create a different man-to-sea relationship.

This hotel is not only going to cater for the sports diver or the young: we are thinking in terms of 50 per cent elderly guests and, as we were told by Hannes Keller, tourists today need more than just a good bed and good food, so our biologist will take the guests along the beaches, explaining the sea's problems, and take them snorkelling in shallow water. We want to make pools where children can swim among fish and get into direct contact with the animal. Certainly we want to encourage underwater photography which, by the way, the C.M.A.S. should also do to a greater extent.

All this, we hope, will help to create a more friendly attitude towards the sea — not to break the coral; not to take shells; not to take souvenirs.

The third thing I want to speak about is a more serious subject.

A year ago, when I was working on my new book '*Welt Unter Wasser*', which has appeared in Germany and in which I describe this whole evolution — this invasion of the sea — I came across reports that sea mammals were being used by Naval Powers. I went to several places and countries to enquire whether this was true and, in consequence, I wrote a second Manifesto, which was published on 13th April 1973 in the *U.N.E.S.C.O.* paper '*Development Forum*':

"For sometime now, several of the Navies of the Great Powers have been training sea mammals (dolphins, sealions, etc.) to perform underwater tasks. Although many of these are harmless — locating lost torpedoes, messenger services, etc. — others are strictly military — attaching magnetic mines to enemy ships; fending off or killing enemy frogmen; spy services. There have even been recent

press reports that one of the Great Powers sent a trained dolphin into a foreign naval base to deposit a recording instrument, and successfully acquired the information they needed when the dolphin returned a week later to collect the data. It is clear where these practices will inevitably lead: in time of war, or international tension these mammals will be attacked and even exterminated. Since they will not be identified by any kind of uniform, any animal appearing in the vicinity of a base or of ships will be suspect, and will be killed-off easily, as they must surface regularly to breathe.

It is an old tradition that the Earth and all that lives on it was made for man, thus enabling him to do what he wants with the rest of Nature. But modern research suggests the contrary. The planet Earth, and the life that flourishes on it, were quite clearly not created exclusively for man's use or pleasure. Rather, we are only part of a process of development which had its beginning with the first organic structures of three billion years ago. In the course of this evolution we have developed as part of the animal world, 'though we also stand above it by virtue of our superior intelligence. Just as this process has always been characterised by the success of the strong and the better adapted, so now we use our power to subordinate the rest of Nature to our interests. But the damaging effects of some of our activities have already underlined the fact that we cannot pursue this course with brutal disregard for the consequences. The whole ecological movement is an attempt to put right these self-inflicted injuries.

*Bearing this in mind, we hope (*I would now say 'we suggest . . . '*) that the Great Powers will desist from the training of sea mammals within their armed forces, since the same service which they perform can be achieved by technical means. Clearly, this involves a degree of self-denial on the part of some scientists who are able to proceed with their research on these animals only because of the research funds which the Military make available to them and which would otherwise be less easy to come by. But this is a disadvantage we must learn to live with, for it is a moral outrage lovingly to rear and study animals if we are simultaneously a party to activities that will ultimately result in their extermination."*

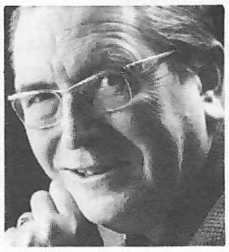
As you see, again, it is not sentimentality that is guiding us, but I feel that something ought to be done — MUST be done — and who should take the initiative — the politicians; those who do not know the sea? The day will come when we badly need the sea; when be badly need Nature; when we have to step back and dispose of our arrogance. As far as the sea is concerned, I think that those who love the sea should be the ones who make a start, and I would be very happy if the *C.M.A.S.* would help me in this cause.

In conclusion, I would just say this: This Congress has been called *'Oceans 2000'*, and I think that we should really think in terms of Oceans 2000 now. Please think back to what happened between 1940 and 1970; now think ahead, to what will happen during the next 30 years, until the year 2000. Thinking in terms of conservation, we must end this period of starting conservation activities only when they have become a necessity.

Certainly, many areas of the globe are not in specific danger yet, but we must think ahead, and this is why I am striving to ban mechanical weapons; in the sea we can still avoid mistakes that we have so amply made on land. It is time to do so and those who were at the start of this whole movement should lead the way.

If you say to a child: "Don't break that piece of pottery" and the child replies "I will only stop breaking pottery when all the children in Siam also stop" this does not lead anywhere. So, let us not make this very mistake — let us make a start, even though it is a sacrifice.

Arthur Clarke: Before we continue, Lord Ritchie Calder would like to say a few words.



The Rt. Hon. Lord Ritchie Calder, C.B.E., M.A.

The Right Hon. the Lord Ritchie-Calder of Balmashannar is Chairman of the Metrication Board and Privy Council representative on the General Council of the Open University.

In 1961 he was awarded the Kalinga Prize — the highest international award for "promoting the common understanding of science".

During the past 30 years Lord Ritchie-Calder has been involved in many surveys and missions to the developing countries of the world and in 1969 he received the first Victor Gollancz Award for services to humanity. In spite of his many other commitments he has had over 30 books published which have been translated into 40 languages.

The Law of the Sea

Those of us who will be examining the Laws of Sea at Caracas will be discussing very profoundly the question of the management of the oceans.

We have had bitter experience of arguments about fishing distances and so on, but, in my opinion, this is much less important than the arguments that are developing about the common heritage of mankind. We have got the unanimous agreement of all Nations — albeit, some of them reluctantly — that, beyond the limits of national jurisdiction, the oceans and the ocean bed are the common heritage of all mankind.

This is not a question of the further and further extension of the claims of coastal states. It is fact that we do, as a world community, as three thousand six hundred million people, individually own a very large piece of Real Estate, and whatever the extension of the limits of national jurisdiction, it will still be a very large piece of Real Estate.

We are having endless arguments, needless to say, about what the limits shall be. The 1958 Law of the Sea left the issue undecided as to whether the Continental Shelf is an underwater extension of the coastal nations to which it is joined. We have had arguments about what that Continental Shelf is — there is 'the slope' and 'the rise'. I want to warn you if you ever hear people arguing about 'the rise', what it means. The Continental Shelf, to its edge (before the dip), is to be fairly justifiable as an extension of the coastal state, but beyond that is 'the slope' on which we are now finding substantial oil resources, and then there is 'the rise'.

The rise is what would be the spill off the moraine of the Shelf and the slope and, according to some, if you can establish that the rise came from land deposits, you can claim the rise. To point out the absurdity of this, I will just mention that they found Brazilian gold about 1,000 miles off Brazil, across a trench. So your rise gives you a practically unlimited claim.

Another point which has arisen is the question of economic, but not complete, sovereign rights over a 200-mile limit called the Patrimonial Sea, which has been claimed, initially, by the Latin-American states. This is in compensation — rather crudely — for the fact that on the West Coast of the Western Continent, Western Hemisphere, there is practically no Continental Shelf whereas, on the Eastern side, Argentina has about twice, if not three times as much under the sea as it has on land.

The Patrimonial Sea may be supported by a substantial number of countries and may be adopted. This does not give me much satisfaction, except that it is a definition which we have been expecting; but, as we have seen in the case of Peru which claimed the 200-mile fishing rights and which thought that by so doing it had practically expropriated the Humbolt Current and which, in 1973, has had a disastrous fishing season from natural causes, this may not be the answer.

As Arthur Clarke pointed out, there is unquestionable and untold wealth in the bottom of the sea, and we who are involved will fight as hard as we can against any greater extension of the claims of coastal nations upon that which should be the common heritage of mankind.

I would also point out that this considerable wealth could be in competition with, and might in some cases be the end of, land mining. Land mining, while it has some deplorable results — slag heaps and so on — is nevertheless the wealth of many of the under-developed countries; the still untouched, unused wealth that they may have to sacrifice in competition with the sea. We must therefore have an ocean regime, an ocean management, which must be something quite different from what we had before. May I remind you that if it is 'beyond national jurisdiction', no nation can adjudicate.

I can see the great multi-national corporations moving to the sea, expropriating — *Deep Sea Venture Corporation* are already doing it, Howard Hughes too has gone to the sea bottom, and is now going to develop the exploitation of manganese nodules in the Pacific. We do not know what this disturbance is going to mean: with the equivalent of open-cast mining on the sea bottom, and refining on the surface of the sea — probably with man-made islands, etc. — you are going to get poisonous waste put back into the sea, and create havoc.

So, we have got a very big job ahead of us. Politicans are not yet fully aware of all the implications; they are still thinking in terms of the old-fashioned grab, and they do not see that this is our last resource which, once destroyed, will not only wreck the sea, but also the living capacity of the biosphere.

During the next year, well ahead of the year 2000, we are going to be facing the situation which will determine whether there is going to be a year 2000 in the sea.

Arthur Clarke: Our next speaker in this section of the proceedings is Dr. Bellamy from the Department of Botany, Durham University. Dr. Bellamy is the only man I know who can make pollution funny. I also suspect that he is a reincarnation of one of my favourite literary characters, Conan Doyle's Challenger, and if you know of Professor Challenger, you will follow me.

Dr. David Bellamy

Dr. David Bellamy, of the Department of Botany, Durham University, is the man who electrified the audience at the Brighton Conference of Underwater Activities in 1966 with a talk about marine pollution — long before that subject became popular!

With the backing of *Triton* magazine he later organised *Operation Kelp* and *Operation Starfish* — two National pollution research projects in which hundreds of amateur divers and scores of clubs collaborated in the collection of samples of marine life for scientific analysis.

What the diver can do

Mr. Chairman, divers and fellow hangers-on, when I was asked to speak at *Ocean 2000*, I asked (I think, quite politely), "Can I talk about my last expedition to the Indian Ocean?" And the answer came back loud and clear: "No. You're pollution; stick to it". Unfortunately, it does stick to one in more ways than one . . .

It is more than 8 years since I first addressed a meeting of divers on the subject of marine pollution. At that time I knew little about either diving or marine pollution, so I told a joke. It went down well and I was in! Over the past 8 years I have learnt a lot about both subjects; unfortunately I have not learnt any new jokes, so I am going to return to my original one. It was simply a statement from the modern version of the Bible that "men who go down to the sea for whatever purpose are likely to see their own business in the great waters . . ."

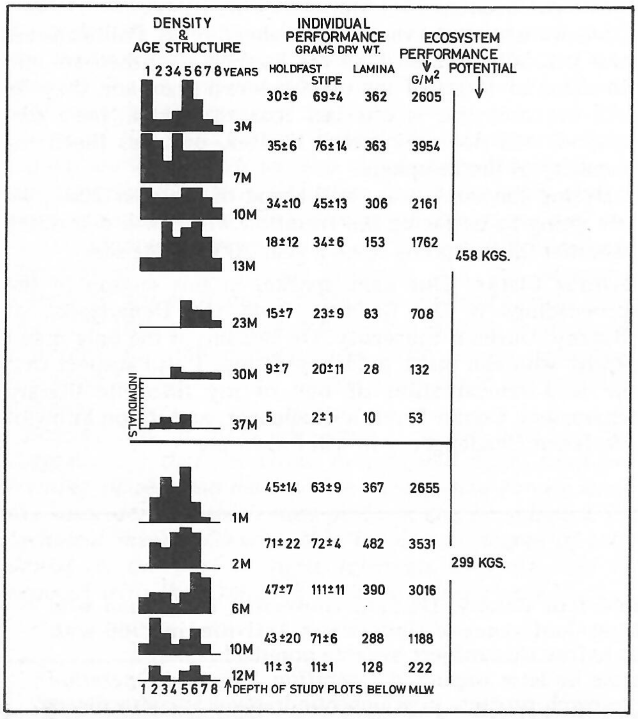
Now, this is still as true today as it was then, a fact which was brought home to me very forcibly while making a film for I.T.V., on the beach at Hartlepool, about two months ago. I was perched with the interviewer in a picturesque pose on some rocks, and the tide was just about to turn; the cameras started rolling . . . I had just got into top gear when an extra large wave rolled in and draped the interviewer in toilet paper and covered the whole of the beach with indescribable little brown objects which rolled gaily backwards and forwards. Now many of you may have seen this film on I.T.V., and it was simply due to the expertise of the cameraman that he kept his feet dry and clean and made it look like a pristine tropical shore — but there is no getting away from it: our seas, in some places, are becoming more and more polluted.

When I think of all the junk I have come across while diving . . . A contraceptive machine in the Mediterranean comes to mind. It had obviously been torn off and chucked into the sea by some local louts, but bore some British graffitti. One I liked very much because it was high-class: 'Tolkein is hobbit-forming'; another: 'this is the worst chewing gum I've ever tasted'! I think it was also the worst chewing gum that most of the fish that were floating about with the other objects, had ever tasted. Yes, the sea is polluted!

There is one great difference between then and now. Then there was very few people working on marine pollution. Today, there are enough marine pollution biologists to create a pollution hazard in themselves if they ever all got into the sea together — very few of them do.

Operation Kelp was launched under the initiative of the B.S.A.C. and *'Triton'* magazine. During the survey you covered the whole of the British Isles, measuring the performance of one plant — the rough stalked kelp — providing not only the background data for our pollution studies, but showing that the expertise of divers could be used on a massive scale to collect data — and meaningful data. I estimate that to collect the same data using conventional research teams, would have cost £10,000.

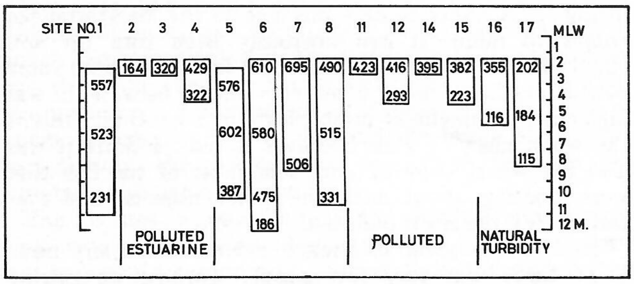
Let us focus on one site which you covered — Sennen Cove in Cornwall. This was studied both before the Torrey Canyon was wrecked, and four months afterwards, and the results show the amount of detail which can be obtained in measuring the performance of the kelp plant.



Comparison of the depth range of the rough stalked kelp forest at Sennen Cove, Cornwall above and St. Abbs below.
N.B. Main reduction in kelp performance is below 13m. at Sennen and 10m. at St. Abbs.

The interesting thing that came out of this survey was that the kelp is limited by light: as we come down to about the 13 metre mark, all of a sudden the kelp plants get much, much smaller and this limitation is simply due to light. This was to be very important in interpreting that data which we found in relation to pollution later on.

Focus on the North and East coast of Britain. At site 1, Aberdeen, we found that the kelp grows down to about 11 or 12 metres below low-water mark, and over the first few metres there is very little reduction in its actual performance, (this is shown by the figures inside the boxes).



The East coast pollution gradients as revealed by the kelp forest. Site 1 Aberdeen. Site 6 St. Abbs. Site 14 Teesmouth. Site 17 Flamborough Head. The boxes show the depth range at each site. The figures show the performance of the kelp at each depth.

Moving into the polluted estuarine situation of the Firth of Forth (sites 2, 3 and 4), we find that the kelp only occurs in a thin brown line just below low-water mark, and where it does extend only to 3 or 4 metres its performance is really slashed back.

On the South coast of Scotland and the North East coast of England (including everyone's favourite dive site, St. Abbs), we are back to the original unpolluted state: clear waters and kelp extending down to at least 12 metres depth. The performance of the kelp at these sites only falls off markedly at depth, where natural reduction of light is the cause.

Along the polluted Durham coast (which in fact was the location which started off the whole ghastly episode of research!) we again find that the kelp is limited to the shallowest water.

Wherever we have looked, the pattern has been the same, pointing to the fact that one of the main effects of even massive and long-term industrial pollution is the reduction of light penetration, which limits both the depth range and the performance of the rough stalked kelp.

The data which you collected allowed us to calculate a very rough value for the total productivity of the kelp forests around the whole of the North Sea. The figure comes to almost 100 Kilogrammes per day, 365 days of the year, and although it is 'peanuts' compared with the productivity of the plant plankton of the open North Sea, it is only double the weight of human faeces that we put into the North Sea.

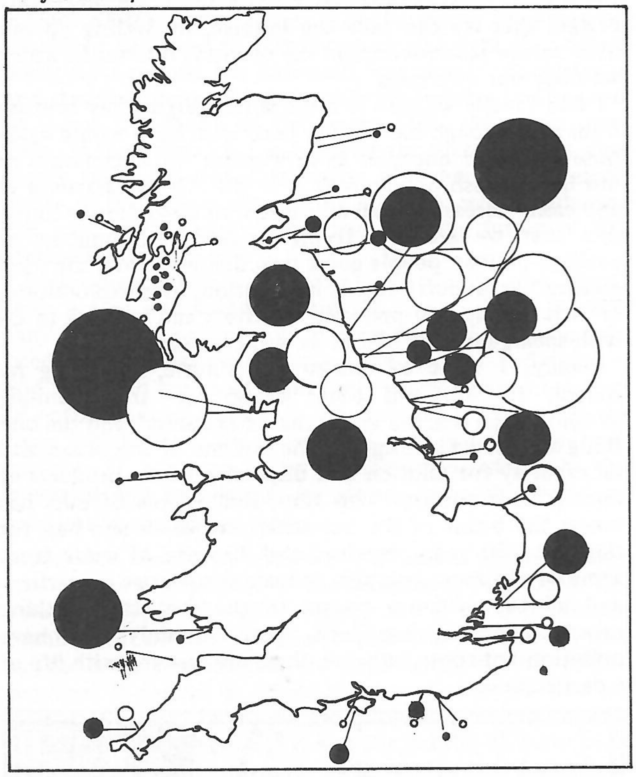
GUESSTIMATES OF THE DAILY ADDITION OF ORGANIC MATTER TO THE NORTH SEA

Primary Production, Plant Plankton	600×10^6
Primary Production, Kelp Forests	0.8×10^6
Input of faecal solids	0.4×10^6

Hereby hangs a rather nice, or nasty tale, depending on how you look at it. Much of the annual production of kelp, once it has been broken down over the winter period, goes to feed all those filter-feeding animals which live inshore. So pollution may be reducing the amount of kelp in the sea, but the loss of natural organic matter from this source is being more than adequately balanced by human faecal material; and some of the filter feeders have responded to the challenge, taken advantage of our waste, and do a very important job for us. So, it could be that everything in the kelp 'sewage' garden is lovely — that is, as long as you are a filter feeder! But surely there are effects of pollution other than sewage?

So this was a question that was uppermost in our minds when we started the search for some dreaded toxic substance. We therefore examined what we took to be polluted and unpolluted living systems removed from the kelp holdfast. In the polluted system we found an enormous diversity of life; lots of different sorts of animals of different ages 'living it up' within the shelter of the holdfast. In the polluted areas we found a very different picture: a much lower diversity; fewer sorts of animals, and all of about the same age. The interesting thing was, however, that there were just as many animals present in the polluted holdfasts, but the majority of them were filter feeders. The typical polluted community being filter feeding mussels which are the prey of carnivorous worms and starfish.

So it would appear that the natural (unpolluted) populations of animals living in the holdfast respond to the opportunities of pollution, producing an efficient(?) sewage filtration system that deals with as much of the sewage as it can, and the really fascinating thing is that it hasn't cost the taxpayer a penny, new or old. It therefore seemed very important to find out just how much strain this new system could be put under when it comes to the pollutants, like heavy metals. This was your task in *Project Starfish.*



Mean concentration of lead ○ and copper ● found in the food chain at each site. The diameter of the circles is in proportion to the concentration.

You may remember that *Project Starfish,* among other things, measured the levels of heavy metals present in certain members of the holdfast food web. Those from the polluted North East coast showed significantly high levels of lead and copper. However, is this due to pollution by man? The rivers that flow into the sea along that coast are all eroding back into Pennine catchments that are rich in metalliferous veins; perhaps the high levels of lead and copper are as much to do with natural as with man-made causes.

In the Mediterranean, another member of the team, Charles Sheppard, has come across a similar problem. Sea urchins collected from the Bay of Naples show markedly higher levels of a whole range of heavy metals than those collected from further South, out of the main effect of industrial outfalls. In fact, it was along this coast that in 1970 a group of amateur divers completed a survey which led to the establishment of the Underwater Park of Castellabate.

So, again, the simple results of chemical analysis indicate that the high levels of heavy metals are caused by pollution. However, it must be borne in mind that the Bay of Naples is itself the crater of an old volcano, and those heavy metals could be the result of past volcanic activity.

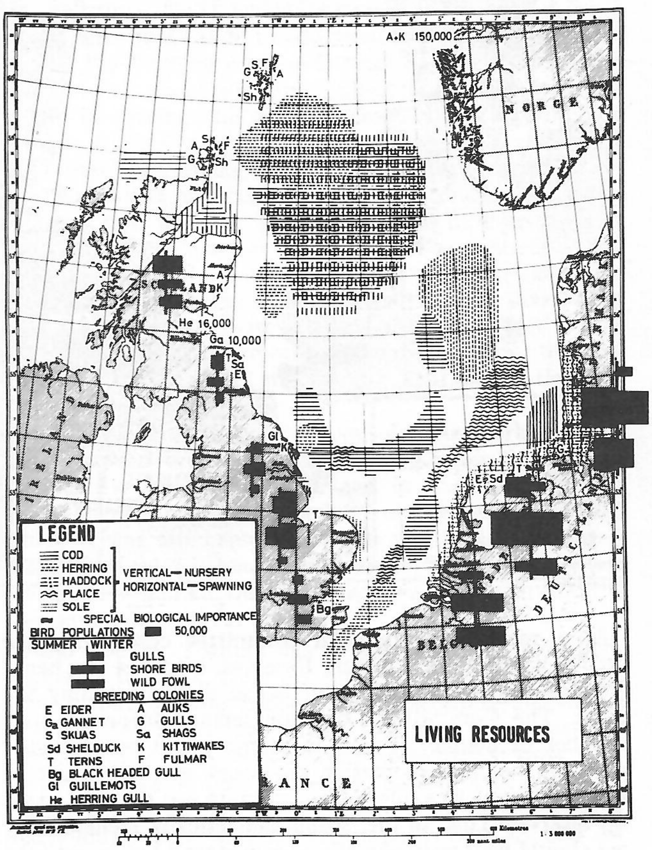
Our work to date has shown that we are studying a very complex problem, and that absolute proof of anything is very difficult to obtain. Yet this is exactly what we need: proof! When dealing with matters of marine pollution a wrong decision could lead to the expenditure of millions of pounds on a non-existent problem.

The recent cholera outbreak in Naples, which was traced to those filter feeding mussels, is probably warning enough as to the gravity of the overall problem. In this respect, it is interesting to note that along that whole stretch of coast the only places in which there are large 'natural' populations of mussels are in the Bay of Naples itself and close to other large sewage infalls.

Even if they solve the cholera problem, the mussels themselves are a health risk because they contain about 50 parts per million of lead — that is more than 200 times the allowed level for edible mussels in Britain. So what legislation will follow? A hundred billion lire sewage scheme which could certainly save the aesthetics and cure the cholera problem? Or, simply, a ban on mussel fishing, or a ruling that the mussels are laid in clean water for the requisite time before they are eaten? Whatever the answer, it is going to affect the marine resource of that coastline in some way.

More than anything else, the work I have carried out with your help has made me do some deep thinking about the resources of the sea. I will take the North Sea as an example.

It is interesting to note that many of the important spawning and feeding grounds of our commercial fish are located in what must be considered as the most polluted waters. Add to this the fact that the total fish catches coming out of the North Sea have been rising for the last few years. This is of course entirely due to increased fishing effort and it certainly cannot go on for ever. A crash must come, and when it comes it will be no earthly good trying to blame it on marine pollution — unless we include within the definition of this term 'pollution' more people demanding more from the marine resource.

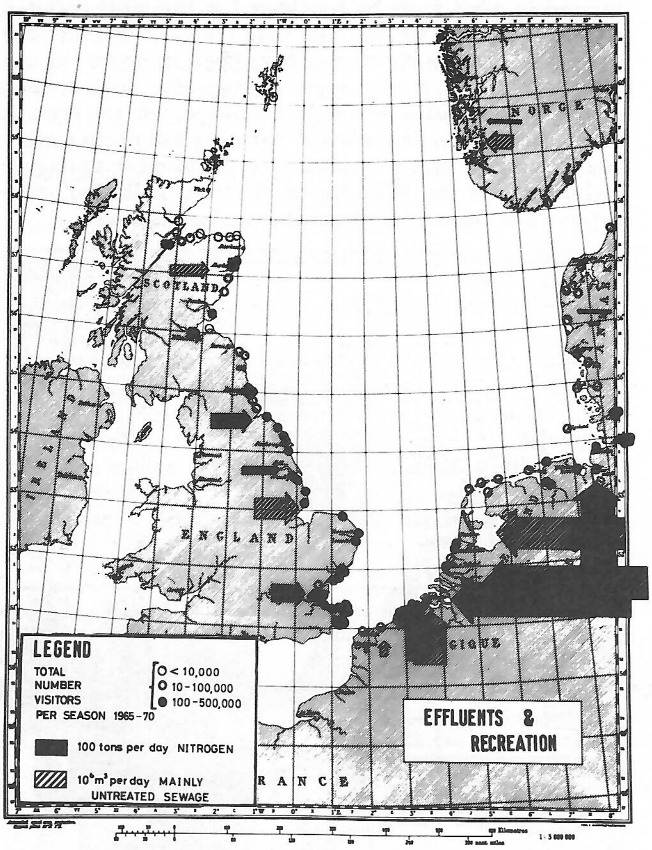


When most of us think about the living resources of the sea, we stop at fish and shell fish, and most of us who dive have taken the odd flatty or lobster or two. But how about the birds? One and half thousand tons of birds feed on the resources of the North Sea each year. Do I hear the cry "Shoot 'em?" If I do, well, don't bother because they only take a very small part of the annual production of this shallow, productive sea.

What we must realise is that if we do anything to affect the population of one of these visiting birds, the main effect may be felt many thousands of miles away, at the other end of the migration route.

Take the Brent Geese, for example: If we allow the building of Foulness Airport to ruin their feeding ground, what will happen in Siberia where they spend their summer? Above all, the birds hammer home the internationality of the marine resource.

I want now to discuss the sociological resources for amenity, education, recreation, sport and wildnerness: It is interesting to note that the British and European public are still using the most polluted waters for their recreation. Does this really matter? Probably the guy who sails his dinghy finds polluted water a little more buoyant; the person who sits in his air-conditioned motor car reckons the smell is ozone. There is only one group of people who have to get into the pollution and come into intimate contact with it, and that is us divers. One urgent job we have got to do is to prepare our own resource map of why and what we do, and where we do it, because our opinion must be taken into account in any future discussion and decision.

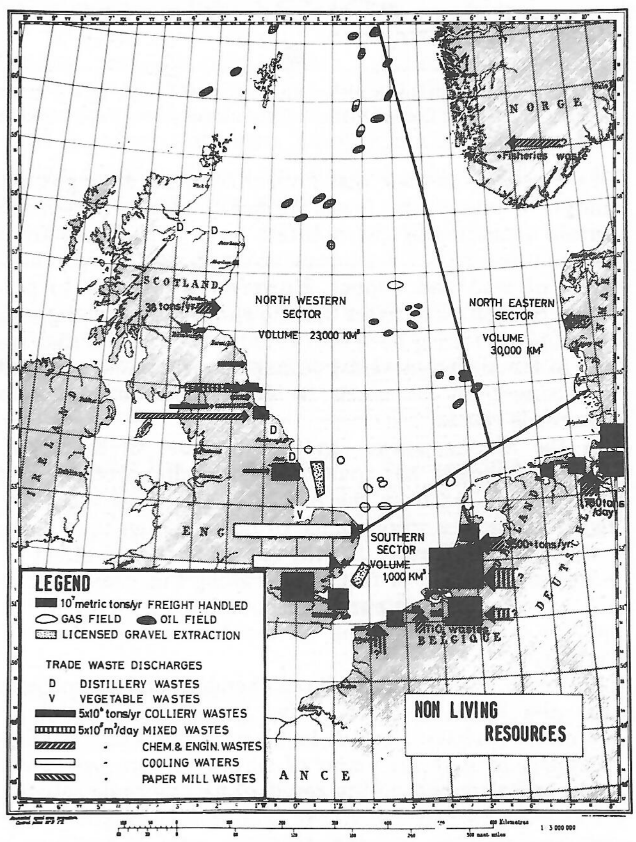


At a recent governmental committee considering the setting up of Marine Nature Reserves, evidence was heard from a large cross-section of ocean users, including the diver. The Committee's decision seemed surprising to a number of people: it was, in essence, that no particular part of the inshore marine resources was in danger of extinction due to exploitation, so there was no need to set up reserves. This, to me, seems fantastically archaic. Why we should wait until something is damaged before we take steps to preserve it, I do not understand. But when one looked at the evidence, the only thing one could put ones finger on, scientifically speaking, was that there are changes occurring in some of our popular diving sites and the population of certain animals appears to be decreasing — the list included lobsters, crayfish, scallops, sea fan and cup coral. I need not tell you, because you know — you probably collect them. The interesting thing is that all these organisms occur at depths greater than those to which we normally go, and they are therefore not in danger of extinction. So, the decision was taken not to set up reserves; the animals are not in danger of extinction.

BUT OUR SPORT IS! If we are doing anything, then we are denuding the areas in which we dive of the very animals we like to see, AND THAT IS A BLOODY STUPID WAY TO CARRY ON. SO WE MUST LEGISLATE AGAINST OURSELVES. I am absolutely certain that we can take the iniative, by setting up our own nature reserves around the country; reserves in which we obey our own rules.

I don't really want to join the anti-speargun fray because I am sure enough has already been said, but I would again pose the basic question as to whether the decimation of our inshore fish populations — in the Mediterranean or in any easily accessible waters — is due to spearguns or to the fact that we are now trying to feed vast numbers of package-holiday people going into that area from the local meagre fish populations. Is it pollution, over exploitation, or is it simply the presence of divers and nothing to do with spearguns at all? What we want is proof.

Finally, I want to discuss the abiotic, non-living resource; the oil and other things we are beginning to find in the sea; the gravel that is extracted, and the one thing we normally forget — the volume of the ocean and its capacity for dilution and dispersion of the products of our *effluent* society. This tiny, shallow sea of ours has borne the brunt of the industrial revolution and has, for the past 150 years, received and disposed of waste from some of the most complex industrial societies on earth — and all the evidence points to the fact that nothing catastrophic has happened, yet. Certainly, we have pollution hot-spots, but even these are buzzing with life of a particular sort.



At present, the main commercial valu of the oceans is in their efficient disposal of effluent, and our work to date has made me believe, at least in the short-term, that we should accept areas of our coastline designated and set aside as sewage works. With positive planning and more research these could be made more efficient and hence, much smaller. The process which must be controlled is the voiding into the sea of morbid material — that is, anything which will taint, poison, or reduce the reproductive capacity of any member of the inshore food web (and as that includes just about everything that we put in, we must be very careful to legislate against the right one, the one that causes the damage).

The success of research efforts like *Operation Kelp* and *Project Starfish* have shown how the diving force can be mobilised and used to gather meaningful data on a broad scale; their success has indicated that simple observations and measurements of the actual living systems can be used to assess the health of the ocean. Most important, perhaps, is that through participation in such projects, this highly trained world-wide matrix of divers is being made aware of the full meaning of the problems which endanger not only their favourite pastime, but the future of the marine resource in toto.

Scuba divers then, have three main roles to play. First, they act as watch-dogs within the hydrosphere; second, they are active participants in gathering the scientific data needed to conserve and develop the resource and, third — and this is to me most important — they become teachers of environmental matters to the cross-section of the world from which they are drawn and with which they have contact. If we leave it up to the specialists, only the specialist will ever know; we are the 'generalists' and we have got to spread the gospel.

Our aim should be eventual legislation which ensures that no new substance is manufactured, or process developed beyond the pilot stage, until it is economically feasible to control all direct and side-effects of that substance or process that are detrimental to the marine resource. It should be agreed at international level that no substance should be discharged into the hydrosphere until its toxicity has been tested and the results of these tests made public; that adequate methods for the determination of that substance and its breakdown products in both the living and non-living components of the hydrosphere have been published and made available.

Above all, we have got to work to make our voices heard and our lobby effective. Is it too much to think of a world centre, supported by one of the international agencies which could help correlate the divers data — data which will be of immense importance in the future planning of this great resource?

As a start, one full-time scientist and a part-time secretary could, at little cost, do a lot of meaningful work, whereas a sewerage scheme to clean up the North East coast of England could cost millions, and we might be cleaning up exactly the wrong thing. With courses for divers at Fort Bovisand, Dale Fort and new ones coming up at St. John Cass College, etc., in five years time we could be making key discoveries, and not just helping others to do so. We may be amateurs in the field of marine biology, but we are professionals in the field of the environment; if anyone understands the new jargon of 'resource', 'environment' and 'survival', it is us.

Every time I look for proof of an adverse effect of pollution, I draw a blank. If I want scientifically, 100 per cent understandable proof, I cannot get it. Yet, every time I go on a dive I feel that the site has changed in some way: the water is cloudy, there aren't as many fish — you will know the feeling. Now, we may be kidding ourselves — it was always beautiful sunshine when I was a kid, but was it really?! But if we are not kidding ourselves, we could be witnessing the first signs of future catastrophe. We have got to try to quantify this vague feeling, to make simple biological information become an integral part of our dive log: the depth range of my rough stalked kelp plant; the number of dead molluscs; the depth range of the main coral zones. If we get enough information on a broad scale, an understandable pattern of what is happening – if anything really is happening — may emerge.

A large chunk of the future of man lies in the resources of the sea, and here lies our new challenge: so join those courses and learn the jargon that we need to understand the resource, and to make people realise that we understand the resource, so that our voices will be heard when the most important decisions are made.

However, as a biologist, I know that the only real long-term answer is to control the human population, and I do feel that you, as environmentalists, are probably going to be some of the only people in the world who will accept this limitation on life, and understand why it is necessary.

Question time

Question: I have a question, perhaps for both speakers. One diver I know has actually observed beam trawls being pulled along the bottom. Many fish were being killed and crushed underneath the trawl and were not recovered, and lots of bottom environments were being completely disrupted. Isn't this, along with spearfishing, a high priority in terms of the destruction caused by man?

Hans Hass: Certainly, it is a main cause of destruction, but this is another issue. We have only limited means here in this Congress and in this Association . . . Perhaps I may use this opportunity to ask my colleague a question: Do you think spearfishing encourages fish life along the coast?

Dr. Bellamy: No, I am quite sure that if I were a fish I would agree that I didn't and I would put my whole lobby behind the banning of spearfishing. But, as a scientist, I still feel that, faced with giving absolute proof as to which factor is causing the greatest destruction, I could not provide it. If I were attending an Enquiry, I could not state that spearfishing has the most damaging effect on our inshore fish populations; I would try and weigh up the evidence that we have. For instance, we have just helped to set up an underwater nature reserve at Castellabate in order to understand why there aren't any large fish there — it is certainly not the spearfishermen because divers have only just begun to move into the area — the fact is that the local population are now, and have been over the past 10 or 15 years, taking much more fish to feed the new tourist trade.

Hans Hass: There has been considerable work done in this Congress: there was an interesting paper about some comparative work in Borneo and in Curacao at a reef where spearfishing was banned and on another similar reef where it was not banned, and this very clearly indicated that spearfishing *does* harm. I think all spearfishermen know the effect of their activity in a particular area, if they go on doing it for a while.

Arthur Clarke: I would like to ask a question here. I am beginning to think, from my own experiences, that something is causing more damage than spearfishing, and that is tropical fish collecting. I have been on some reefs in Ceylon where there were a dozen collectors at work with their little plastic bags, collecting all the fish they could see on the reef. Of course, keeping tropical fish is a marvellous hobby and it encourages people to take an interest in reefs, but isn't this collecting as dangerous as spearfishing?

Hans Hass: This is a different issue; we must work step by step. Certainly, aquarium fish, dynamiting and the new fishery methods do enormous harm, but so does spearfishing with these mechanical weapons.

Dr. Bellamy: Spearfishing is our own particular problem and if we don't make this clear and put our house in order, then nobody is going to listen to us when we speak of other matters of conservation. We can go around saying that we are the people who know, but if we continue backing this practice in the sea, we are not going to have our voices heard when we turn around and say that other forms of fishing are damaging, or that all the other things mentioned are damaging. We have got to get our priorities right: tropical fish collecting is damaging, along with collecting all the other animals I mentioned, and we must stop doing it.

Question: Dr. Hans Hass, you have mainly referred to fishing, but divers play a very large part in the collection of crustacea: Do I assume that in the future one might have a Manifesto banning the taking of these by divers?

Dr. Hans Hass: Actually, I include this in 'fishing'. I include spearing lobsters, or taking them by hand. All this I would include in spearfishing. I think that all this should be reduced.

Arthur Clarke: If the object of spearfishing is to demonstrate the diver's ability to kill, surely there is a simple alternative. On land we have clay pigeon shooting; if you want to show how good you are, devise a system by which you can propel something underneath the water, and strike at it if you can. Would Dr. Hass or others be prepared to co-operate in developing such an international system?

I don't apologise, as did Dr. Hass, for being emotional about killing. I share Dr. Bellamy's belief that there is no distinction between using a hook and shooting with a spear; we are just being savages.

Dr. Hans Hass: I'm absolutely in agreement with you. Instead of spearfishing championships, one could devise methods of showing who is the best diver or who the best shooter, without killing animals. I am absolutely ready to co-operate in this way. I agree with you totally.

I would like to add something further to the spearfishing discussion. I was the one who made the comparison between those two reefs, one undisturbed and one where a lot of spearfishing is done. The most important difference between spearfishing and commercial hook and line fishing is that the spearfisherman selectively exterminates his targets, especially those of resident species that do not swim away into the open water, but which hide in holes and crevices in the rocks.

Arthur Clarke: I would just like to make one point. A major movie made by Mike Nicholls and entitled *'The Day of the Dolphin'* is to be released in a few months. It is about dolphins as weapons of war, and perhaps we ought to latch on to the people involved and try to get a ride on their publicity; it could be a very good opening for this.

Commander Taillez

Commandant Taillez was a pioneer in the field of underwater exploration; in 1926 he was a helmet diver and swimming champion of France. In 1937 he was a mini-torpedo instructor and in that year met a young gunnery instructor called Cousteau, and they dived together with primitive goggles and fins. At weekends they would meet and design underwater equipment, and the first ideas of the aqualung started to emerge.

In June 1943 in the South of France, under the very nose of the occupying allied forces, Commander Taillez was one of the first three men to dive with an aqualung — the other two were Cousteau and Frederick Dumas.

Ecology and Mankind *(Translation from French)*

I have come to London just to meet the old divers whom I knew I would see here; those younger divers whom I know and some I don't yet know. You see, perhaps it is the last time that I shall come to a gathering of this kind . . . I am a very tired man and it is something of a trial for me even to be at this hall in front of a sea of faces. But I have come to ask you to join me in breaking the surface and in diving into the silent depths of the mind.

First, I should say that I am, like Hans Hass and all the divers of the old days who have been diving for a long time, terrified to see the acceleration in the destruction of the balance of life and Nature; in the air and sea, as well as on land. Quite simply, we are really terrified because we can measure the rate of this destruction against our much earlier experiences; we fully understand that those who have come after us are less worried, because they are measuring this loss of equilibrium in Nature on a shorter time-scale. But we have a duty to talk about our anguish: it is very important that those who come after us know better what can be, and what ought not to be, done in the sea.

Certainly, we need to dream and to prospect, to plunge ourselves into the past and to imagine the future . . . Like Hannes Keller I have thought about how many people one could accommodate in the sea, though I admit I did not think specifically of a house 1 cubic Kilometre in area into which one could put a million men, but thinking along those lines: there are one thousand million cubic metres in such a house, and into each of these cubic metres one can, by squeezing them in rather like sardines in a tin, put four, five or even six people. That makes six thousand million men: the six or seven thousand million men who will be in existence in 30 years time.

When we reflect on how little is the mass of humanity, the human bio-mass, we are surprised that it is capable of bringing about so much destruction — and why is this? It is because there are not simply three thousand million men, but everything they surround themselves with, everything they need (and often false needs) in order to live.

The subject of my talk is *The Significance of Ecology in Terms of Ethics and Natural Morality*. Doubtless this will seem a boring topic, and you would probably prefer to hear something else, but I want you to think about this. First of all, let us try to define the exact meaning of the term 'ecology'. You will probably tell me that one should ask the ecologists! Certainly, we all know that it is the study of the relationships existing between the diverse manifestations of life on our earth, and the environments in which they occur, but who does not see that, even in this very limited sense, a confusing extent and diversity exists in this subject — so much so in fact that many men of science deny the possibility of making such a vast question the object of science. This is mainly due to the fact that, following the cartesian method, science has by degrees become compartmentalised to such an extent that you have to gather together an immense number of specialists to tackle a single question. But if we give such a limited definition of what we call ecology, which covers the totality of the inter-relationships of the phenomena of life, we must also take in its wider application.

What we call a 'phenomenon' is the term that we use in science to define things and make them objects of measurement. It is true that, beginning with measurements of this kind, a study of phenomena should proceed with the variations which we see in space and time. Ecology in its widest meaning is the study of the inter-relationships in space and time of all the phenomena of the universe. This definition is united in some sense with what we call evolution; evolution in space and time — space and time which are always inexorably linked together.

If we turn our minds to the phenomena of the Universe, and try to think about the minute as well as the immeasurably huge, to appreciate the tiny and the immense in space and time, what do we see?

If we consider first what mean call 'matter', we see: at all levels of the atom, starting from their nuclei, all atoms up to the levels of the greatest complexity of matter, going from atoms to atoms, from molecules to molecules, and from the systems of these molecules, everywhere we see an accelerator and braking mechanism. Now, leaving the level of what we call 'matter', for what we call 'life': a unit of atoms and molecules becoming cells, combinations of cells becoming organs, groups of organs forming organisms: in all these, we find the presence of braking and accelerating regulators. Everywhere!

No, not everywhere! Since the time that man invented technology, which has certainly allowed him to survive, he has not thought it good nor necessary to set up any regulatory mechanisms to his actions; in all the prodigious development of techniques born directly of scientific knowledge, one only hears of expansion. Now look at what could be called the 'peace bomb', that is to say, the indefinitely growing number of human beings — no braking mechanism. This is frightening and, believe me, population growth will be stemmed some how. But man has to ensure that the human race survives this period through an individual and collective responsibility, by realising that regulator mechanisms exist and are necessary to all forms of matter and life, and if we do not restrict ourselves of our own free will, the bio-phenomenon of humanity will perish.

What does ecology and evolution mean in the end? It means that the whole Universe — everything created — is linked, and you cannot touch anything anywhere in the whole of time and space, as it unfolds, without the whole reverberating. Very simple people know this; poets know it too. They say that if you meddle with a flower, you upset a star. Artists know it as well. I am thinking of Calder, the man who invented mobiles: you cannot touch any part or anywhere on his brilliant invention without everything rustling, moving and quivering in the whole.

Yes, everything in the Universe is, as in Jules Verne's expression, 'mobiliste immobile'.

I believe that the greatest advance in the awareness of the unity of inter-dependence in the world was made by Einstein in his equation: $E = MC^2$; the total energy of the world is equal to its mass multiplied by the square of the speed of light. The world is one in its diversity; one cannot ignore the unity of the world — the double helix of life.

If we want to talk about the sea, let us begin with what man has done since he left the sea. (He is returning to it now with a mask and fins). Let me tell you something that has struck me from the first time that I ever put on a mask, going straight towards the shore, face down to the seabed: Here is the surface of the water, here the bottom, the seabed stretching towards the land. When you are in the sky or somewhere on land you have an obtuse angle, an altogether different view of the sea. But if you are here, take your mask and move and turn your gaze and your mind towards this line that marks the frontier between land and sea; that line which is sometimes calm and sometimes lashed with waves all along the millions of Kilometres of coastlines. Young divers, make this simple movement and see above you that roof of the undersea world, and then that slope of the seabed, and the triple line. That line is the junction of the three great spheres of Nature: the junction of air, land and water where, somewhere in the past, life was born; the cradle of life. I am talking to you about it now because it is at precisely this point that the three natural environments which are necessary to life — with solar energy, of course converge, and because the pollution that is happening now starts from the surface and the shores — at precisely the point where life began long ago. We should all take heed of this fact and make a joint effort to protect the seabed from the pollution from land and the surface.

How and why should we fight? Certainly, we must find a higher motivation than that of making more and more technology so that man can become stronger and stronger, or that of being able to exploit the marine element — just as he has, more and more, the land. It is quite certain that the sea is at the base of everything, and that all the pollution of the Earth converges to it by gravity alone, whether we will or no. It is there. And to fight it we have to have recourse to a system of ethics -- in my case, it comes to some extent from my sense of amazement at having been plunged into this Universe, a creature within Creation. When our minds go to the brink of Creation we are forced to feel this unity; some people accept it, others push it away. It is a feeling of transcendence, beyond the reach of our senses, and I believe that man's struggle must be situated somewhere between this idea and a level higher than that of religions. If you descend to the level of a religion — which ever one it may be — you cannot reunite a great body of men, because of the diversity and confusion that exists in the different religious groups. For myself, *Credo in unum Deum:* I believe in one God, creator of the Universe. I stop there. I place my struggle at a higher level than that of a particular religion, or of any dependence at all, whatever it might be, whether religious or political. I place my struggle above them out of loyalty to myself, and it is only in this way that one can bring together the maximum number of men to unite in this struggle against the loss of equilibrium in Nature; in a spirit of brotherhood.

If, at my age, I still have some strength left to fight this battle I owe it to these reflections and considerations (which I know I have expressed badly). I think it is possible to derive strength to try and see what man can be made to do; what kind of interest he can be allowed in the sea, and what he does not have the right to allow himself to do.

There are some minds which guide the rest of us. We need a call to action, an awakening, to steer ourselves towards a future. The most pressing need at the moment is for mankind to set up these stop-go mechanisms about which I have spoken and which are common to all levels of life and matter. If he does not do so, the human race will perish. This does not mean that the Universe will disappear altogether; what humanity leaves behind will be able to live perfectly well, to revive and return to equilibrium — but only when man has been removed for all time.

This is what I came to say.

Arthur Clarke: Thank you very much Commandant, for your eloquent statement of our predicament here, as divers and human beings.

You heard Dr. Hass' very interesting talk this morning about banning spearguns, and we would just like to get some idea of what the audience feels about this. How many of you think that mechanical spearguns of any kind should be prohibited? A vote was taken.

There is certainly a great majority in favour of banning; it is obviously a matter that is going to be discussed in great detail in the years ahead.

I now have pleasure in opening the afternoon session with a very distinguished speaker — Commander Scott Carpenter — who was the second American to orbit the earth in the Mercury spacecraft Aurora 7, in 1962. He then left the space programme and converted from an astronaut to an aquanautical role in the Navy's Sealab programme, and he is going to tell you a great deal about the connection between sea and space.

Commander Scott Carpenter

Commander Scott Carpenter, astronaut-acquanaut, was the second American to orbit the earth in Aurora 7 in 1962.

After leaving the space programme, he joined the US Navy's Sealab experiment, and in 1965 spent 30 days in Sealab II at a depth of 205 feet below the surface of the Pacific off La Jolla, California.

He has been told he can never dive to such a depth again due to decompression troubles on the ascent from Sealab II.

Tapping the oceans' wealth

First, I think it is important to define 'wealth'. It is generally well-known that the most immediately available wealth to be found in the sea comes in the form of oil, but there is a great wealth of other minerals; whether it is economical to extract them is a question that remains to be answered.

I am sure most of you are aware of an ongoing programme by the *Hughes Tool Company* in the United States which had spent many millions of dollars and many years in the development of the chemical process required for separating the strange combination of minerals that appears in manganese nodules. This has taken a development period and funds that I believe only a man of Hughe's wealth could support. The pilot plant is successful and his equally expensive recovery system is at sea now trying to prove that the manganese nodules themselves are really close to hand after all. We also have food resources, in both plant and animal form, to be found in abundance in the sea. I would like to speak about this source of wealth a little bit later, because its value is controversial, as well as is its frailty.

The wealth of the sea that, to me, is most important is the knowledge we can gain from the exploration of it, just as I believe that although the moon rocks we brought back are in themselves worth nothing, the knowledge they represent is priceless. In addition, the knowledge that we gained just from having built the capability to send a man to the moon and return him, is priceless beyond measure, and we will continue to reap benefits from what we have so far done for hundreds of years; the same obtains with the wealth of knowledge that we can gain from the oceans.

The material wealth of the oceans, by and large, is considered to lie in water less than six hundred feet deep, and that is in concert with the definition of the Continental Shelf. If you total all the continental shelves of the earth together you come up with a total land area roughly equal in size to the continent of Africa, (or to the entire lunar surface). Here, only six hundred feet away, lie riches untapped and untold, and food and minerals, oil, fresh water upwellings and knowledge in abundance that we can't begin to understand yet. Contrast this with the barren Moon: there may be water there that we can use, there may be minerals there that we can use, but our ability to utilize the Moon's resources on this planet are many decades away. The ability to use the oceans' resources tomorrow are here and for that reason, among others, I believe it is important to us — as divers, as oceanographers, as international opinion-makers — to pay more attention to these resources.

We talked about food from the sea; we talked about the ecology of the sea — are we ruining it forever? There are heated arguments among real experts about whether or not man can destroy the oceans. I am sure you know the good Captain Cousteau's position on that. He says, and I believe I paraphrase his words properly - that the pristine oceans, as they were hundreds of years ago, are destroyed forever. He believes that it is no longer possible for the United States to establish National Underwater Parks along her shores; national, closely tended underwater gardens possibly, but not National Parks left to thrive alone.

Dr. John Craven of the American Navy's Deep Submarine Systems project, a very bright oceanographer currently with the University of Hawaii, argues heatedly that it is beyond man's capabilities to overload the ocean. I honestly do not know what the answer is, but I must say that I was pleased to see the number of hands shown in favour of barring spearfishing: it was nearly unanimous, which means that you all feel very dearly the need to keep the ocean as it is, and I think you have an appreciation of the damage that has been done by improper spearfishing. I have an idea that you are right when you fear spearfishing that much and I have an idea that Cousteau is right when he says that we are destroying the ocean. It is the safest assumption in any event.

Captain Cousteau says, among other things, that you must outlaw fishing because we cannot just draw the animal food resources from the sea by present methods and expect the sea to survive — this is questionable in the minds of many, but he said another thing that is unquestionable. He took the words of Frank Borman, Captain of the three-man *Apollo* crew that made the first circum-lunar flight; the first men to see what this planet looks like from sislunar space. He saw it in its true light as a closed cycle orbiting space-craft round the sun wherein a survival situation exists. In a survival situation military men will remember their training, to throw nothing away, and Cousteau believes we should throw nothing away, not the albatross, not the polar bear — nothing. We need everything to keep the balance properly. We are all a crew on this space-craft and we must all depend on each other's contribution if we are to survive. And. then Captain Cousteau said, if this is so, (and I think it is so), we must also outlaw war because war is a mutiny among the crew of the space-craft. These are good words.

I further support the belief that it is within our power to destroy the ocean because I have developed, through my work with *N.A.S.A.* and the United States' Navy, an abiding faith that anything man can imagine, given enough money and given enough time, he can accomplish. Erasing life on this planet, I must tell you, *is* possible; let us hope that with our concerted and well-planned effort we can help that not to come to pass.

It is now my pleasure to get the meeting a little out of the long hair regime and back to a very important issue where the world's oceans are concerned, and that is food from the sea.

Mark Fisher

Mark Fisher, a Director of *Mariculture Ltd.*, was born in 1941, and educated at Eton and Harper Adams Agricultural College, Shropshire.

After leaving Harper Adams, he spent six months in the U.S.A. studying modern methods of American agriculture, and on his return to the U.K. became involved in the agricultural side of the broiler chicken business and with large-scale commercial egg production.

He has been with *Mariculture* since its inception, and 'commutes' between the family farm at Framfield, Sussex, and the Cayman Islands.

Domesticating the turtle

Perhaps I am stating the obvious when I say that the world will have to turn to the sea if it hopes to feed the hungry and over-expanding population but, in 1968, with the object of learning how the sea's most valuable reptile – the green sea turtle – could be farmed commercially, *Mariculture Limited* was formed by a group of private businessmen on Grand Cayman Island in the British West Indies.

The 12.5 acre *Mariculture* farm is situated on a coral rock at the edge of the Caribbean. Here, 125,000 turtles, ranging from mere hatchlings to 3½ years of age, live in 125 open-air concrete swimming pools containing a total of nearly 2,000,000 gallons of sea-water.

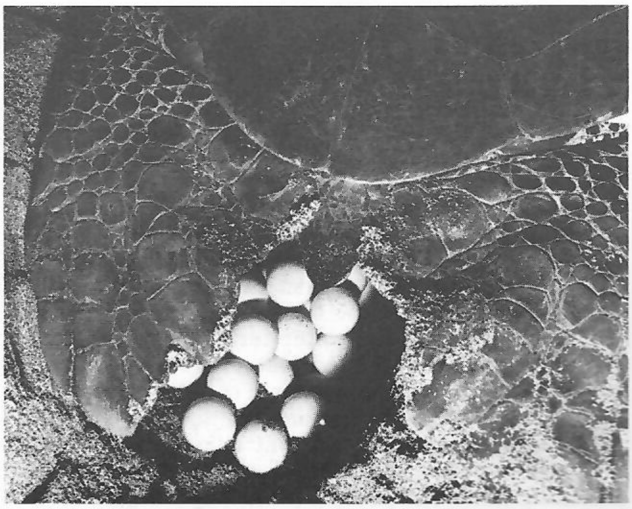
Another 3,000,000 gallons capacity is to be added during the next few months to accommodate the increasing stock which is expected to treble in three years. Every minute of the day, 65,000 gallons of fresh sea-water are needed to circulate around the complex of pools, which also includes 100 smaller research and development tanks.

Obviously, research is a vital part of our project on Cayman, in fact, it is at the heart of the venture for when we started no one knew how to go about hatching and rearing turtles in captivity. There is too little time for me to tell you as much as I should like about our search for knowledge of the species, but we are conducting a wide-ranging research programme into nutrition and turtle health, and experimenting in poly-culture – the use of the nutrient-laden effluent from our tanks, and of the tanks themselves for rearing species like shrimp, lobster, oysters and conch that have a commercial potential. This research is carried out by our own staff and by consultants who are among the world's top experts; among these I should mention Professor Sir Alan Parks, leading authority on reproductive physiology, and Professor Amoroso, also well-known for his involvement in the reproduction of captive animals. Only a commerical venture can justify a financial outlay of such magnitude; to date some 3.5 million dollars have been expended, with a like sum still to go before we even begin to make a profit.

The green sea turtle, known as Chelonia Mydas in scientific circles, is defined as an endangered species by the International Union for the Conservation of Nature. Despite having to compete with some of the most formidable natural odds, the species had survived almost unchanged for some 60,000,000 years until, during the last century, relatively small-scale local fishing and the whims of far-distant gourmets combined to cause its rapid decline. Our company's aim, therefore, was to supply the market for turtle products with *farmed* turtles.

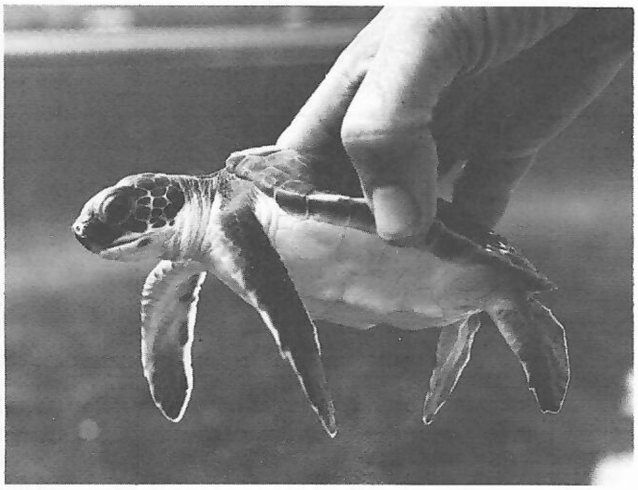
Initially, this meant with eggs harvested from the wild nesting beaches where, in some cases, the high lava content of the sand or the changing tides substantially reduce or completely remove the possibility of a successful natural hatching. But, *Mariculture* has recognised all along that this collection of eggs from the wild, even from doomed nests, must only be a temporary measure; that we should make every effort to get our captive adult females to mate and lay eggs on the farm.

Until 1973, however, the adult stock obtained three years earlier and living quite happily in a 1.5 million gallon breeding pool, had taken no interest in breeding. So, in April, we introduced two more adult males from Surina into the pool, with electrifying results: these males started copulating with healthy enthusiasm and then some of our original males got the message and began following suit. After this initial excitement in the breeding pond, nesting and laying on our own artificial beach started within a few weeks. Individual turtles have nested up to eight times, and one particularly prolific lady whose nickname is 'Sexy' has so far produced 1,500 eggs. To date some 19 of the 60 females have already laid and we expect to hatch over 75 per cent of the fertile eggs, if the early hatching results we are now obtaining are maintained. *[*12,000 eggs were produced].*



The turtle makes a hole for herself in the sand and then, with her back flippers, digs a 2 to 3ft. deep nest for her 150-egg clutch. When she has finished laying, she pats the nest sand back into position and moves the hole that she built for herself to another spot on the beach, thus removing all evidence as to the true position of the nest. The mother turtle returns to the beach about every 8 to 10 days, until she has laid between 600 and 1,000 eggs.

Our men watch the beach each night and recover the eggs immediately; if they are not removed within ten hours of being laid, the hatching results are not up to standard. The eggs are packed in polystyrene boxes and removed immediately to the hatchery where, about 61 days later, the turtles, each with a perfectly formed egg tooth, chip their way out of the eggs.



The baby turtles are now laid out in long trays until their shells have straightened out and their egg sacs have been re-absorbed into the body. In the wild state this would normally take place near the beach and the turtles would wriggle their way to the surface, taking two days to do so, during which time they would have absorbed the yolk sac. Having achieved the surface, they would then rush for the sea in a fan-shaped formation, those on the outer edges of this formation standing the least chance of survival from the waiting armies of ghost crabs, birds, etc.

At *Mariculture*, the majority of the baby turtles are now released into small shallow pens on the farm, but several thousand of those hatchlings that were collected as eggs from wild beaches are returned to their natal area and released under their own steam into the shallows; in this way they orientate themselves to the sea and, hopefully, to their original beach. We then re-capture these hatchlings and take them right out to sea, beyond the immediate reach of enemies hovering in the surf.

At the end of one year on the farm, a further one per cent of the young turtles that have survived collection from wild nests are flown back to their natal beach, tagged and released. Best estimates give only two hatchlings in one thousand a chance to survive in the wild, whereas on the farm well over five hundred in a thousand survive to a marketable age.

Obviously, the art of good farming is to keep competition for food to a minimum, so our animals are fed on a strict rotation basis with an expensive extruded feed that floats among them in the tanks. Handled, examined and constantly checked, as the turtles increase in size so they are transferred to larger tanks, the runts being culled out because they retard the growth curve.

After three and a half years, the turtles, which now weigh 80lbs. and more, are sent either to the breeding pond or to the slaughtering plant where they are humanely killed and packed. At the beginning of 1973 we started a limited production at the plant with some 60 animals daily, each weighing about 90 lbs.

The turtle is a valuable animal: only 13 lbs. from every 100 lbs. is waste, and even this may ultimately be used in some way or other. Products include the meat, which is delicious, tender, rather like veal and only 2 per cent fat; leather for export to New York, London and Tokyo; soup products marketed in London, Europe and Australia; oil, jewellery items and shell. The total shell from our unscarred turtles is so fine that it is frequently mistaken for that of the Hawksbill, an inedible but much hunted and now nearly extinct marine turtle. (One of the benefits of the *Mariculture* project is, therefore, that apart from taking the pressure off the green turtle in the wild, we are also relieving pressure on the Hawksbill).

Turtle farming, as we have demonstrated publicly at *Mariculture*, can open up vast new possibilities for our hungry world. Replicas of our facilities could be built almost anywhere in the warm water areas of the globe, and there are many such areas where starvation problems are the worst. We now have the technical know-how to reproduce our facilities in any one of these areas, indeed the base required for a turtle farm would often be on land near a seashore which would otherwise be quite useless for food production. It may help to illustrate the economic value of the turtle if I explain that to produce 4,000 lbs. of catfish — a species under serious use for aquaculture today, but not comparable in quality to the turtle — it is necessary to supply a volume of water that can, over the same period of time, produce some 200,000 lbs. of sea turtle.

There is no doubt that thoughtful people, scientists, governments and many ordinary men and women, ponder man's future and our exploding population with some gloom. They realise that almost three-quarters of the world is covered with salt water and think about exploiting this area for food. Yet, currently, only about 2 per cent of our food is obtained from the sea.

Given the proven extraordinary value of the turtle, I feel that *Mariculture's* development of commercial farming technology is of major importance. In 1974 *Mariculture* will produce over 1.2 million lbs. of turtle, and with the current multi-million dollar expansion programme now under way on Cayman, this figure will rise to 6 million lbs. by 1978.

If we can succeed at *Mariculture* — and signs show we are already well on the road — there is enormous promise not only for the preservation and restoration of the green sea turtle, but also for the feeding of man himself.

Arthur Clarke: There are a couple of things I forgot to mention during my first discussion: It is through the good auspices of *Barracuda* and *Oceans 2000* that I and my wife are here and I want to thank you both very much for that opportunity. Any chance to get together with divers as a fraternity is very welcome for me, and any chance to visit London again is very welcome to both of us, so to both of you, thank you.

There has not been too much levity so far and even though we are a bit over schedule I'm going to tell you a short funny story. It applies to oceanography and it may be a little difficult for non-Americans to understand, but those of you who don't laugh may consult with me after the session and I'll explain it.

It has to do with an oceanographer in La Jolla who worked for Scripps (*Institute of Oceanography*) and who lived very close to the ocean, separated by a grove of trees from a cove in which two porpoises lived. The oceanographer developed the very strange theory that if he were able to feed those porpoises nothing but seagull meat for thirty days running, the porpoises would achieve everlasting life.

Accordingly, he laid in a good supply of gull meat in a freezer on the back porch of his home and, for twenty-nine days running, early in the morning got the gull meat, walked through the grove of trees to the cove and fed the porpoises. Early on the twenty-ninth day it so happened that a lion escaped from the state zoo; wandered through the city; terrorised the natives and late that night took up residence on the oceanographer's back door step. So, when the oceanographer rose and on the final, thirtieth day of his experiment, got the gulls and opened the door, he saw the lion on the back door step and was sore afraid. But realising that the experiment hung in the balance, he very gingerly stepped over the sleeping lion, walked through the grove of trees and, low and behold, out from behind a tree stepped two F.B.I. men who arrested him. He was incredulous. "What have I done?" he asked, and they replied "Sir, it is clear that we have caught you red-handed crossing the state lion with gulls for immortal porpoises."

It is a great pleasure to see Gosta Fahlman again and I take great pleasure in introducing him to you. He knows as much, if not more, about diving, diving equipment, diving complexes and submersibles than any other man around.

Costa H. Fahlman

Gosta H. Fahlman, Senior Staff Engineer for *Lockheed Petroleum Services Ltd*, has been associated with undersea matters throughout his career, ever since he graduated from the Royal Swedish Navy's Submarine Officers' School in 1950.

From 1955 to 1966 he was Director of that Navy's Diving Submarine Rescue and Salvage Section, then joined the *Lockheed Missiles and Space Company* where he was responsible for the conceptual design of a deep diving system for the submersible *Deep Quest*.

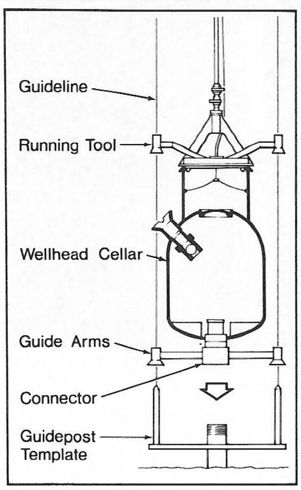
Subsea Oil and Gas Production

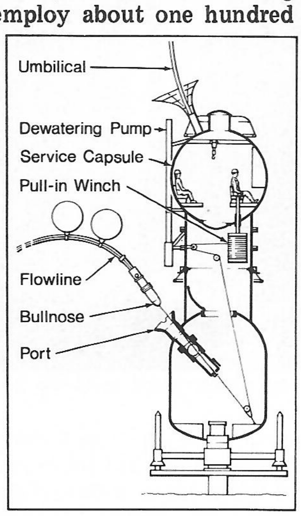
I am going to give you a brief description of the sub-sea oil and gas production system that we have developed at *Lockheed Petroleum Services Limited.* This system enables man to work on the sea floor at great depths without being exposed to the pressure or to the wet environment. We feel that this system will also decrease the risk of oil pollution in the water.

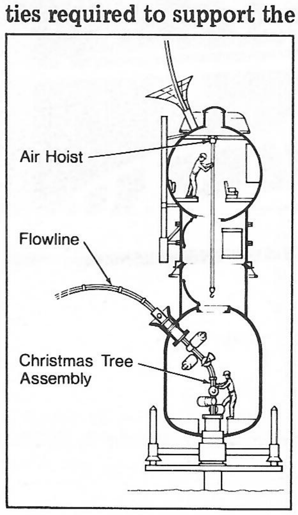
In September last year an offshore oil well, the first one-atmosphere sub-sea production system to be used, was put on production in the Gulf of Mexico, about 100 miles South East of New Orleans. Owned by *Shell Oil Company*, it is in 375ft. of water and is, to my knowledge, the deepest oil-producing well in the world. The completion of this well was the first phase in a joint development programme by *Shell Oil Company* and *Lockheed.*

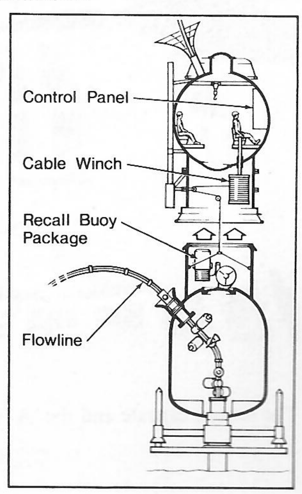
Lockheed Petroleum Services Limited is a Canadian subsidiary of *Lockheed Aircraft Corporation.* Our head office, where all our engineering work is done, is located in New Westminster, about 50 miles south of Vancouver. We have a regional office in Houston, Texas, for U.S. Marketing and Gulf of Mexico operations, and also a marketing office here in London. We employ about one hundred people and our main business is in offshore oil production; we sell sub-sea hardware and services to complete, service and maintain sub-sea wells. Our present sub-sea production system was conceived in 1966 at *Lockheed Missiles and Space Company* in Sunnyvale, California. (In August 1969 when the *Lockheed Petroleum Services* was formed, the development was moved to that company). The hardware for the first system was built in Canada and in the summer of 1970 qualification tests were carried out in Georgia Strait, just outside Vancouver. The tests were conducted in 900ft. of water and, encouraged by the success of these, *Shell Oil Company* and *Lockheed* agreed on the joint development programme I mentioned.

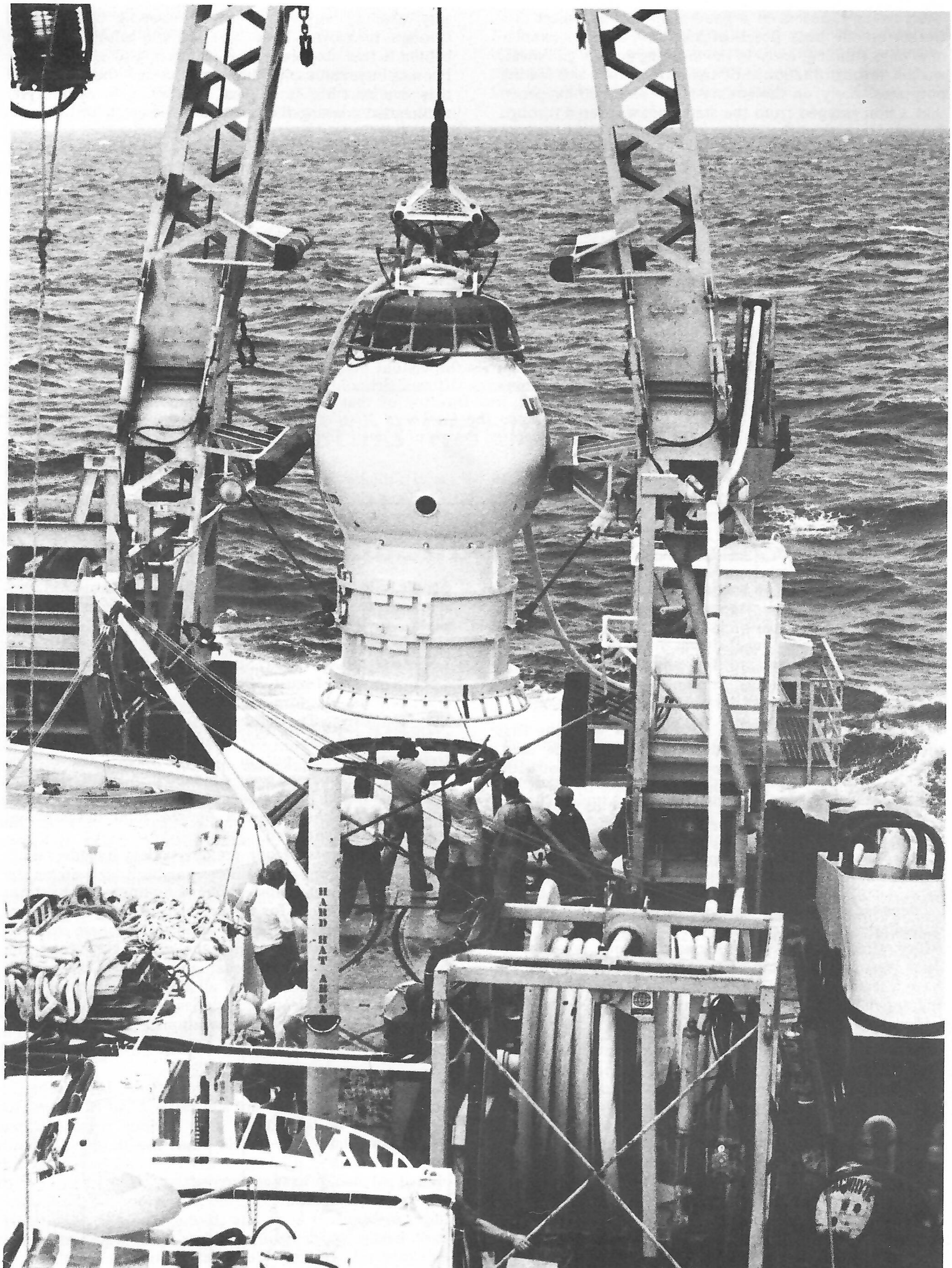
The components of our present system include a wellhead cellar — a one-atmosphere chamber which sits on the bottom and encapsulates wellhead equipment (christmas tree) and equipment for the production of oil or gas from the well; the service capsule — a one-atmosphere chamber which transfers men, equipment, tools etc. from the surface to the wellhead cellar and, thirdly, the surface support vessel, which carries all the environmental, electrical and communications supplies and monitoring facilities required to support the operations.











The service capsule and the 'A'-frame for supporting the 36,000lb. capsule.

The *wellhead cellar*, which can be either cylindrical or spherical in shape, is part of the hardware that we sell to the customers and is designed and built to their specifications: the *Shell* cellar is 20ft. high, approximately 11ft. in diameter and weighs 44,000 lbs. in air. At one side of the cellar there is a cone-shaped port (the bullnoze) where the flow lines which transport — in the case of the Gulf project, the oil — from the well to the production platform, are pulled in and connected to the christmas tree.

The *service capsule* is a 10ft. diameter pressure sphere with an open cylindrical skirt beneath. Rated to a submerged depth of 1,200ft., it is 18ft. high and weighs 36,000lbs. in air; in water it is approximately 4,000lbs. buoyant. Descent and ascent are regulated by the operator inside the capsule who controls an hydraulically-powered winch which pulls the sphere down via a cable attached to the wellhead cellar. A rubber gasket at the base of the skirt mates with the ring and 'teacup' on the top of the wellhead cellar, the hydrostatic head pressure providing a tight seal. Two high capacity pumps remove water from the capsule's skirt and from the teacup on the cellar, so that entry into the cellar through the capsule's bottom hatch is possible; the top entry hatch is used when the capsule is on the surface support vessel.

Instrumentation includes T.V. to observe capsule-to-wellhead cellar mating, and gas sensors. In addition, there are numerous safety back-up features on board, including breathing equipment, emergency battery power and, in case it is necessary to sever the umbilical supply from the surface support vessel, explosive cutters; the capsule is always positively buoyant and would make a safe, free ascent to the surface.

Our present *surface support vessel* is 165ft. long and 38ft. wide, a slightly modified offshore supply ship which has a launch and recovery system mounted at the stern. This system consists of a hydraulically operated 'A' frame that swings inboard to raise the capsule from the deck and swings outboard to lower the capsule into the water on the 'backhaul cable'. While the capsule is in the hoisted position it is steadied by four 'snubbing lines', and heavy rubber bumpers on legs of the 'A' frame prevent damage to the frame or capsule should the capsule swing laterally.

Other support equipment on board the vessel includes the umbilical winch, controls to monitor the operation inside the capsule, (TV monitors, read-outs of the atmosphere inside the capsule, wellhead cellar, etc.), together with a maintenance and repair van which has a work-bench, tools, compressor, vacuum pump, to provide for proper air circulation inside the capsule and wellhead cellar.

Mode of Operation

The well is drilled in the conventional manner: tubing is run and plugs are set; the marine riser and blow-out preventor stack are then retrieved. The wellhead cellar is suspended from the drillstring by means of the *Lockheed* combination running tool. The cellar runs down the guidelines and its connector locks on to the wellhead preparation. The running tool is hydraulically unlatched from the wellhead cellar, and the drill string and running tool are then retrieved to the surface. The guidelines are pulled and the drill rig is moved off station.

The support vessel is then put on a four-point mooring about 150ft. upstream or windward of the wellhead cellar. The downhaul cable from the cellar is released by an acoustic release mechanism, and attached to the capsule's downhaul winch. The capsule, normally with three men on board, is now launched and winches itself down to mate with the wellhead cellar.

One of the first jobs that the men have to do when they arrive is to prepare the wellhead cellar for pull-in of the flowlines: a special buoy package installed in the cellar is released, taking the pull-in cable to the surface. This cable is attached to the 'bullnose' end of the flowline bundle; the flow lines are pulled in on the downhaul winch in the capsule.

The next step is to assemble the christmas tree components and to connect it to the flowlines. The entire installation is then pressure and drift tested, after which the well is ready to be put on production.

In performing all these tests, the capsule makes several trips down to the wellhead cellar. Normally, one capsule team goes down to the cellar for a 12-hour workshift, and in ideal conditions all the jobs necessary to put the well in production should be completed in about five and a half days.

Future Developments

Our first installation has been very successfully producing oil for over a year. At the beginning of September 1973 we made a re-entry into the wellhead cellar to investigate and evaluate the condition of the equipment. We found that the equipment was in good operating condition and the well is back in production again.

Encouraged by the success of this first installation, and based on the experience we have gained from it, we are now concentrating our efforts on developing the complete sub-sea oil and gas production system. Our next operation goal is to emplace a manifold centre which will commingle and test the production of several sub-sea wells.

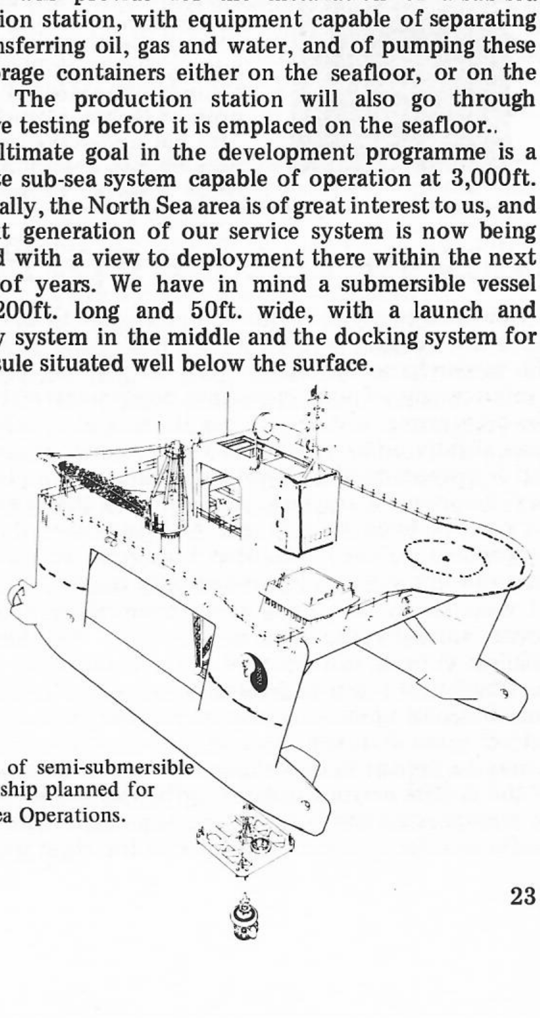
A manifold centre was recently delivered to our plant for assembly. It is 12ft. in diameter, 30ft. long, and has six ports on one side and three on the other for flowlines from wells, and three ports for control lines to a platform. The mating hatch to our capsule is at the top, and the same system applies as with the wellhead cellar: people can go down and work inside this manifold centre on the sea floor in what we call a 'shirt-sleeve' environment.

By mid-1974 this manifold centre will be land-tested in the Gulf of Mexico area, and by early 1975 we will install it in the Gulf in about 250ft. of water, and it will then be connected to six sub-sea wells.

The third and final phase in our development programme will provide for the installation of a sub-sea production station, with equipment capable of separating and transferring oil, gas and water, and of pumping these into storage containers either on the seafloor, or on the surface. The production station will also go through extensive testing before it is emplaced on the seafloor..

The ultimate goal in the development programme is a complete sub-sea system capable of operation at 3,000ft.

Naturally, the North Sea area is of great interest to us, and the next generation of our service system is now being designed with a view to deployment there within the next couple of years. We have in mind a submersible vessel about 200ft. long and 50ft. wide, with a launch and recovery system in the middle and the docking system for the capsule situated well below the surface.



Concept of semi-submersible support ship planned for North Sea Operations.

Question time

Question: Mr. Fahlman, do you think the support vessel working over the sub-sea unit should be dynamically-positioned, or should it be anchored with pre-positioned anchors — bearing in mind that with a manifold system you would be rather fouled-up with anchors down there?

Gosta Fahlman: We would prefer a dynamic-positioning system, but economic considerations are very important and, as you probably know, these systems are very expensive. However, for the North Sea operations we are seriously considering using a dynamic-positioning system because of the severity of the weather conditions.

Question: Mr. Fisher, you have consistently said that the green turtle is going to be the salvation of the food shortage problem and I wonder if this is only possible in those areas and fish products that have a luxury market? You say that you are feeding these turtles with a very high quality food and I wonder whether one could produce more food if this mixture were fed to sheep or cattle which have a higher feed conversion efficiency, or perhaps even directly to human beings?

Perhaps the only reason you are making money on this particular project is because of the shells and the leather and that sort of thing that you are getting out of it?

Mark Fisher: First of all, I did not mean to imply that *Mariculture* was the salvation of the world's food shortage: I meant farming the sea in general. To try and answer your second question: the turtles are fed not only with our man-made feed which, as you rightly say, comes from the land, but also on turtle grass which is mechanically harvested from the sea-beds around Cayman. Because the turtle has been extinct in Cayman for nearly a hundred years, there was about 36,000 acres of unutilised turtle grass in this area, so we are harvesting a food which would not otherwise be used to feed these animals.

Question: As I live in the Cayman Islands, I have been rather fascinated by the apparently enormous expenditure on this project and I would like to ask Mark whether it would not have been more economical at the outset to have used the natural resources of North Sound, rather than the mowing machine; let the turtles browse within the pens and cut out a lot of the heavy pumping gear and disposal that you now have to do?

Mark Fisher: We did originally consider an attempt to free-range the green turtle but, since the animal is a migratory beast, we did not think we could get our shareholders to put up vast sums of money and then see that same sum vanish around the world. The first year of a turtle's life is known as science's missing year, no one knowing what happens to a baby turtle in its first ten months, so we felt that free-ranging was quite impossible and that the only way to farm successfully was to be able to control the environment totally.

If we got over the problem of the turtles migrating away from us and maintained them in the virtually enclosed 36,000 acre North Sound area, we would not be able to visit the stock and see how they were getting on, or to control the environment. We would not really be farming, and we did not think that the commercial results obtained that way would justify the capital expenditure we had made.

Scott Carpenter: I would now like to introduce the next session Chairman, Professor Dennis Walder who is one of, if not the, leading expert in Great Britain on decompression and bends.

Prof. Dennis Walder

Professor Dennis Walder is the leading expert in Britain on bends and compressed air problems.

He is Chairman of The Society for Underwater Technology diving technology committee, President-Elect of the Undersea Medical Society, President of the European Undersea Bio-Medical Society and Chairman of the Medical Research Council Decompression Sickness Panel.

He has undertaken simulated dives for research purposes, and is currently engaged in research into decompression problems, blood flow and allied medical aspects of diving.

Man in The Deep - Part 1

It now falls to my lot ladies and gentlemen to amuse you for a few minutes before I let the rest of the speakers in this session loose on you.

Interestingly enough, there have been several editions of the programme, and on each one the title of my paper has been slightly different, so that I have therefore spent the last few weeks hastily altering my notes practically every day in order to try and keep up with the latest programme! I hope that in the end you have the same programme as I and that what I am going to talk about doesn't come as too much of a surprise to you.

I want to say something about micro air embolism. In Great Britain we have come to classify decompression sickness as being of two types: Type I, otherwise known as "the bends" in which there is pain in a limb, but no constitutional upset. The pain may be very severe but the subject is not ill, doesn't look ill, and doesn't feel ill. Type 2 may be present in one of several ways: as a disturbance of the central nervous system — with paralysis and/or loss of sensation, usually in the limbs; as a disturbance of the cardio-vascular system — with pain in the chest similar to that which occurs following a coronary thrombosis, or as a disturbance of the respiratory system — with difficulty in breathing, and an associated blue appearance. This latter condition is known as the 'chokes'. In all these Type II forms of decompression sickness, there is a constitutional upset — the subject looks ill, feels ill and unless something is done quickly he may suffer permanent damage, or even die.

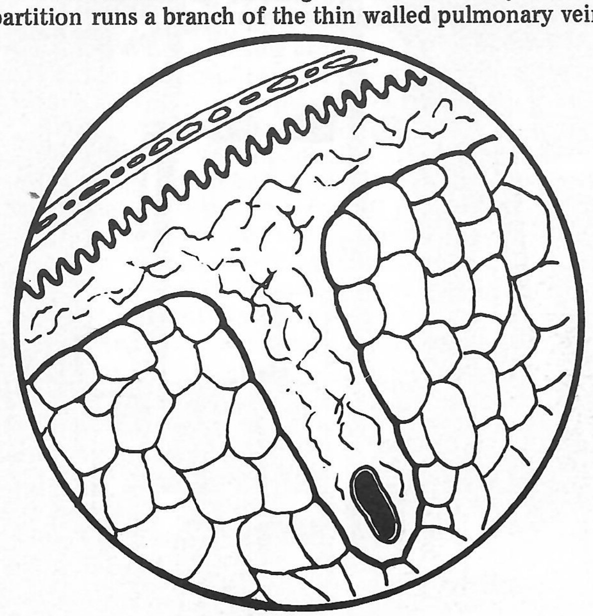
As you know, classically, decompression sickness is thought to be due to the presence of bubbles in the body. It is said that these bubbles arise because the decompression procedure has been too fast and some of the body's tissues have been left with an excessive amount of gas which has come out of solution in the form of bubbles. The longer and deeper the dive the more gas will be taken into the tissues and the greater will be the danger of decompression sickness. Conversely, short shallow dives in which very little gas enters the tissues will be safe, a fact recognised by the existence of no-stop decompression schedules.

Occasionally, however, a diver who has only carried out a short dive at a shallow depth (say five minutes at 30ft.) will develop the signs and symptoms of decompression sickness. This can cause consternation and disbelief, unless the mechanism by which such a condition can come about is appreciated.

The suggested explanation is that when a diver is at depth a small pocket of air becomes trapped in his lungs and on the subsequent decompression, when this pocket of air expands, it bursts into his circulation as a stream of bubbles which give rise to the signs and symptoms of Type II decompression sickness. This could be called micro air embolism because it is different from the situation which occurs when a man carries out a free ascent and inadvertently keeps his glottis closed. In this case, all the air in his lungs is trapped and when it expands it builds up a pressure until it finally bursts through into the circulation to give rise to massive air embolism. The two conditions are quite different as the former can occur in a diver who is returning normally to the surface after a short shallow dive, and the signs and symptoms are indistinguishable from Type II decompression sickness.

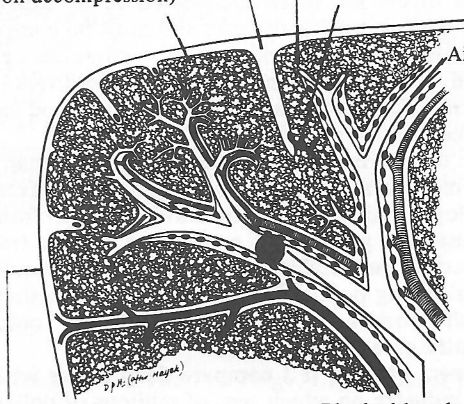
When we examined the lung radiographs of men who had suffered from this unexpected Type II decompression sickness we sometimes saw something very interesting. The men had cysts in their lungs. The condition obviously required closer investigation. It transpired that small animals undergoing short, shallow simulated dives never suffered from cysts in the lung and this gave us a clue. The structure of man's lung is different from that of an animal's.

In both man and animals the lungs have a branching system of airways which, like the branches of a tree, conduct the breathed gases to little air sacs which are arranged on the branches like the leaves of a tree. It is at the air sac that the exchange of gases with the blood takes place. The whole lung structure is covered over by a membrane which is called the pleura. Man differs from animals in that, here and there, the pleura dips down between adjacent groups of air sacs to form partitions. These partitions contain some loose material which enables their two sides to slip one against the other during small movements of the lung. At the extremity of each partition runs a branch of the thin walled pulmonary vein.



Detail of septum to show structure. Two layers with loose connective tissue between them. Vein at bottom of septum.

When a diver is at depth, all the air sacs are filled with gas at the same pressure as the breathing gas. As the pressure of the breathing gas is reduced during the subsequent decompression, the gas in the air sacs will normally vent freely through the airways. If however a branch airway becomes blocked by, for instance, a viscid blob of sputum, the gas in the air sacs served by that airway will not be able to vent, and will therefore distend. After a few feet of ascent there will be some air sacs that are distending and some that are remaining the same size because they are able to vent in the normal way. As a result of this a shearing force will be set up along the partition and eventually the tissues will rupture and tear.



Diagramatic cross section of human lung to show where shearing forces and tearing will occur if a branch of the airways system becomes blocked before or during decompression.

The tear will involve both distended and non-distended air sacs as well as the thin-walled vein. As a result of this, air will enter the vein and be conducted to the heart, from which it will be pumped round the circulation to give rise to the signs and symptoms of Type II decompression sickness.

Experiments with isolated lungs using various differential pressures between adjacent groups of air sacs have shown that this is a reasonable explanation of what takes place. Pressure differentials of as little as 2psi, or the equivalent in diving depth change of as little as 4ft., can result in lung damage and micro air embolism.

There is an important practical implication of these findings. It means that if you go diving when you have, or have recently had, a cold, influenza or an attack of bronchitis, which has left you with some viscid mucus in your chest, then you are in danger of getting an unexpected attack of severe Type II decompression sickness. All the men I have known who have suffered from an unexpected attack of Type II decompression sickness have been found on enquiry to have had a cold in the week or ten days prior to the dive and had presumably returned to diving before their lung mucus had had time to return to normal.

I would now like to introduce the next speaker, Henri Delauze, President of *Comex*. *Comex* is probably the world's leading professional commercial diving firm and yet it has only been in existence for about eleven years. This meteoric rise to fame and success is due, in my opinion, to their having first undertaken carefully planned experimental dives in the laboratory and then, by their own efforts, built them up into practical working dives in the North Sea.

Henri DeLauze

Henri G. Delauze, an MSc in geological engineering, was born in Avignon, France. He began diving in 1946 and has carried out 2500 dives, most of them professional.

He carries out 100 dives per year and performed the first wet simulation dive to a depth of 1100 feet in Comex's Hyperbaric centre in 1968.

He has made about 100 dives in the bathyscaphe *Archimede,* of which 30 were deeper than 1500 feet. One was to 31500 feet in the Japan Trench in 1962, the year in which he created Comex.

Deeper and deeper

Deep sea divers are often considered to be supermen. True, they perform difficult tasks and must be competent engineers conversant with mechanics, hydraulics or electronics and who, at the same time, are good divers in top physical condition, having a good brain and a good calm – but supermen they are not.

For me, the definition of a deep diver is a man who works at more than 200ft. using oxy-helium mixes and who employs a diving bell to travel to and from his working site. At yesterday's conference on the training and safety of divers, statistics showed that the North Sea commercial diving population, probably representing two-thirds of the world's, is about 700 and, of these, only 200 dive to depths greater than 180ft.

It may seem strange if I compare deep diving with the aerospace industry on which tens of millions of dollars are expended, but even though there are maybe no more than 50 or 60 deep diving systems in use, and of these only ten that are able to take divers to 1,000ft., the chain of equipment necessary to support a diver down to 500ft. or 1,000ft. is extremely complex and expensive.

There followed a 25 minute film showing divers working in Labrador at a depth of 600ft. or thereabouts in a water temperature of —2° Celsius.

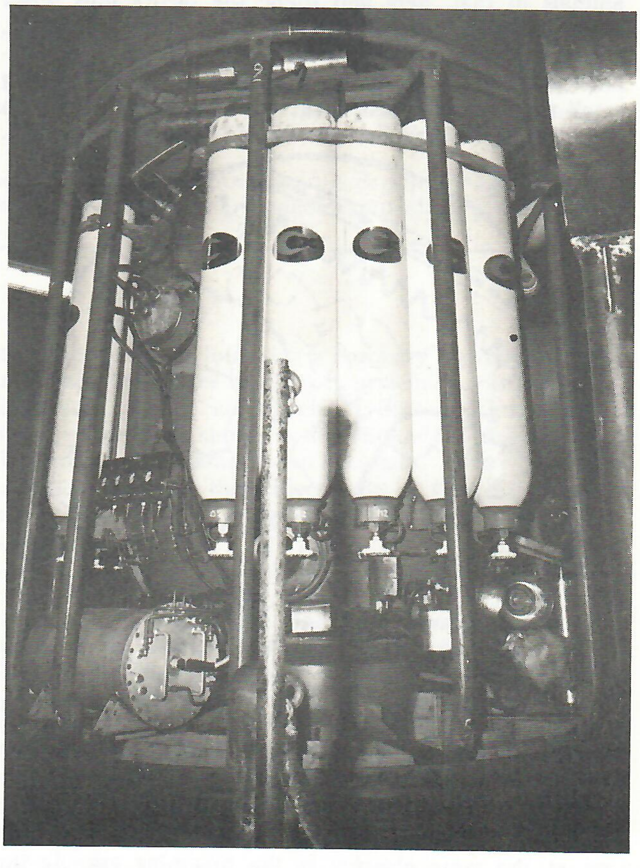
You have just seen a film made in 1971 showing the drilling ship, *Typhoon,* moored with 12 anchoring lines. A more advanced ship, the *Pelican,* has been recently developed by *Total.* The *Pelican* is a dynamic-positioned vessel kept in place by a number of computer-controlled propellors. Once positioned over an acoustic base on the sea-floor, the ship interrogates this base continuously; the computer analyses the ship's position in relation to the base and when the theoretical and actual positions differ by more than a few feet, it automatically transmits orders to the motors to bring the ship back. With a total power in the range of 20,000 h.p. the computer can, by means of a variable pitch, change the full power from one side to another in a matter of five to ten seconds, which means that the ship can stay within a few feet of its theoretical position in a 50-knot wind or in a sea state of 50ft. waves.

Of course, this is fantastic: if an emergency arises — say, an iceberg is moving towards the ship—the vessel can be moved out of the way in ten minutes, and return to its original position in an even lesser time, while with the old system, laying eight to 12 anchors can take up to one day.

On the other hand, there are new problems to diving from a dynamically-positioned ship: releasing 12 anchors takes quite a time, during which we can tell the divers below what is going on and raise the bell. Whereas, if the electronically-operated positioning system goes wrong, the ship moves off location immediately and without warning, and the diving bell is dragged along the bottom.

We first dived from the *Pelican* at the end of 1972 and experienced this problem several times when divers needed to return to a bell which had moved away unexpectedly. We have now changed over from using bells to submersible lock-out capsules with four or six propulsion units. These have no guidelines and in case of

Drilling system on *Typhoon* drilling ship.



Pelican Diving Bell.

emergency the sub-operator can, using the propulsion units, maintain station for as long as it takes to pull the divers back through the bell re-entry tunnel.

Of the 80 to 90 offshore oil drilling rigs in the world, about 50 per cent will be operating in the North Sea in 1974. Things are moving very fast in this area at the moment, most of the discoveries being in the 250ft. — 600ft. depth range, but there will probably be a considerable amount of drilling in deeper water soon, and we must prepare our divers for this.

Most of the *Comex* operations are worked in the 300ft. — 600ft. range, but in Marseille we have a Simulation Centre where divers, controlled and surveyed by our team of physicians and Director of Research, are trained, and where decompression schedules are established and the technology for very deep diving is being prepared.

The decompression time for about one hour spent working at 600ft. is approximately 40 hours, with complicated steps and gas mixtures. However, in very deep diving, we do not decompress after each dive. Instead, the divers, having been transported in the pressurised bell to and from the work-site, are transferred to a pressurised chamber on the surface where they live and are kept at saturation level, at what we call 'storage depths', until they are required to work again or until they have completed their work assignment and subsequent lengthy decompression.

We are not yet ready to work at 2,000ft.: in spite of all the sophistications of our equipment, the benefits of which — in the field of communications propulsion systems, navigational aids and more effective suits and helmets — will be felt by the sports diver, so much of it is at the prototype stage that it will take a long time before everything is really safe and reliable. We have to be so very careful when we are deep diving, for the forces involved are immense: a derrick hook on a drilling ship may have a one million pound force and the man working underwater with this big and rough equipment faces a true challenge.

Professor Dennis Walder: We now come to a talk entitled 'Diver Narcosis — from Man to Cell Membrane', which is being given by my friend, Bill Paton, Professor of Pharmacology at Oxford University. He is a doctor, a scientist of great renown — having been accorded the honour of Fellow of the Royal Society of England, and an academic who is considering some of the fundamental scientific factors which lie behind some of the problems of diving — like nitrogen narcosis.

Prof. W. Paton

Professor William D.M. Paton has been Professor of Pharmacology, University of Oxford, since 1959.

After qualifying in medicine in 1942, and undertaking progressively more important medical jobs, his scientific research work began in 1944 when he joined Sir Lindor Brown's team on diving and submarine physiology at the National Institute of Medical Research.

Although later attracted into pharmacology, and distinguishing himself in that field, he has remained associated with high pressure work since then.

Diver Narcosis: From man to cell membrane

I think there are nine hurdles in the divers' Grand National and, of these, there are two that may or may not prove to be insurmountable obstacles: anaesthesia by inert gases and the effects of pressure per se.

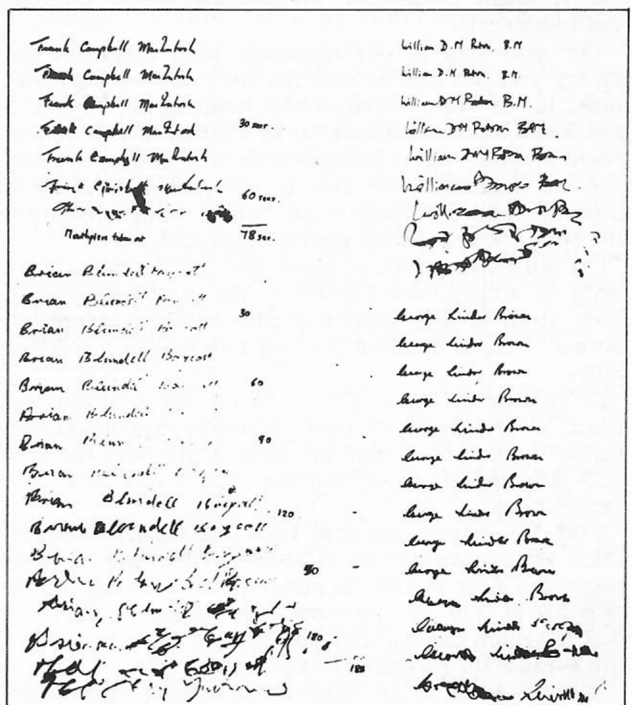
Firstly, to bring out two points about anaesthesia:

Some time ago we at the Medical Research Council did some work on carbon dioxide intoxication: three colleagues and I breathed carbon dioxide at 20 per cent, 15 per cent, 12½ per cent and 10 per cent in oxygen, meanwhile signing our names continuously. Delicate changes in our hand-writing became apparent almost immediately, and finally we reached a stage of total illegibility — at which point we were in fact unconscious, failing to respond to commands, and amnesic.

What I want to point out here is that even though we were unconscious, we were still trying to do the tasks allotted to us, still trying to write. So, a person can be quite fundamentally affected and yet still persist in his previous behaviour.

The second point is that even when completely unconscious in these conditions, we were far from being at a state of surgical anaesthesia. There is a great difference between the quantities of narcotic of these anaesthetic drugs that will affect a man's operational efficiency — his judgement, resourcefulness or ability to adhere to a programme — and the amounts necessary to attain surgical anaesthesia.

The reason that most of us believe that anaesthesia is effected by molecules getting into the fatty part of the body is that if you measure the tendency of gases to go



Showing the effect on handwriting of subjects breathing 20% CO_2 (F.C.M.), 15% CO_2 (W.O.M.P.), 12.5% CO_2 (B.B.B.) and 10% CO_2 (G.L.B.) in oxygen.

into fat, and correlate this with the potency of the gases, you get an extraordinary correlation which deviates from the expected by, perhaps, about 20 per cent, and I think one should rely on this to show that it is a fatty, as opposed to watery, part of the body that is really involved at the molecular level.

Comparison of Rank Order of Inert Gases

	Low				High
Decompression sickness ($1/P_\infty$ for mice)	He	N_2	Ar	SF_6	N_2O
Water solubility	SF_6	He	N_2	Ar	N_2O
Fat solubility	He	N_2	Ar	SF_6	N_2O
Total body solubility	He	N_2	Ar	SF_6	N_2O

P_∞ is the maximum pressure from which a rapid decompression to atmospheric pressure is possible without hazard after long exposure.

Comparison of the liability of various gases to produce decompression sickness with their water and fat-solubility, showing the best correlation with fat solubility (or total body solubility, to which fat solubility makes the major contribution with most gases).

The next question is, of course, what do we mean by a fatty part of the body? Membranes are an important class of fatty material. All our cells have a limiting membrane which is a sheet of fatty molecules with a water-attractive head, and pairs of peripheral tails that dip down like double leaflets. One can envisage the anaesthetic molecule — whether it is chloroform, xenon or nitrogen — getting among these leaflets and disorganising them.

There is another sort of potential hydrophobic or fattiness and that is the lumps — macromolecules — in the membranes, which transport glucose, carry ions and mediate the responses to drugs. Crystallographers have found that these big protein molecules (macromolecules) can coil in a variety of ways so that the water-attractive areas of the molecule and the hydrophobic or fatty components may localise in regions. If this occurs, there is a sort of binding force between the similar fatty materials and it has been suggested that the fatty region may even hold the molecule in position in the membrane. Now, if one inserted an intrusive molecule which has an affinity for fat, it might disorganise the binding which holds the macromolecules.

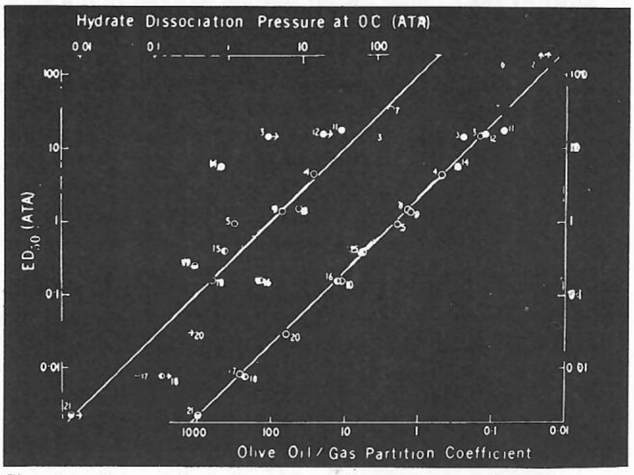
The next step in our researches both supported this theory and brought us into the field of very high pressures. In our work at Oxford with Brian Smith, Ray Smith and Keith Miller we queried as to whether helium or neon could anaesthestise if pressure were increased sufficiently, and we wanted to be able to compare the effects of pressure applied through a gas (which would dissolve in the body), with pressure applied hydrostatically.

For our experiments we chose the Crested Italian Newt, which is amphibious. The newt, like us, if turned on its back, tends to right itself and if the animal is completely normal it has a hundred per cent response to this rolling reflex.

At pressures of up to 120 — 150 ats., the newt only just began to be affected by neon. A similar experiment with helium produced roughly the same results with the newt 50% affected at about 150 ats. This might have been "anaesthesia".

Next, we exposed the same animal to water — in which there are no strange gas molecules. This time the newt responded fully at 100 ats. pressure but again began to be affected at 120 ats. upwards. We concluded, therefore, that if helium and neon are anaesthetics one cannot prove this because the pressure takes effect first.

Then we came to an interesting question: suppose one combined high pressure and anaesthesia, would they add or even mutually potentiate, or mutually antagonise? We began by exposing the newt to about 30 ats. of nitrogen; this virtually blotted out its ability to right itself. Then the pressure was further raised using helium, regarding this as equivalent to hydrostatic pressure; the animal presently recovered as the pressure was increased until it practically got back to normal. However, eventually the pressure effect re-established itself and the newt was roughly fifty per cent paralysed, but not as originally, at approximately 150 ats., but at about 250 ats. It looked as though pressure could antagonise anaesthesia, which would support the general theory of the molecule getting into the fatty material, thus impairing its function.



Showing the much better correlation and anaesthetic potency (vertical logarithmic scale) with solubility in fat (lower horizontal scale) than with ability to form clathrates (complexes with water molecules: upper horizontal scale). (Miller et al, Anesthesiology *36*,339. 1972).

It is known that when anaesthetic dissolves, membranes expand very slightly; at a surgically anaesthetic concentration they expand by about 0.5 per cent. If one estimates thermodynamically how much pressure is needed to neutralise this expansion, one finds that it agrees closely with the pressure we needed to antagonise anaesthesia. Thus, it looks as though expansion is linked to anaesthesia, and if you can prevent the expansion (by pressure) you prevent anaesthesia.

If one can antagonise anaesthetics with pressure, one might be able to antagonise pressure with anaesthetics in the same way. We have already seen that nitrogen shifted the 50 per cent paralysis point from around 150 ats. to 250 ats., and trials with a variety of pressures of another anaesthetic, nitrous oxide, showed the same thing, and that the data fitted a simple theoretical equation.

It is unlikely that the human race will ever require to work at such extreme pressures, but I think these studies are important if only because they help to establish the safety factor for operations at lower pressures.

But if the future of mankind depended on being able to get to 20,000ft. one could see ways of doing it. Speaking as a pharmacologist, I do not think drugs offer very much. But one can think of other strategies. First, one could select very fit people whose resistance to anaesthetics might permit them to go up to three times deeper than the least resistant.

Secondly, I am sure that you are familiar with the fact that if you are habitually cold you tend to put on fat and your thermo regulation improves. One could therefore develop and exploit this ability of the biological system to adapt to suit the environment by establishing villages at 5,000ft. and 10,000ft. then at 15,000ft. and 20,000ft., thus generations would gradually develop a capacity to withstand high pressures.

But I do not believe that we need to think along these lines; it is far more important to make diving safer and freer at ordinary depths — there are still deaths from decompression sickness, squeeze and carbon dioxide.

When looking for ways of attacking decompression sickness, we may find that our theories on molecules in the fatty tissues of the body are very relevant. To clarify this a little further: when one ranks gases according to their ability to produce decompression sickness, one finds a very close correlation between this and their fat solubility. The reason for this being that if a gas is very soluble in fat, of course there is more of it present to form bubbles.

In his talk Dennis Walder discussed a type of decompression sickness and how these bubbles are possibly generated, but for ordinary bends, the evidence points to them arising on what is still an unknown nucleus.

It is known from Newton Harvey's work that you can treat bubble fluids so as to rid them of the gas nuclei, so fluids do not *have* to bubble. Yet, of course, they do in practice. Taking all the evidence, perhaps the best postulate is that bubbles are likely to arise at a point where a watery and a fatty surface meet; where you get two immiscible phases creating a potential space. So I suspect that, looking ahead some 30 years, the greatest advance in science will occur at the point where we now have our greatest ignorance: we don't know how bubbles arise.

If we could look at the properties of the lipid fragments of membrane, or something still to be found in the tissues, and map out its chemistry, then the way might be open to pharmacological intervention — not necessarily by a pill, it might be a delicious elixir or something you put in beer! If that succeeded, it would be a bigger contribution to solving the diver's problems, in giving him freedom and flexibility and safety from bends, than anything one can otherwise foresee.

Professor Dennis Walder: I think that was a superb example of how, if you know what you are doing, you can design relatively simple experiments, and draw very far-reaching conclusions. In this sort of way academics will probably soon come up with some revolutionary ideas that will make heavy diving machinery irrelevant.

Dr. Arthur J. Bachrach

Dr. Arthur J. Bachrach is the Director of the Behavioural Sciences Department of the Naval Medical Research Institute, Bethesda, Maryland.

His diving research activities are largely concerned with deep dives and have been centred around experimental methods of assessing behavioural and physiological changes in divers.

He has been involved in research on the 1000ft. Westinghouse chamber dive in 1971 and, as Visiting Investigator at the Institute of Environmental Medicine, a 1200ft. chamber dive after that. In 1973, he collected tremor data on the US Navy/Taylor 1600ft. chamber dive.

Panic

For some time Glen Egstrom and I have been working on a somewhat negative aspect of diving — the destructive problem of panic. My remarks today are, in effect, a distillation of our work. About 120 sports divers are killed each year in the United States and, of these, cave diving produces 25-30 deaths in Florida alone. There are perhaps two million divers, so this would not appear to be much of a statistic, but if you compare this with the five deaths each year in an equally popular high-risk sport — skiing — you will see why we wish to examine what is killing our divers.

The problem of panic has three elements: *training*, which needs to be improved in many ways; *physical condition*, which is becoming more and more a source of concern for us and, finally, *equipment*.

Most deaths occur at shallow depths or on the surface and seem to be associated in very large measure with loss of control — panic. Most of the divers pulled out of the California waters still have their weight-belts on, yet when you look into the training programmes it would seem to be automatic that a person should jettison his weight-belt to save his life. Certainly, they have enough air left in their tanks, but frequently the mouthpiece has been spat out, implying that there has been a loss of control oh the part of the divers.

This is not only true for sports divers, it also applies to a number of deep divers. Commander Carpenter will certainly remember concerns expressed by some of the divers on *Sealab II:* about scorpion fish, loss or failure of equipment, failure of CO_2 sensors. These are things that are beyond the control of the diver but, above all, his greatest concern must be a personal loss of control, which would mean that it was beyond the diver's capability to handle a problem.

Competence and self-confidence seem to be the two things that are important in controlling panic. When an individual, who is basically a land mammal wearing strange equipment, is in trouble in the water, he will begin to struggle — clawing the water, with his head held back, struggling to keep out of the water. He has spat out his mouthpiece and still has his weight-belt on. The hard struggling results in keeping the head higher but also increases the weightload, and the body responds by increasing the heart and respiration rates. Therefore, the individual rapidly reaches the state where he cannot possibly sustain this excessive workload, and becomes exhausted. It has been estimated that an individual can sustain a workload like this for less than a minute, and exhaustion can bring an additional psychological stress which will mean he may or may not be able to perform another manoeuvre such as ditching the weight-belt or inflating a flotation device.

We have a theory, which is unproven, that it may well be psychologically antagonistic for a diver, with his hands up and trying to keep his head out of the water, to put his hands back into the water to release his weight-belt or to pop the CO_2 cartridge. It could be that in engineering equipment, it would be more practical to have such a safety feature on the shoulder or closer to the head.

Following work at the Royal Naval Physiological Laboratories at Alverstoke, Peter Bennett and I, working at Duke University, conducted further research into the subject of apprehension as experienced during deep dives. We prepared a spectral analysis of a tremor and with diver-operated force transducers measured the psychophysiological changes experienced by divers in a chamber at 870ft.

The results showed that the professional divers, who had been saturated for a while and were resting and waiting to travel to 1,000ft., produced peaks at 3-5Hertz. The normal frequency at which this takes place being 10 Hertz, this suggested a pathological tremor which does not necessarily mean that the individual has suffered any permanent brain changes, but that he was experiencing what we may loosely call 'apprehension'.

As they began to compress to 1,000ft., the tremor and their level of performance returned to normal, suggesting that the divers' stress had been experienced prior to travelling on compression.

During an evaluation of the Mk XII, which is a system that the U.S. Navy may adopt to replace the old Mk V copper diving helmet, we listened to a diver's heartbeat while working a UCLA pipe puzzle in very clear, warm water with a three-quarters of a knot current. As the telemetry recorded back through the 60ft.-deep water, Glen Egstrom, with whom I was preparing the preliminary data, remarked that the diver probably hadn't been in the water for a while. On checking with the Director, we found that the diver had not been in the water for about six months. What gave Glen this suggestion was that we were peaking 184 beats at one point where he was working the old Mark V on the pipe puzzle. The normal moderate workload would probably be about 140, and the marked increase in heartbeat suggested that the diver was not in good physical condition, had not been in the water for a while, and was not functioning effectively.

If we study this aspect of stress, knowing that it is normal both to professional and sports divers, we would assume that training is reflected in competence. Competence is also a reflection of physical condition, and if you have a diver who is what we call in the United States, FOB (fat, old and balding) he should not be in the water, or at least the dive instructor should be aware that there are going to be problems.

We feel that swimming pool training is not sufficient for ocean divers and that specialities such as cave diving also require further training. There is a need for intermediate kinds of training in between pools and oceans — perhaps in controlled coves or quarries, or some area where an individual can get into more open water than the controlled, safe aspects of the swimming pool.

How automatically one performs a task is very relevant to the experience of apprehension and panic. It is important that a task be learnt to the point where a diver no longer has to give it much thought, so that he is relaxed and not continually concentrating on moving the equipment, or himself, through the water.

There is an important aspect of training which I think relates very definitely to the psychological problems that we meet in sports divers, and that is the aspect of competition. Any individual who thinks that he is going to compete by saying that he has gone further on less air than another diver, is a dangerous diver; he should be competing with himself in terms of his own skills and abilities, and not in terms of depth and air consumption. With regard to this aspect of competition, one should be aware and cognizant of the fact that one of the main motivators of human nature and behaviour is the fear of looking foolish, and it is important that dive instructors stop individuals from taking chances, or from getting into situations in which they may get into trouble because they don't dare *not* to go.

We have talked about transportation — the means of getting down to the particular brand of diving in which we are interested, the equipment, and certainly the social aspects of diving, all of which are important aspects of training and the enjoyment of the task. Finally, let me turn to the task itself, which is one of the problems in sports training that has still not been resolved. We have trained people to use equipment to get down to depths, but we have never trained them really systematically to *do* anything.

To help control apprehension and panic a diver should have a function, whether it be underwater archaeology, shell collecting, observation, photography or whatever, so that he is not just down there listening nervously to the harmonics of his regulator, but rather, absorbed in taking photos or in doing something purposeful.

Herb Prosser believes that hyperventilating is one of the least recognized but most important causes of drowning. Certainly, the diver who is clawing the water and trying to get fresh air instead of tank air may hyperventilate, which causes all sorts of physiological changes including, probably, passing out within a very short period of time.

We also feel that there is some evidence that hyperventilation and hypoglycaemia have similar types of physiological effects and it may well be that some dietary aspects of hyperventilation and control may be important, so that beer may not be the best thing to have just before a dive.

Let me turn to one other aspect of what happens when an individual gets into a panic situation. Under stress, an individual's narrowing of perception is quite marked, he begins to focus in an almost tunnel fashion, losing peripheral vision to a very marked extent. Not only is the vision narrowed but his problem-solving capabilities are also narrowed. Picture a diver whose reserve valve had been accidently pushed down while he was working among rocks: he may start to breathe a last hard breath and put his thumb on the handle of the pull release. Nothing happens because his reserve is already pulled: a non-coping response occurs — he keeps pulling, with no results, and begins to panic. Once you have this stereotyped response, any problem-solving becomes almost impossible. There was a case in Tucson, Arizona some years ago of a woman diver who was drowned in 12ft. of water in a lake on a golf course. When she was pulled out she not only had on her weight-belt, she was clutching a bag of golf balls. This is non-problem-solving behaviour and very hazardous, but it happens, and this is one of the things we are puzzled by in psychology.

We know a good deal about experienced and inexperienced stress responders. Some years ago a couple of psychologists did some work on sky divers and found that the experienced sky divers were frequently apprehensive about going out and doing a jump. The interesting thing about their research was that the apprehension occurred usually on the morning of the jump and if they felt sufficiently apprehensive they would call and cancel, whereas the novices would peak their anxiety just before the ride to the jump site. So, there was a temporal difference in the apprehension of the two types of divers. Again, there may be some factor about looking foolish and not wanting to cancel. I have a feeling that there may be this parallel between sky and scuba divers: the gallows humour that you see on the way to a dive site may well be the kind of apprehension release that the novice divers require. Probably, the experienced scuba diver who doesn't feel too comfortable about going out, doesn't go; whereas the novice diver tries to overcome it and peaks his anxiety just before he is about to dive. These are things that a dive instructor should be aware of and do something to control: to cure the need for foolhardy face-saving and to be thankful for sinuses and colds, because they always provide an excuse for getting out of a dive.

Finally, I would like to mention what I think is going to happen with regard to sports diving in the future, and I'm going to say a couple of things which I am sure are controversial. I know that there is an argument about controlled emergency ascent or free ascent: many of us believe that there is a very critical need for training in these areas, and the U.S. Navy and the Royal Navy are not very positive about this. However, for many of us interested in sports training, the controlled emergency ascent is a very important potential lifesaver.

Secondly, I foresee that there will be less and less training in sharing (buddy breathing) and more and more development of equipment similar to, but more efficient than, the octopus rig. Buddy breathing not only causes concern about the buddy who is running out of breath and the return of one's regulator, but is also an inefficient method with which to handle this emergency situation.

Diving is a fine sport. With proper physical conditioning, equipment and training the individual can expect much excitement and pleasure in diving — but let's be certain the excitement is of the positive kind.

Question time

Question: Although great steps have been made in allowing safe deep diving, a great deal of expensive equipment seems to be required to give people only an hour or so actual bottom time. I would like to ask Mr. Delauze for his comments on the possibility of applying to undersea operations a technique which has been very seriously considered for air operations — namely, replacing manned aircraft with remotely-controlled vehicles. Does he envisage a situation in which a small submersible is controlled from the surface by closed-circuit television, remote manipulators, and so on?

Henri Delauze: I will answer the question without using this table as a marketing platform, as in our company we also supply subs and mechanical arms! I will also answer as a man who has spent a lot of time underwater, including submarines, because I have been involved with the French Bathyscaphe for nearly seven years, and I have spent hundreds of hours on the bottom, down to 31,000ft. in the Japan Trench.

I think that a specific situation should receive a specific solution and that neither those who are in favour of remote-controlled vehicles, nor those for human skills and direct human power are right. To illustrate my point: About five years ago, a Government body developed a remote-controlled vehicle, similar to the U.S. Navy *CURV*, which was to be used to control a sort of mock-up of a sub-sea tank farm set in 350ft. of water. Eventually, a group of divers using a diving bell had to go down and rescue this vehicle because, although it was able to enter the tank farm, it could not get out. So, remote-controlled vehicles are not always the answer.

Secondly, the design of the sub-sea vehicle mechanical arms is usually based on those used for atomic nuclear energy. Generally speaking, these are unsuccessful underwater because often the operator has to work against currents and in nil visibility — conditions that cannot be imagined by a designer who has never been underwater.

Every drilling spread exploring the North Sea costs between £20,000 and £30,000 a day: insurance of the drilling rig alone costs between 8 per cent and 10 per cent of the value of the platform per year, and a modern semi-submersible drilling rig represents an investment of £10 — £15 million. So, when I tell you that the cost of constant diving support at a depth of 1,000ft. is only £1,000 per day, you will readily appreciate that this expenditure is small when compared with the whole. Yet, to design underwater equipment capable of reproducing the manoeuvrability of the human mind, applied with human intelligence, will be very costly indeed.

Question: As a corollary to the last question, Mr. Delauze, I presume you could overcome a lot of the problems of logistics and air supplies if you were to put the diver on liquid air equipment? Do Comex plan to do this?

Henri Delauze: This morning I listened to my friend Keller talking about 45 per cent of xx and 55 per cent of ∞ to be introduced into our blood and that this would enable a diver using a scuba system to work without inert gas to depths of up to 7,000ft. So, despite the fact that scuba is ideally suited to depths of up to 200ft., and that beyond this depth there is very little light, and no more interesting fish or seaweed, it is apparent that sports divers still want to go deeper. Well, I may be wrong, but I don't imagine that, even in 20 years time, liquid breathing will be used, even for industrial purposes.

When the diver cannot work at a given depth, then we will come to the submarine, and all the companies will spend the necessary amount of millions of pounds to make the submarines reliable and safe.

Professor Walder: The time has now expired. I would like to thank my speakers. I hope you have enjoyed the session.

Dr. Takashi Ino

Dr. Takashi Ino is a director of the Marine Parks Centre of Japan and chief of Sabiura Laboratory.

He lives in Tokyo and graduated from Tokyo University of Fisheries in 1936.

Since then he has held a number of important appointments including chief of shellfish culture division in Tokai and later Deputy Secretary-General of Southeast Asian Fisheries Development Centre, Bangkok, from which he resigned in 1973.

Marine Parks in Japan

One of the main topics under discussion at the First World Conference on National Parks, held in Seattle in 1962, was that the marine fauna and flora are subject to the same dangers of destruction as are those on land. Accordingly, a recommendation was approved that the governments of all countries with marine frontiers examine, as a matter of the utmost urgency, the possibility of creating marine parks.

In 1964, Dr. Tamura, formerly President of the Nature Conservation Society of Japan, organised the Marine Parks Investigation Committee and took the initiative to survey suitable areas and to consider ways and means of implementing the recommendation.

In 1967, the Marine Parks Investigation Committee became an autonomous foundation known as the Marine Parks Centre of Japan, and Dr. Tamura was appointed Chairman of the Board of Directors. In July 1970, eight areas were designated as Marine Parks, further areas being added during 1971 and 1972, so that we now have 32 along our coasts.

When selecting a suitable site for each of the Marine Parks, the Investigation Committee had to take a number of criteria into consideration:

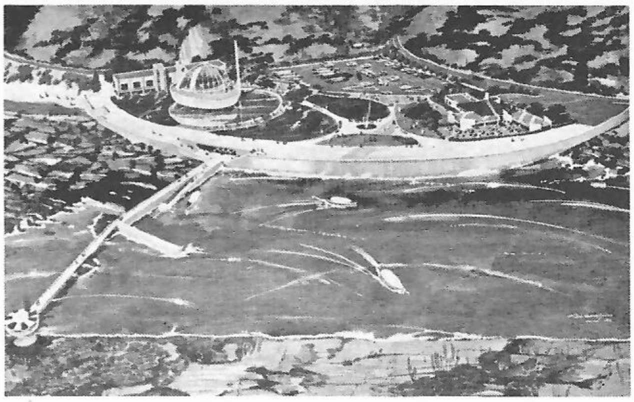
Our country is composed of four main islands and many smaller ones, the shores being washed by a warm current from South to North, and by a cold current from North to South. Our fauna and flora are therefore divided into two distinct categories: tropical or sub-tropical, and temperate.

In parklands, plants provide the main interest, but under the sea the ratio of animal-to-plant life is reversed, and although the temperate zones afford Laminalia, Undaria, Eisenia, Ecklonia or Sargassum, these only flourish during the cold season, and their abundance may fluctuate annually or horizontally according to variations in currents, temperature, etc. Therefore, the marine parks had not only to afford perfect visibility, topographical interest and negligible tides — all ideal conditions for viewing from glass-bottomed boats — they should also be sufficiently large in area to include all the fluctuations and variations in marine life. However, the average acreage is only 13.0 hectares, and this point may need future consideration, both from the fisheries' and parks' standpoints.

Secondly, they chose marine sites that were situated near an attractive landscape in one of the designated National or quasi-national Parks, removed from sources of pollution such as cities, factories, farms or estuaries, and with a sufficient supporting land acreage for visitors' lounges, an aquarium, parking lots and other ground facilities.

Lastly, the Marine Parks Project prompted a serious problem in connection with fisheries. Japan produces about 10 million tons of fish each year, the coastal fishing grounds for fish, shellfish, crustacea, algae, etc. being essential to the livelihood of local fishermen. The fishery right has been established under the Fisheries Law, and a fishing ban would not be feasible under our political and economic circumstances. It was, therefore, absolutely essential that we try every means to develop a full understanding with the fishermen, and advise them as to the objectives and advantages of marine parks. For this reason an expert acquainted with local coastal fishing has always been included as a member of every Marine Parks Investigation Team and from the beginning any decisions have been made only after deliberation among the representatives, not only of tourist organisations or nature conservationists, but also of the fisheries; the administration of the park areas being conducted jointly by the local public bodies and the fishermen's cooperative associations.

Only a short time has elapsed since these designations were established and, so far, no serious problems have arisen because we have made certain necessary compromises to meet with the fisheries' requirements. According to the National Park Law, only tropical fish, corals, seaweed, etc. are conserved to protect the underwater landscape; fishermen may collect commercial fish by using hooks and lines, nets or other means. But, although marine animals in the parks are now protected against capture by visitors, this is not the complete answer to the problem. The sea bottom has become littered with miscellaneous trash and this pollution should be controlled by strict legislation. In addition, with the increasing popularity of skin diving and hence the resultant increase in the influx of thoughtless divers to these areas, the conflict between divers, sports fishermen and commercial fishermen has become very severe — so severe in fact, that even amateur divers only wishing to take underwater photographs or to collect specimens for their studies are meeting with a lot of opposition.

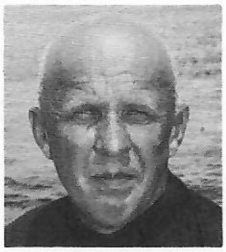


Artist's impression of Marine Parks Research Institute, Kushimoto.

To overcome these problems, we must have even closer co-operation between the various organisations concerned — between the tourist industry, nature conservation agencies, the fisheries, diving and sports clubs — in various phases, and from government to local level.

The marine parks are not only, as sanctuaries, playing an important role in the conservation of fish resources, many also promote tourism which contributes greatly to the economic improvement of the fishing communities, while the laboratory facilities attached to the parks provide the fishermen with important information on marine organisms. In some parks, they have succeeded in luring schools of natural commercial and miscellaneous fish around the underwater observation tower by scattering fish-food several times daily, and some parks are planning to liberate quantities of seed abalone, for the benefit of the visitors and fishermen alike. These attempts may contribute greatly to the development of fisheries in such areas, and they will certainly create better ties between park officials and the fisheries' representatives.

Hans Hass: Our next speaker is Dr. George Benjamin, who discovered and has for many years explored, one of the great underwater wonders and mysteries of the world: the Blue Holes in the Bahamas.



Dr. George Benjamin

Dr. George J. Benjamin of *Benjamin Film Laboratories Ltd.*, is a research chemist specialising in colour film processing in Toronto, Canada.

He has been interested in photography, cave exploration and diving for over 40 years and in 1960 established a base camp on Andros Island, Bahamas, to explore the famous Blue Holes.

His film *Andros Blue Holes* subsequently won awards in the American underwater film festival and was named Best Documentary of 1969 of the Photographic Society of America.

The Andros Blue Holes

An edited transcript of his narration for the film entitled *'15000 Years Beneath the Sea'*, taken from the series *'The Andros Blue Holes'*.

By profession I am a research chemist, and I sometimes feel out of place among professional divers. I am strictly an amateur, diving only for one reason — because I like it!

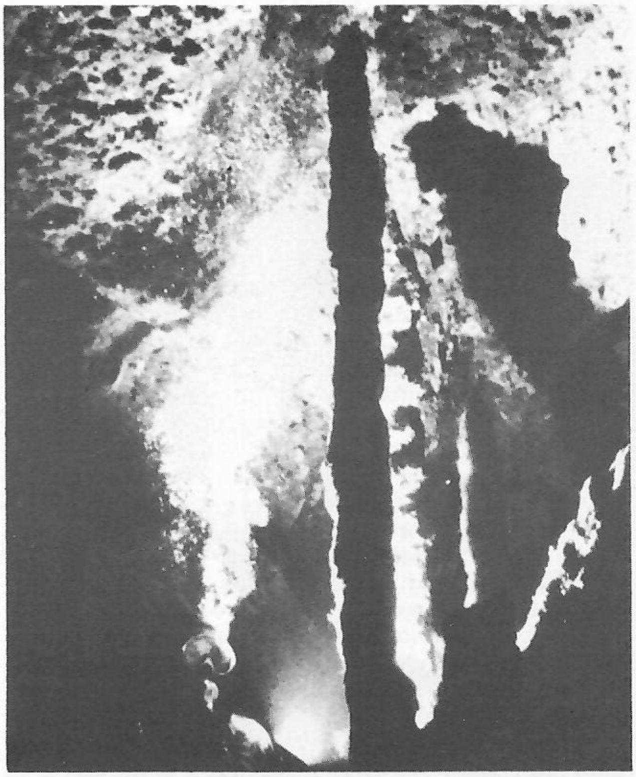
I have climbed mountains and explored caves for a great many years. These two things have a lot in common: they test one's ability, and fulfill man's desire to put his feet where no one has trodden before. There is also a very big difference. Climbing mountains in blinding sunshine over rock and ice, I can see the mountain top, which gives me the concentration of the last resources of my strength. Cave exploration is totally different: one is in darkness, crawling down long passages, most of which turn out to be 'dead-ends'. I wonder what the driving force behind caving is and what keeps us going, since it is nearly always disappointing!; it must be the hope that we shall break through into the greatest cavern that mankind has ever seen, decorated with the most beautiful formations. In fact, I have been lucky: it has happened to me twice.

My talk is from the film series entitled *'The Blue Holes'*. These undersea wonders are so called by the natives because, from the surface, they appear as a dark, very satuated blue spot in a light green lagoon. I have been asked whether the blue holes are peculiar to the Bahamas and the Andros Island and the answer is definitely, 'no'. The blue holes are related to certain geological and hydrological conditions, and if similar conditions exist elsewhere, then there should be blue holes.

Geologists tell us that during the Ice Age a lot of earth water was trapped in the Polar caps, and the ocean levels fell, some say 200ft., even 600ft. During that time, the Bahamas was a huge limestone plateau and, washed out by rain, small cracks became caves. About 15,000 years ago the water rose again and the whole area was flooded, which is how these underwater caves were formed.

I and my team have been diving in underwater caves for over 15 years and we are still alive: we avoid dangers and proceed only when we are fully ready, which means quite simply that if we explore a cave and find that neither our equipment, our knowledge, nor the divers are fit for that task, we stop further penetration, upgrade our equipment, learn more about the currents and other dangers, and train the team. Only then do we proceed, but there are still plenty of dangers which cannot be avoided.

It is well-known that stalagmites are formed from the mineral deposits left by dripping water in dry caves. For ten years we searched the Andros Blue Holes and found nothing, until, in 1970, disbelievingly we found them in a place which most likely protected them from destructive elements. We gathered samples and had them analysed. This proved that the cave had once been dry. It happened approximately 15,000 years ago, which is the title of this particular film taken during the last decade of the exploration of the Andros Blue Holes. I will personally narrate and try to describe some of our striking experiences.



Candle-like stalagmites at the entrance of the Grotto are 10 ft. tall and less than one foot in diameter at the base.

A tremendous current — three, four or five knots — rushed out of the caves, following the tide, and so we had to pull ourselves along the rocks. As we got deeper, so the cave narrowed and the current became impossibly strong: if we had let go our holds we would have been carried out and back to the surface.

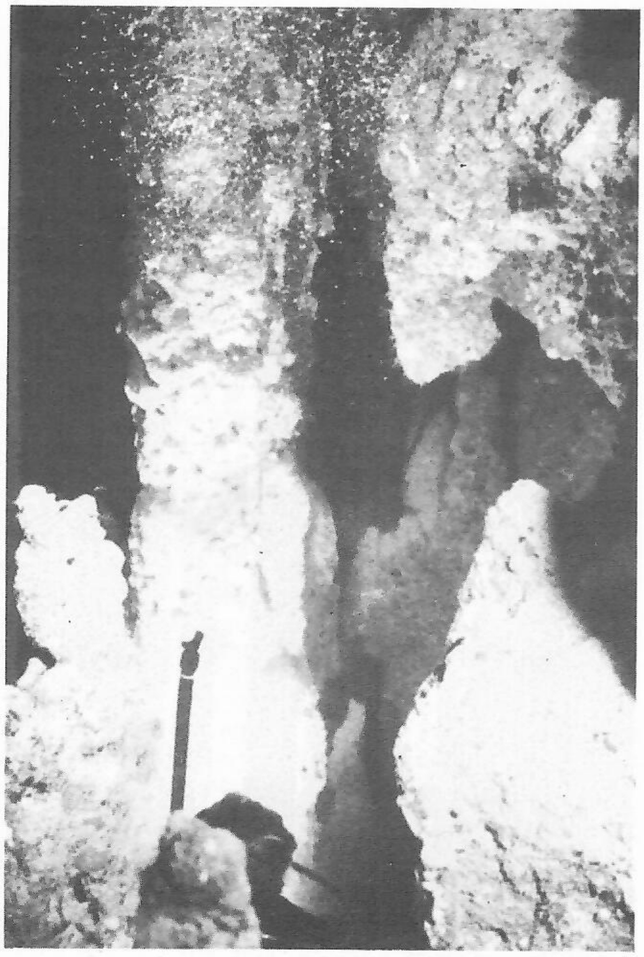
There was an abundance of marine life: large crabs, shrimp, and even nurse sharks. Turtles, barracudas, and sting rays remained at the entrance to the cave.

After a time, something seemed to be different. The fish were swimming in a leisurely fashion: the tide had changed and the current had gone. The clarity was superb. The cave water (80°F both in summer and in winter) started to mix with the lagoon water. But, as the tide turned yet again, so the scene changed and the water rushed back forming a whirlpool in which some of the fish were trapped, rotating in a wild spin.

Most whirlpools go clockwise but, oddly enough, here were some that went in an anti-clockwise direction. These whirlpools, like underwater tornados, go on for approximately seven hours. The exact moment for our next dive was pin-pointed by releasing a dye in the cave mouth.

At 140ft. the shaft widened into a huge chamber. At almost 200ft. we reached the bottom: there were passages going in several directions; the cave seemed to stretch for miles. In the excitement, we lost the sense of time and had to watch our gauges very carefully.

In December 1967, my son Peter and I were the first men to descend into this hole, and when exploring one of the passages three years later, we suddenly came into an area with huge stone pillars. Some of the free-standing stalagmites measured over 10ft. and several columns stretched from the bottom to the ceiling for 20ft.



Massive columns are 20 ft. tall. The material is heavily corroded. Several samples contained crystalline cores.

We fixed a mile and a quarter of permanent lines. Since the discovery, this cave has been visited by many divers. Unfortunately, the formations are very fragile and the best of them have been broken. I glued several of the broken stalagmites together with underwater glue — but sooner or later they will be destroyed by careless visitors.

Next, we went on a different kind of expedition: inland, following the cracks in the rock to explore another type of blue hole — the freshwater sink holes, some of which are 400ft. deep.

Getting to these ponds is not easy; sometimes you have to carry your equipment, about 100lbs. of it per man, for miles and miles over very difficult terrain, but it is worth the effort.

At 80ft. we found another of nature's wonders: huge stalactites, similar to those found on the island of Bonaire (Dutch W.I.) at well above sea level. We were descending in cold spring water to a depth of 100ft. when we hit a layer of hot mineral water full of sulphur. Suddenly, we felt as if we were bouncing off an invisible trampoline. The stalactites ended at this level. We are sure that there are connections between these sink holes and the sea because the water levels fluctuate with the tides, but so far we have not found them.

In 1967 we descended the entrance to this blue hole. It took us three years to find the stalagmites, but now we were preparing to go much further and much deeper. This time, we were fitted out with diver-operated propulsion vehicles. It is quicker to swim without vehicles, during slack tide, but in this way we were ensuring that on arrival at the inner cave we would still be fresh and our tanks full, and that we could start work at once.

Swimming as high as possible in order to save on bottom time, we followed the lifeline about 1,000ft. into a passage until we came to a huge cave, approximately 300ft. long, 200ft. high and 50ft. wide. From here on we had not explored before.

We continued along the passage for another 1,000ft., came to a pit, shone our aircraft landing lights down there and still could not see the bottom; it was pitch dark. To go any further we would have to use re-breathers, and to go deeper, we would have to use gas mixtures. The dive is so timed that the current is sufficiently strong to return us to the surface even if our vehicles break down.

During the shooting of Cousteau's film series, Phillipe Cousteau asked me what I thought was a successful dive. I replied: "When, on return to the surface, I count my divers and they are all safe and well, that to me is a successful dive".

Hans Hass: I have great pleasure in introducing as our next speaker, a German artist who brings an entirely new element into the assorted community of divers.

Jurgen Claus has discovered the sea as a possible means of artistic conception.

creative. We must conserve nature and not pollute it. Please, Jurgen Claus, say a final word to that.

Jurgen Claus: I would answer this question in a very practical way. For instance, how do we understand the professional architect?

A leading Japanese architect was commissioned for this first Tokyo Bay project. Then they expanded and a group of architects called Metabolists was employed, and now they have a master plan for the whole of Japan, including the ocean. So, the architect is more or less getting into the profession of planner, or designer of the complete environment. In this sense, I think the architect has not only to follow technological, profit-orientated development, but to suggest designs from his view point. This is one example of a small, local project growing into a national plan and I think it is the right direction for the artist.

Peter Throckmorton

Peter Throckmorton is one of the world's leading underwater archaeologists, but was originally a New York photo-journalist.

In 1958 he arrived in Turkey — he already had both land and diving excavation experience — and worked with Turkish sponge divers in an attempt to locate ancient wrecks in the area.

He found the seabed almost littered with them and finally located the site of a Bronze Age ship — the oldest shipwreck ever found.

Since then, he has worked on marine archaeological sites all over the world.

The future of the past - The promise of archaeology

Ladies and Gentlemen, friends and old shipmates — there are many of them here — it's a great honour, of course, to be asked to discuss the progress of shipwreck archaeology. What might happen by the year 2000? Perhaps nothing. There might not be any wrecks left, at least not at what we think of today as diveable depths.

You know, a lot of the goings-on in nautical archaeology in the last ten years remind me of my father's receipe for Fish House Punch. You take a bath tub and you fill it up with cracked ice, then you get six quarts of vanilla ice-cream, two quarts of maraschino cherries, a bottle of cherry brandy, half a gallon of fine old port, half a gill of Jamaican rum, six grated nutmegs, five peeled lemons and the whites of 12 eggs. Then you get a case of the best Scotch whisky. Into the bath tub filled with cracked ice you put the vanilla ice-cream, maraschino cherries, cherry brandy, port, rum, nutmegs; then you throw it all away and drink the whisky!

Eleven years before our last conference in 1962, I was one of a dozen or so happy owners of aqualungs in the Hawaiian Islands, stirring up my Fish House Punch with a stick. I was supporting a sports-car and my limited education by liberating underwater scrap, spearing fish for Chinese restaurants and diving from a glass-bottomed boat. I remember in those days we couldn't get tanks so we used to dive with fire extinguisher bottles which weighed about 40lbs. It was always very interesting to dive off that glass-bottomed boat, have one's regulator quit, and there you were — 40ft. down with tourists looking at you, and you've got 40lbs. of fire extinguisher bottle on you!

About that time I saw Captain Cousteau's article about his Roman wreck in the *National Geographic* magazine. The idea of seeing ships that were last handled by Greek or Roman sailors some 2,000 years ago excited me a lot and it still does. I managed to get into what there was of nautical archaeology by more or less kicking the back door down; there wasn't much of a front door anyway.

Working on the University of Pennsylvania Museum's Underwater Archaeology Project, George Bass, Joan Taylor and myself as technical director, excavated a Bronze Age shipwreck in Turkey. This was the oldest shipwreck that had been found, or has since been found to date, and it was, we think, the first shipwreck that was excavated scientifically. Our technical inspiration came from the work of Captain Cousteau and his colleagues in the South of France — especially the job done at the *Titon* excavation directed by Commander Phillipe Taillez who spoke to us yesterday. We felt that we had moved their work another rung or two up the ladder of technical progress and nautical archaeology. We felt rather pleased with ourselves back in 1962. However, not everybody shared this opinion: I remember a very senior scholastic person from my side of the Atlantic who was heard to say in a common room somewhere, "Promising young fellow that Bass, until he got mixed up with that maniac Throckmorton". You know, Bass and I thought we were very respectable, we were trying to do archaeology and yet the kind of looks we got are rather like the ones my wife and I received the other night when we checked into the hotel . . . She didn't have a wedding ring. Now, our four kids know that they sawed off her wedding ring because the callouses were gaining, but it's pretty hard to explain to a hotel clerk in the middle of the night! I'm sure that a similar sort of aura of old-fashioned sin surrounds a lot of underwater archaeological work.

Most of us in the field are not really qualified or have degrees. I have a very good degree from the old school of hard knocks; Jeremy Green, who is running nautical archaeology in Northern Australia, is a physicist, and so forth.

Land archaeology itself began not too long ago as a rather scholarly, gentle sort of a treasure hunt (excuse me, archaeologists!) — practised by people who could afford it. So we divers struggle along trying to find a recipe for what we are doing, sometimes finding it difficult to understand that the land archaeology world has only very recently got its working principles sorted out. Obviously, today's archaeology students learn what Sir Mortimer Wheeler — who is really the founder of great scientific archaeology in England — called 'the art of digging people', but it has taken nearly 40 years for the general public to understand that archaeology has more to do with how people lived in the past, rather than finding and collecting Treasure, as reported by the popular press.

So we can't really complain, we divers who are interested in the sea, the ships, the stuff in them, when people who were brought up on Jules Verne find it a bit difficult to understand what Alexander McKee and

Margaret Rule and their little devoted gang of divers are doing down there in Portsmouth with the *'Mary Rose'*.

A good example of the kind of misunderstanding that prevails today is a recent review of a book entitled *'The History of Seafaring Through Nautical Archaeology'*, edited by George Bass. The reviewer is very distressed because the text wasn't based on, and I quote: "A traditional hypothesis based on literary text and graffitti". He goes on to say that the sketches are 'pretty'; he regrets that we've not included the work of the French school of nautical archaeology. Now, many of you know as well as I do that when you've spent hundreds of pounds in working up an accurate scale survey, it's distressing in the extreme to have it called a 'pretty sketch'. What escaped the attention of the reviewer of that book — who is a nautical historian of note — was that the contents of the book were described by its title *'A History of Seafaring Through Nautical Archaeology'*; that every writer in that book has, with his crew, seen, photographed, measured, raised, analysed, preserved and continued to observe the thing he is writing about. It is about real things, not theoretical things — graffitti on walls, literary references — it is about real ships. Bass could not include the work done by the French school mainly because Commandant Taillez' work does not seem to have been furthered by the initiation of any more major excavations or creations of museums in the South of France. In the meantime, nearly all the diveable wrecks in France have been destroyed by skin-divers. The same applies to Italy; the same thing will shortly apply in Britain unless you can pull your socks up.

French and Italian Government organizations responsible for nautical archaeology have spent about ten times as much money as the Pennsylvania Museum people did in all their ten years work on projects, so I'm not a rich American standing up here preaching at you; I am a very poor American, and we are really as badly under-financed as you are in England! I understand some of the problems that have occurred in the South of France and Italy. I have led expeditions in both countries, and a lot of the people have failed, like me, because the Governments and administrations they were working for had no idea of what nautical archaeology was.

In short, having been in nautical archaeology for 15 years, I think that we are involved in problems too big for us, as individuals, to understand. I have recently been reading a book, which I don't completely understand, entitled *'Future Shock'*. Written by a man named Alan Taffler, in it there are a lot of good examples that make it easier for one to understand what is happening in the modern world. For instance, in 1500, Europe was producing books at the rate of about a thousand titles a year; by 1950 the rate had increased to 120,000. Any scientist, physicist, especially those employed in the field of electronics, will give you similar statistics. So, similarly, nautical archaeology is expanding at a rate which is far in excess of the administrative capacity of the institutions that control and finance it. For instance, our work in Greece: The basic law concerning archaeology in Greece was written before 1900, and re-written in 1932. Luckily, this law is so worded that it covers all antiquities whether they are on the sea bottom or on land, but it does not cover conservation. In 1932, conservation of archaeological material meant a pot mender, usually an old boy who could not read or write, who was very expert with a pot of hot varnish under a bunsen burner, who had a few dental tools and a few very simple chemicals. Undersea finds today require a graduate chemist with many assistants and a whole industrial workshop that could be as big as this ballroom.

In Britain, the law concerning salvage was written some 80 years ago, and the first law that protects historical wrecks was passed in 1973, after a long campaign by the Council of Nautical Archaeology.

In many of the United States, notably in Florida, the existing laws concerning antiquities under the sea seem to be written more with a view of guaranteeing the speedy destruction of shipwrecks than to preserve them. There are horror stories from Florida that make your blood run cold, but there is a good and simple reason for this. I want to suggest that the reason that marine archaeology is less acceptable in some countries is because things are happening so fast, and it is very hard for old institutions to adjust.

Italy is very typical: The first organised national effort to work on shipwrecks occurred in Italy, yet there was, and still is, a tradition of separation of the academic from practical people involved in archaeology. In other words, a dumb sailor like myself would never be invited up on a platform like this in front of a lot of professors; they would have a professor with a Doctorate. The structure of Italian and French Universities makes interdisciplinary work very difficult, makes it difficult for a physicist to work with an archaeologist, and so forth, so the older countries have more difficulty in adjusting to what Mr. Taffler calls 'Future Shock'. Part of this difficulty lies in people's reluctance to accept ships as part of man's cultural heritage.

In the year that I was born, in 1928, there were 200 square-rigged ships in America; today there are six, and only one of these sails. Speaking as a professional seaman, I am very grateful that I no longer have to work for 12 hours a day or eat hard tack and baked beans as a steady diet. Instead, I can push a button and make my boat, with its lovely Gardner diesel, start up and take me where I want to go. Yet sailing ships really meant something in the Northern and Mediterranean peoples' culture.

I remember an old boy named Charlie Newman, who had spent his whole working life as Bo'sun on a ship called the *Preussen*, one of the biggest square-rigged ships ever built, and wrecked in England in 1907-1908. Old Charlie spent 20 years of retirement, until his death aged 90, in the basement of the old sailor's home in San Francisco building the most beautiful model of that ship you ever saw. It is now in the San Francisco Maritime Museum. The point is that although a completely illiterate man, but a poet, he dedicated his life to remembering that ship. Similarly, we would be wrong to forget the thousands of seamen that starved and died of sickness and were hung at the yardarm in Nelson's Navy so that England could enjoy a hundred years of peace and prosperity. We would be equally wrong to forget those French, American, English, square-rigged sailors, Germans who battled Cape Horn so that the modern world could become what it is. I doubt that anybody here would advocate that we scrap Nelson's *Victory* down in Portsmouth or the *Cutty Sark* or Captain Scott's *Discovery* because they are obsolete and expensive to keep up. We preserve our historical monuments so that we and our children and grandchildren can understand the people that lived and worked in them. But, in my lifetime, there have been serious movements to destroy both *Cutty Sark* and *Victory*: a full list of ships of similar value which have been destroyed since World War II would fill about a dozen typewritten pages. In short, archaeologists and archaeological administrations and social departments of governments have often failed to think of preserving worthwhile monuments of nautical antiquity for future generations, and these monuments have been most wantonly destroyed.

For the record, I don't believe that a skin-diver who goes down and dynamites a wreck so that he can pay for his hobby is any more guilty of vandalism than a civil servant who destroys an historical ship because it cuts down on his paper work. Both of these people are victims of an outdated salvage system which rewards the destruction of antiquities and which penalises those individuals who see the necessity for preserving them. This is not the fault of any individual; the future is at stake and yet we are not prepared to cope.

Museums traditionally have been conceived as places where small valuable objects can be preserved. The idea that a whole culture will disappear and that museums should preserve not only a few valuable objects but a whole way of life is a relatively new concept. The Norwegians were way ahead when, in the 1930's, they took a whole island in Oslo and turned it into a living museum with buildings of folklore taken from all over Norway. In terms of ships, the concept was further developed in America by Carl Cutler and the founders of the Mystic Seaport Museum which was conceived as a place where ships, buildings and their contents — the whole setting of the 19th century — could be preserved in its natural context.

Projects of this scale — we are no longer dealing with a fuddy-duddy museum with a few old art objects and old Professor What's-it taking care of it, but with a big, million-pound enterprise — are very difficult to finance. Most local museums are founded by individuals and are kept going by small donations or by an endowment from the founders. They are not large-scale projects financially or administratively, and they are not generally a teaching institution. What has happened then is that institutions like the Wasa Museum, the Mystic Seaport Museum, the Roskilda Museum in Denmark, have become teaching institutions, more like small universities.

Peter Throckmorton then gave a slide show:

Here at the California Maritime State Park, are preserved an old ferry boat, a lumber schooner, etc. This museum costs the State of California a packet of money and the ships are rotting because they are not earning enough to maintain them. Why? Bad Management.

At the San Francisco Maritime Museum, this tug boat — a paddle steamer — is turning out to be very expensive: It took an investment of a couple of hundred thousand pounds to bring her from England to San Francisco, but there is no proper place to house her there.

The Balclutha, a British full-rigged ship of 1,200 tons, was saved from being scrapped by Carl Cordon, Director of the San Francisco Maritime Museum. The Unions, lead by the chief of the seamen's union, got together with the museum to rebuild her at a cost of around $100,000 — almost everything was given free. This work, if it had been quoted flat-out, would have cost nearly a million dollars. *The Balclutha* is now an extremely successful exhibit, making a clear profit of something like £40,000 a year, which supplies a research facility in the Maritime Museum, an enormous library, and so forth.

So my point here is that ships are ships, even if they are in a museum; they have got to be managed properly or they don't pay. Managed properly they are very profitable.

And now to turn to a sailing ship that was built eight years after the *Cutty Sark*, in the same yard as that in which the builder of the *Cutty Sark* did his drawing apprenticeship. She is an exact sister ship of the *Otago*, the first ship that Joseph Conrad ever commanded. I am in the process of rebuilding her in Piraeus Greece, for the Maritime Museum in Vancouver. We are going to sail her across the Atlantic to Vancouver where she will be installed in San Francisco as a permanent monument to all those men who died off Cape Horn.

This is our ship *Elsa*. She doesn't look much like a sailing ship at the moment and you can imagine what a big project it is going to be to re-rig her, but the accommodation under the awful cabin is intact, as is her deck. This ship, which will be completely reconstructed within a couple of years, is too important to be allowed to be scrapped: the last one of her kind in the world, it would be criminal to scrap her.

The last of the *Erikson* ships stands in a nautical museum in Mariehamn, Finland, where they are going broke because they are not charging admission and because they are trying to maintain her in the wrong kind of way.

Pictured here is a half-size copy of Donald McKay's *Flying Cloud*, a famous American clipper ship. Noboby goes to see her; she is rotting in a boat dock in Boston — there is no hope for her, or her like, people will only go to see real ships.

What I am trying to say is that although we can't criticise the average museum director for not being a showman — because that is not what, up to now, he has been supposed to be — it is a fact that ship museums can be made to pay, and to be a very profitable investment for the community that is lucky enough to have them. But if they are mishandled they are ruinously destructive and expensive.

So, these projects require a new kind of museum director: a dynamic scholar who is also very much of an engineer who understands technical things, a fund raiser and so forth. Last year a Greek Government official asked me to present a budget for the excavation and preservation of a 12th century ship that we are working on. I replied that we had to begin by building a conservation facility that could be turned into a museum, but it turned out that the whole price tag for Byzantine antiquities in Greece was exceeded by our budget, so they weren't very interested in my ideas.

I believe the only way the problem can be solved is by setting up a national or international organization, supported by the governments of the United Nations, which can administer the capital necessary to construct the institutions that we need to save our nautical heritage. It is just as serious as that: if we don't save it, it will disappear forever. But the institutions required are so big that they are beyond the normal fund-raising capacity of museum systems.

What no one realises is that the vast flow of nautical antiquities that has been overwhelming museums since the invention of diving is about to stop. I have recently read that over 150,000 divers a year qualify in America; there are 22,000 in Britain. You don't have to be very clever to figure out that if each one dives on a historical site and takes one souvenir, there is not going to be much left very soon. So, Dr. Hass has given us a good description of what is happening to fish, the same thing is happening to antiquities in the sea.

The past ten years have been ones of organizational and technical progress: we have learned how to be archaeologists under water, how to excavate and to preserve. During the next ten years we have got to ensure that institutions that will make it possible to protect maritime antiquities are set up in all our countries, and that we harness the vast reserves of ingenuity and enthusiastic energy that the diving community represents. We divers, whether we want to be or not, or whether the Establishment wants us to be or not, are the Trustees of our ancient maritime tradition. If scholars and civil servants make it impossible for us to have a legitimate interest in nautical antiquities, these antiquities are going to be destroyed.

Co-operation is beginning in England: there is the Committee for Nautical Archaeology combining with the Maritime Trust and the British Sub-Aqua Club — a combination of force that can take on a project like the *Mary Rose* and many other projects. In Greece, we have started a similar organization, with similar aims, because we realise that Greek people interested in nautical archaeology have no channels for their work.

You might ask what an individual can do to build a project like Michael Katzev's excavation which cost over

£100,000, or the Wasa Museum which cost millions of pounds, or the Roskilda Museum. Well, the Wasa Museum was started with nothing more than a rowing boat and a plumb bob, and Miss Rule and Alexander McKee are going to give us the *Mary Rose*. None of these people had a bean when they started; none of them has a bean now. They are all broke. Yet we all agree that it doesn't pay to pollute our environment, kill our fish, or dynamite our shipwrecks. These things belong to our children, they don't belong to us. Man is not free to ruin the world any more and unless we pull our socks up it is finished, there will be no nautical archaeology in the year 2000.

Michael L. Katzev

Michael L. Katzev was born in Los Angeles, California, in 1939 and obtained his BA degree from Stanford University (Economics) in 1961 and his MA from the University of California, Berkeley (History of Art) in 1963.

During the spring of 1964 he participated in the American School's excavation at Nemea, Greece, and between 1964 and 1967 was a member of the University of Pennsylvania Museum's underwater excavations of a Roman and a Byzantine ship sunk off Yassi Ada, Turkey.

Mr. Katzev is now Vice-President of the American Institute of Nautical Archaeology.

The Kyrenia Ship Project

In introducing our session this morning Peter has indeed painted a rather grim picture of what lies ahead in the next 30 years, but I would like to take this opportunity to show you one project that has been done, and to use it as an example of what can be done in the next decades.

The subject of our conference puts me in a rather peculiar, if not awkward, situation in that instead of looking ahead to the year 2000 I am going to look back to 2,000 years ago.

In 1967, at the invitation of the Department of Antiquities of the Republic of Cyprus, I lead a small group of divers, archaeologists and specialists, in a search for ancient shipwrecks. We were fortunate in finding several off Cape Andreas, where Jeremy Green subsequently returned to make further surveys, and several off Cape Arnauti.

However, the best site was reported to us by a sponge diver named Andreas Cariolou, off Kyrenia on the North coast. A few years earlier he had found a mound of amphorae at a depth of 90ft., but had been unable to take bearings and had devoted several years thereafter in trying to relocate the site. He had just been successful in doing so when we arrived on the scene and explained our mission. Very sympathetic to the world of nautical archaeology he kindly co-operated with us, first, by taking us out to the site and then by giving us innumerable aids in the course of its survey.

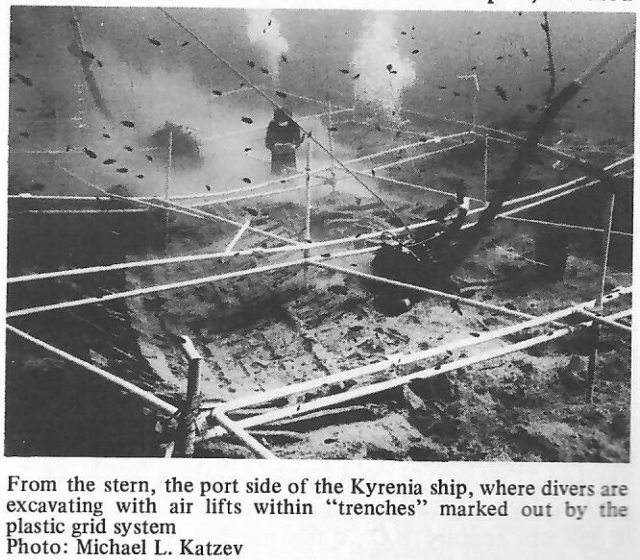
On our first dive on the site, about 80 ancient wine jars were visible, spread over a distance of about 10 x 15ft. We were not certain what we were dealing with, whether it was a small lighter, an average-sized merchant ship, or whether the overburden of sand hid much more. But we knew it was a ship because its cargo — the amphorae — was still neatly stacked as it must have been when originally placed aboard the vessel. So, we conducted a survey, probing the overburden of sand and mud covered with eel grass, to determine the extent of the ship. Positive hits were found over a length of almost 60ft. and a breadth of nearly 30ft. We realised then that we were dealing with an average-size ancient merchant man.

We then refined that survey by using a metal detector designed by Jeremy Green, and an underwater proton magnetometer devised by Teddy Hall at the Oxford Research Laboratory. By now it was apparent that the site warranted excavation: the covering of sand made it highly probable that we would find the wooden hull hidden beneath, and the shape of the amphorae indicated that we were dealing with a shipwreck dating from the time of Alexander the Great — the fourth century before Christ.

I returned to the United States and began the very arduous task of raising funds and, having achieved some measure of success, enlisted a crew and returned to Kyrenia in the summer of 1968. We loaded a barge with compressors; with all the paraphernalia necessary to underwater archaeologists working in the Mediterranean; with a decompression chamber; and with a new invention that had first been used on George Bass's work — an underwater telephone booth.

We had a crew of between 20 and 30 divers, most of them students and graduate students of archaeology, classics, history, many of them also specialists, diving technicians and doctors. We had to provide everything possible for their safety — hence the telephone booth which we positioned just beside the shipwreck itself. It encapsulated an air bubble and, in an emergency, divers could find refuge there. Fortunately enough, we had no mechanical failure at the depth of 90ft., so the booth primarily became a communications centre into which divers could swim and ask for equipment to be lowered, other gear to be turned on, inform the next team of divers what they could expect, and convey instructions back and forth as to how to continue the operation.

In undertaking the excavation, our first problem was that of clearing the overburden of sand. In part, we used

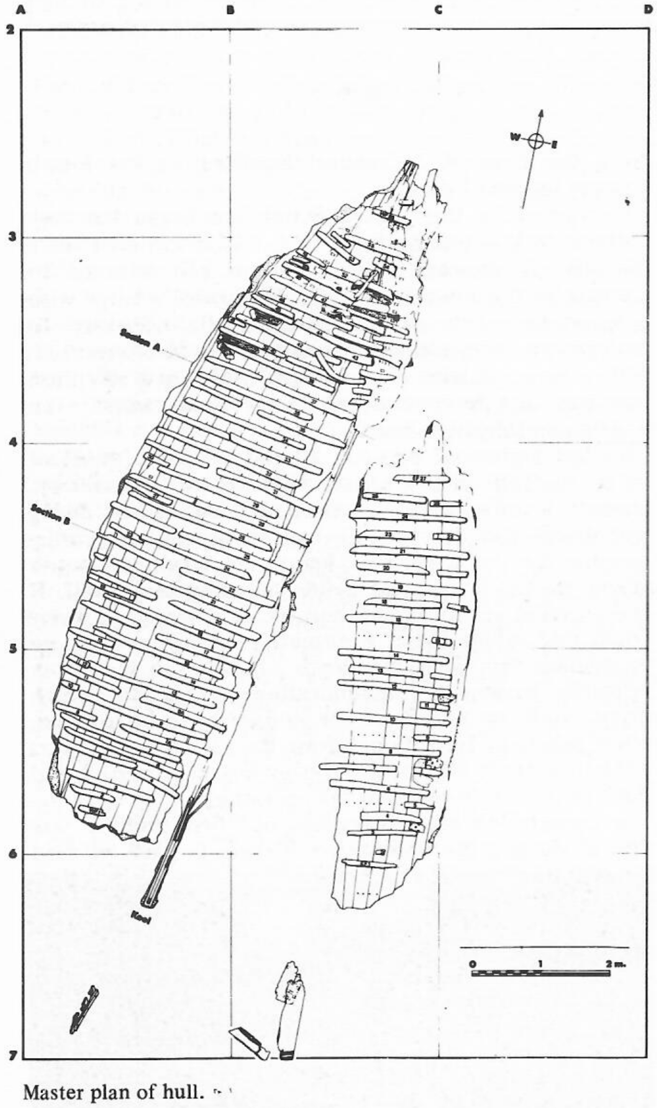


From the stern, the port side of the Kyrenia ship, where divers are excavating with air lifts within "trenches" marked out by the plastic grid system
Photo: Michael L. Katzev

an underwater sucker, but found the familiar air lift much more successful and, in the end, we had some seven of these planted around the site, moving the overburden, clearing and exposing the amphorae and eventually, exposing the hull.

Once the material had been uncovered we attempted, as have other underwater archaeologists, to duplicate, at least in accuracy if not in method, the scientific recording of our land colleagues; we could not dig trenches as they do, so we established an artificial trench system, simply by putting a grid system over the wreck.

If we had manually measured every object, it would have taken a considerable time. Instead, we used a stereo system — a two-metre-long bar, at each end of which was mounted a Nikonos camera with an underwater corrected lens — the diver simply flying over the wreck taking pairs of photographs. These were processed and studied on land, and from them every object was accurately plotted and put on a plan.



Master plan of hull.

From these plans we came up with the theory that the ship had gone down on its side, and there had become quickly buried in the mud and sand. However, the upper side was exposed to attack by teredo worm and had eventually fallen outward, hence the random distribution of the amphorae here as they spilled out.

This theory was in fact to be proved as we moved deeper into the excavation.

In all, we raised over 400 amphorae (wine jars), most of which were made on the Island of Rhodes in the last third of the 4th century B.C.; a fair number of another type came from the Island of Samos a little bit further North along the Western coast of modern Turkey; and some odd ones were found whose origin we are not able to identify. They may have been remnants of an earlier voyage or earlier ports-of-call, carrying cargoes of a more precious nature, hence fewer of them were carried on the vessel. Because of their distinctive shapes, the amphorae have made it, in part, possible for us to conjecture the ship's route.

As we moved the amphorae and probed deeper into the hold, we began to find clusters of nuts: 9,323 almonds have now been counted. Although I cannot tell you in exactly what year the Kyrenia ship sank, from these 2 000-year-old almonds I can tell you approximately the time of year. Almonds in the Mediterranean area are harvested in late August/early September. This cargo would not have lain in a warehouse for very long before it was loaded aboard, so we can assume that the Kyrenia ship sank sometime in the late summer or early autumn, perhaps September, or early October.

Having removed most of the amphorae, we came down to a pile of blocks: these were millstones — upper and lower blocks which, when rotated one on top of another, ground coarse grain into flour. Peculiarly enough, we found 15 upper blocks and 14 lower blocks, and when we tried to match them up we found that the upper blocks were always too large for the lower. However, many of them were scratched with a mason's mark, and we thought that this might be a clue as to how to match upper with lower blocks. But, in the end, we had to come to the conclusion, if only because we didn't have matching pairs, that they were remnants of an earlier cargo. Perhaps the captain, who had probably picked them up in one of the Dodecanese Islands (which seems likely because of the type of volcanic stone), had not been able to sell all the millstones at an earlier port-of-call. Instead of leaving them behind, he had very carefully loaded them aboard, surrounding them with fine grain pebbles, occasionally even the size of a fist, in three neat rows directly over the keel, using them as ballast.

We have been able to study the ship and to establish that she was a 25-tonner and yet she was only laden to about 22 tons when she sank off Kyrenia.

The fore and aft parts of the ship contained crockery used by the crew: small bowls, plates, drinking cups, pitchers and little jugs. Their distribution indicated where the crew stored its utensils. In the stern section we found evidence of a cabin area forming a quarter deck upon which the helmsman stood. From this material we also began to gain a better idea of shipboard life: we found four drinking cups, four oil jugs, four salt cellars and four wooden spoons. We believe then that this 45ft. vessel was manned by a crew of four: the Captain and three mates. The pottery is useful not only in reconstructing the life on board, but also in pinning down the date of the sinking of the ship: the vases are comparable to those found in the earliest cemetery at Alexandria, so we can establish that this ship dates from the last decades of the 4th century B.C.

Unfortunately, we did not find any gold or silver coinage, but we have five bronze coins, something like your penny, and not any more valuable than that. Today they are rather more valuable for these coins can be associated with two successors of Alexander the Great: Antigonos, The One-Eye, and his son Demetrius, The Besieger. Hence, through the numismatic evidence, we were able to pin-point the sinking of the ship to about 300 B.C.

To us, the nautical archaeologists, what was most exciting was what we found after removing the cargo: a rather well-preserved ship with confirmation of the fact that she had broken her back on the bottom. We found the smaller, less well-preserved starboard side, where the amphorae had been randomly distributed, and the much better preserved port side, which extends in length almost 40ft. — or about 80 per cent of the original ship.

Crew's crockery
Photo: Susan Womer Katzev

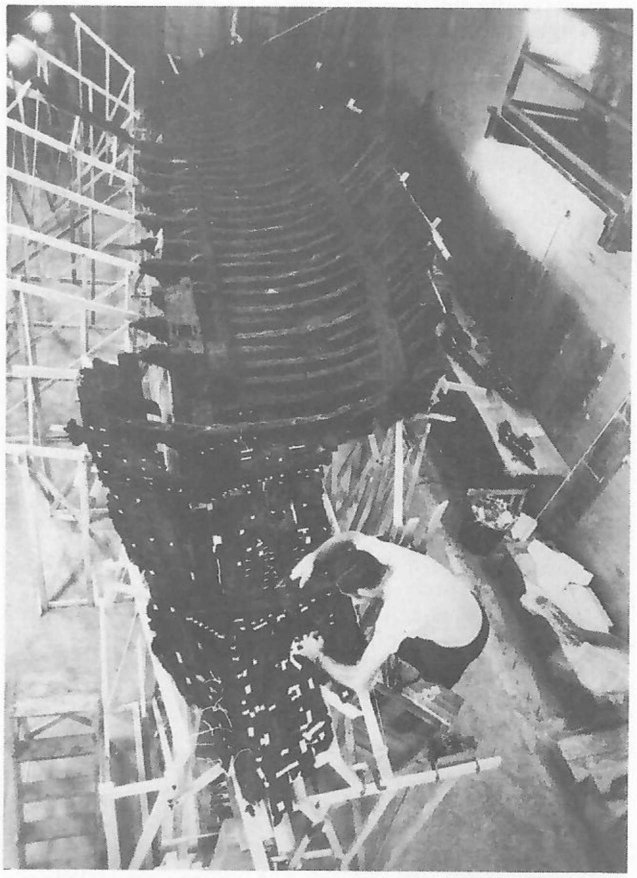
As we began to uncover the hull, for the first time we had a chance to inspect its exterior, sheathed with lead. Originally we had thought that this was a method of anti-fouling: to protect the hull from teredo worm; but now we have every reason to believe that the lead sheathing went all the way up to the cap rail, and it would seem that its primary purpose was waterproofing. It appears that it was applied rather late in the history of the ship, to weatherproof the seams that had worked loose over the years.

The ship had two steering oars — no rudder — on the aft port and starboard, and we were fortunate enough in finding one of these, perhaps the only one found from classical antiquity. We also found a pulley block, belaying pins and the mast-step — a massive, remarkably well-preserved piece of timber. We have now been able to study the step in detail and, interestingly enough, there are cuttings to indicate that the mast could have been set in six locations; perhaps each captain over the life of the vessel preferred a different setting, or in different winds the mast could be moved so that the ship would sail better with the wind.

In addition, we found an interesting group of objects which are most informative: over 100 lead rings. These little rings were sewn to the leeward side of the sail to prevent the lines, with which the crew raised, lowered and reefed the sail, from fouling. It must have worked very much like a venetian blind.

The Kyrenia ship had only a single square sail, and we have found from tests with a scale model, that although she could have sailed rather efficiently into wind, her maximum speed under sail might have only been 4 knots, despite the fact that her hull speed was upwards of 12 knots.

Each piece of the hull was photographed in situ, tagged, and then put into a metal tray, and brought to the surface with lifting balloons. To prevent the wood from being damaged during the lift, the tray was covered with a sheet. Once on the surface the wood was placed in a freshwater tank to leech out the salt. It was at this stage that we began the analysis of the wood and discovered that it was almost entirely of pine, although the tenons were of oak. Next, we photographed both surfaces of each piece of wood and, by tracing, made full-scale drawings. We used different colour codes to indicate the nail holes of the copper spikes which held the frames in place, the lead sheathing, and particularly the small copper tacks that held the sheathing in place. From these drawings, and using our Master Plan, our naval architect, Dick Steffy, was able to project the lines of the ship, and with these lines we could consider beginning the reconstruction. In fact, we have made four reconstructions: of the hull, using the original wood; a one-fifth scale model; a fibre-glass model also one-fifth scale; and a full-scale replica of a section of the ship for two metres aft amidships.



Reassembling the Kyrenia ship.
Photo: Susan Womer Katzev

I will deal now with what we have done to preserve the wood. Pine is a soft wood, which is perhaps easier to treat than a hard wood, but the pieces were badly degraded through the years of submersion and the extensive attack of teredo worm. Our problem was to drive the water out of the wood and to replace it with a substance that at room temperature would bulk the cell walls and provide dimensionally stable wood.

We immersed the wood in heated tanks in which a solution of polyethelene glycol 4000 was pumped and re-circulated. After eight months of submersion the strakes were removed from the treatment tanks, sponged clean, placed in plastic bags and left to cool down to room temperature. In three years we have been able to treat over three cubic metres of wood in this way, each piece of different size requiring almost individual treatment. Considering our objective: to obtain dimensionally stable wood, we have found that this method is 99 per cent successful.

Although we are not able to determine all the building processes employed in the ancient shipyard, many of which would have depended on the available manpower, we do know that the Kyrenia ship was built shell first. First, the shipwright cut the keel, then the strakes and, having cut the mortices into which tenons were set, he secured the strakes. After having thus built up the entire hull, he was ready to shape the frames and set them into the hull. The frames were secured with copper spikes which were driven in from the outside and clenched over the inner surface of the frames.

On the contrary, in reconstructing the ship using the original preserved timbers, after setting the keel, we found it more convenient then to reset nearly all the frames on the better preserved port side. Next we attached the planking, gradually putting on the shell, securing the strakes to the frames and attaching one strake to another with stainless steel rods.

We have not yet finalised the reconstruction. About 10 days ago we had completed assembling most of the port side, and I believe that by now my team will have finished the entire bow section. The vessel was about 45ft. in length; we have about 40ft. preserved on the port side, and although the starboard side is not as well-preserved, we will reconstruct it.

We have learned a tremendous amount from the reconstruction of this ship. You might think that this exercise has been rather meaningless; that it is only intended for a museum Board.. But this could not be further from the truth: every time we handled the wood, be it on the bottom or on land, we learned more about the ship. As Peter Throckmorton mentioned, a lot of work has been done by scholars; I am not ashamed to admit that I am a Classical archaeologist myself. But our previous knowledge was based on literary references and representations of ancient Greek vessels, not on the actual physical evidence of an ancient ship such as this: a typical merchantman of the time of Alexander the Great, dating from the 4th century B.C.

It is my hope that other archaeologists involved in the study of naval architecture from the Greek and Roman world will be able to follow this example, and I am certainly more than willing to lend any assistance I can in order to aid in reconstructing ancient ships.

I would also like to extend an invitation to you — one and all — to visit the Kyrenia ship, which will be housed in a museum that is being established in co-operation with the Department of Antiquities of the Republic of Cyprus, in the Crusader Castle at Kyrenia.

This then is the story of the Kyrenia ship, about which I was asked to speak. However, having looked into the past, I should now like to look to the future and to the year 2000, the subject of our Conference.

I doubt personally whether the archaeological methods that we have used on the Kyrenia ship will change greatly in the next several decades. Just as our land colleagues 30 years ago were still digging with picks and shovels, I think we shall still be working with air lifts, knives and brushes underwater. We shall still need as many careful man hours of contact with our material on the bottom and as many careful study hours topside. What we as archaeologists place great hope in is new research for better and faster methods of preserving water-logged wood. I would predict that within less than 30 years, hopefully within 10, we will be able to cut our conservation time, especially our treatment of wood, down considerably.

Our consciences tell us that in striving for accuracy we can no longer 'make do', as some of our colleagues in the past have done, with simply pottering about making underwater measurements of an exposed hull, perhaps raising a few sample pieces, and then leaving the rest of the wood there. This is criminal! We must be prepared to raise and conserve the wooden evidence we find, and if we are fortunate enough to find a hull intact, or in any degree of preservation, we must re-erect the structure whenever possible. The reasons are three-fold. First of all, as I have tried to convey, the exercise of rebuilding yields a great volume of information, not only by fixing the subtleties of the ship's lines, but also by allowing us to step into the minds of the original shipwrights, recreating their methods, even their idiosyncrasies. Secondly, we owe it to the scholars who come after us to be able to check the original evidence in the ship's timbers. We are bound to have made some mistakes in our reconstruction of the Kyrenia ship, and only by providing this original evidence will future scholars be able to re-study the material and, hopefully, come to better conclusions in the light of on-going research. Lastly, the most important reason: the public deserves to learn from and enjoy the results of our research.

Nowadays a traveller can visit thousands of Greek and Roman sites, from Britain to Turkey, to see buildings and walk through towns representative of the past. But where are the ships that founded and sustained these civilizations? Nowhere in the Mediterranean can one yet go to see original ships of the period. I consider this sad. With the Kyrenia ship, we are just beginning to fill in this void; we will soon have on view a merchant vessel typical of a thousand such hulls on which depended the commerce of the Classical world. That is a humble start for the next 30 years. But we must fill in the gaps that exist. We have found nothing from the Neolithic period, but ships were sailing the seas in that age. George Bass has worked a Bronze Age ship, but unfortunately nothing of the hull remained. Roman and Byzantine ships have been dug, but there is nothing of them that we can see. Let us hope that in the next decade it will be possible to see ships from these periods. Certainly, underwater excavation is an expensive undertaking, and therefore we have to be selective as to which projects to begin. However, with ever-improving conservation methods our goal must be to bring an historical progression of Mediterranean ships out of the sea and into public view.

Meanwhile, I plead to you today, to divers not only here, but throughout the world, to help all of us who love the sea. Just as we are on the horizon of being able to raise and preserve ships, the amphorae and anchors — the tombstones that mark the graves beneath — are being taken by souvenir hunters at a horrifying rate. Once they are gone we have no hope of finding the ancient hulls about which we know so little. Just as we are discarding our spearguns, let us join together to stop the pillaging of antiquity from the sea. What we sacrifice in souvenirs on our mantelpieces can be the start of a maritime museum for all to share.

Jeremy Green

Jeremy, who is a physicist, worked for many years with Teddy Hall at the Hall's Institute for Archaeology at Oxford. A veteran of Michael Katzev's expeditions, he is now Curator of Maritime Archaeology in Western Australia.

Archaeology in Western Australia

Having found a wreck at Cape Andreas in Cyprus, which I had originally hoped to excavate like the Kyrenia wreck, I left the Mediterranean in 1971 and returned to Dr. Hall's laboratory in Oxford to be greeted with the information that I had "got the sack" because the economic climate in the U.K. had reached the point that I was now a luxury they could no longer afford. Very luckily for me, I was then offered the position of Curator of Maritime Archaeology in Western Australia, and went out to join a very organized set-up concerning the preservation of wrecks.

In 1963/64 a Wreck Act, the main concern of which was to ensure the preservation of five 17th and 18th century Dutch and English East Indiamen, was passed, and all wrecks prior to 1900 — nearly 2,000 of them — were put under the legislation and administered by the Museum. The attitude of the Museum then was that the Government had passed the legislation, but how was it to be implemented? It was a difficult problem and the immediate solution was, simply, to try and police the sites.

This was reasonably successful, particularly after an active excavation programme started, however, looting of the post-settlement wrecks then began. These wrecks, dating from about 1830 up to 1900, presented a serious problem which we have been trying to overcome by encouraging diving clubs to work with us on excavating these wrecks. I have spent many, many hours in what Bazza McKenzie would call "sinking ice cold tubes of beer" with diving clubs, explaining why we want to protect these wrecks for excavation, or why we want to protect them just as a sort of natural resource or underwater park so that they can be dived on and looked at without disturbance; if we don't protect them and they do not co-operate, then in a few years there will be no wrecks left.

Having done this, we are now trying to persuade people to come forward and tell the Museum of their wreck finds, and I think the situation is improving. The reasons for this being, firstly, that according to our legislation, a reward of up to 1,000 dollars based on an assessment of the value of the wreck, and another based on the bullion content of the wreck, are offered — so there is something tangible to be gained out of giving information. Secondly, we don't just say "thank you very much for finding us a wreck; here is the money — now go away: this is marine archaeology"! We believe that if diving clubs and marine archaeologists are going to work together, they must co-operate. So, we provide them with equipment and get them to come and work with us on the wrecks that they discover. As a result, there are now lots of clubs that are justifiably proud of the excellent surveys they have done, and many people who have found a rewarding purpose for skin diving.

Our Museum Marine Archaeology Section works on a budget of something like £50,000 a year, over half of which goes on salaries and a quarter each on administration and excavation. We have spent three months this year on colonial wreck excavation and a five-month diving season on the *Batavia.* We are based on a small uninhabited island some 100 kilometres out to sea, excavating the *Batavia* — a 50m Dutch East Indiaman Flagship, built in the same year (1628) and of approximately the same size, as the *Wasa.*

Batavia Iron Cannon from stern section being raised by work-boat 'Henrietta's' electric winch.

Of course, if you excavate a wreck, you have to become involved in the problems of conservation. These become very apparent when dealing with some 38 tonnes of wreck artifacts that we have so far recovered: Four large iron cannons that we raised had to be transported to the mainland in our work-boat, there to be packed and sent off on a 500 kilometre journey back down the coast to the conservation laboratory in Perth. When we found 122 blocks — some form of portico — which was part of the *Batavia's* cargo, we had to send them down to Fremantle for preservation treatment. This, then, is a problem of distance, but we never dreamed of our next setback:

Jeremy Green tags *Batavia* side planking prior to photographic recording and raising. In mid-picture can be seen ribs showing the curve of the hull, and in the background are the two stern cannon.

When we chartered a vessel to take the material down by sea from the island to Fremantle, the Skipper decided that the load was too heavy and that he would have to make two trips. We could not afford the delay, so we filled the Skipper with beer and quietly loaded the lot on board the ship. With the sheer physical bulk of material — tonnes and tonnes of stuff, thousands of artifacts — one soon realises that storage is a serious problem, and future excavations will be limited by the storage capacity of the Conservation Laboratory.

Compared with the techniques employed on Michael Katzev's excavation, our mosaics or photogrammetry is rather crude because we cannot afford to leave our timber on the bottom overnight and to risk losing it in a storm. Nevertheless, our method will enable us to reconstruct over 95 per cent of the timber so far recovered. With this in mind, the possibility of building a museum and of trying to do to the *Batavia* what Michael Katzev has done in Kyrenia is now being seriously discussed.

Because of Michael's work and a lot of earlier excavations in the Mediterranean, marine archaeology is at last becoming respectable; I hope that in the future we will see many more countries other than those in the Mediterranean area taking part in this work.

Margaret Rule

Mrs. Margaret Rule is the Curator of the Roman Palace and museum at Fishbourne, near Chichester in Sussex, and Honorary Secretary of the British Council for Nautical Archaeology and the Nautical Archaeology Trust.

As a land archaeologist, she directed excavations on Roman and medieval sites in Britain before she joined the team searching for the *'Mary Rose'* in 1965.

In 1970 she learned to dive with Southampton Branch of the BSAC and is now Secretary and Archaeological Director to the Mary Rose (1967) Committee.

The Mary Rose Project

You have heard about two very exciting projects, the first of which is nearing completion and the second of which appears to be well-financed and underway; I am now going to speak about a project which is really, in strict terms, only just beginning.

Henry VIII's great ship the *Mary Rose* lies buried in the evil-smelling mud of the Solent, beneath 13 metres of water. Built as a 600-ton, four-masted vessel in 1509 — the first year of Henry VIII's reign — she was a revolutionary ship in several ways, but most importantly because she was the first English ship we know of that carried complete batteries of heavy siege artillery on the main deck. She was a successful ship, not a drawing board failure and, having sailed for 36 years, was sunk through bad seamanship just as she was going into action against the French. She sank just outside Portsmouth Harbour in July 1545, with most of her men, all of the equipment and their personal possessions on board.

After years of documentary research by Alexander McKee, the naval historian, a sub-bottom anomoly, combined with a localized seabed scour, was identified by sub-bottom and side-scan sonar in the area where the wreck was believed to lie. At that time it seemed impossible to obtain an exclusive license to salvage the ship and we viewed with some alarm the legal but competitive salvage of other wrecks which was current in Britain at that time. The Mary Rose 1967 Committee applied to the Crown Estate Commissioners for a lease of the area in which the wreck was thought to lie and this was promptly given. Now, at last, we were able to protect the site under normal laws of trespass; we could not strictly protect the ship, but Heaven help any diver who put his flipper down on our mud! Neighbouring groups of professional and amateur divers, however, showed an admirable respect for the site and very deliberately kept away, and we are most grateful for their co-operation.

Today, the ship is one of five designated as Historic Wrecks under the Wreck Protection Act of 1973 and the Mary Rose Committee has been recommended for a license to continue their archaeological survey and salvage.

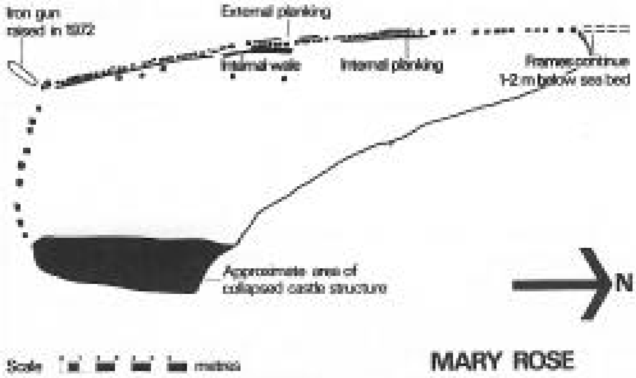
The seabed is a soft yielding mud covered by a lighter fluctuant silt, devoid of all the usual anchorage artifacts save for the odd polythene bag or beer can which rests lightly on the bottom, and no portion of the ship's structure had been seen in situ until, in 1970, a trial trench was dug across the area of the buried anomoly, and an oak plank and the barrel of an iron gun were recovered.

The plank clearly derived from the hull of a large carvel-built ship; the wood had high mechanical strength and when we cut a sample for dendro chronological dating we were amazed to see saw dust trickling from our cut. Examples have been examined for mechanical and biological degredation, but at the moment it looks as if we have very good, sound English oak.

The barrel of the breech-loading gun (the breech chamber was missing) appeared to date from the 15th or 16th century. Still in position in the breech end was an immaculately preserved iron shot; there had been no corrosion because the residue of the black powder (the carbon) was still closely packed around it, thus preventing oxidation and decomposition. Superficially, this gun looks like the well-known stave-built, built-up gun, of the type recovered from the *Mary Rose* in the 19th century by pioneer hard helmet divers but, after it had been conserved by electrolysis, it was examined by gamma radiography in the laboratories of the Royal Naval Dockyard in Portsmouth and this revealed that the gun had been fashioned by a hitherto undocumented process in this country. From a single wrought iron plate the smith had formed a cylinder around a mandrel, and had reinforced this cylinder with a series of iron hoops and rings. There is only one seam in the main iron plate of that gun.

Visibility on the site is normally between one and two metres, quite often it is zero, so we cannot work at all, but in the Spring of 1971 the tops of nine or 10 frames could be seen protruding five or eight centimetres above the seabed. These had been eroded by mechanical action, gribble and teredo worm, but 14 to 16 centimetres down in the mud the wood appeared fresh and new.

Over two seasons of work we have exposed a 24 metre run of the main frames of the port side, the inner planking being visible at seabed level most of the distance and external planking existing in some places at a depth of one metre. There is an internal wale part-way along the ship and the main frames continue around what pretty obviously was the transom. A castle structure overlies the starboard stern quarter of the ship; it has collapsed exactly like a house of cards, and is not broken-up wreckage.



Outboard on the port quarter we dug a profile to a depth of three metres and found that the ship was carvel-built and fastened with wooden pins. The caulking is still in position; the wood looks new and bright and shows the marks of the shipwright's tools, and the joints are tight and sound. She is a mechanically sound ship; there has been no break-up of the structure in any of the areas that we have so far examined.

We transferred the profile on to a conjectural drawing of how we think the *Mary Rose* looked. It would appear that she is lying at a slight-angled heel to starboard, with about 30ft. of the main hull buried in the mud. This means that not only do we have a 30ft. depth of ship, we shall also have all the contents within the hull preserved as they were on the day the ship sank. In other words, it looks as if we have an English version of the *Wasa*.

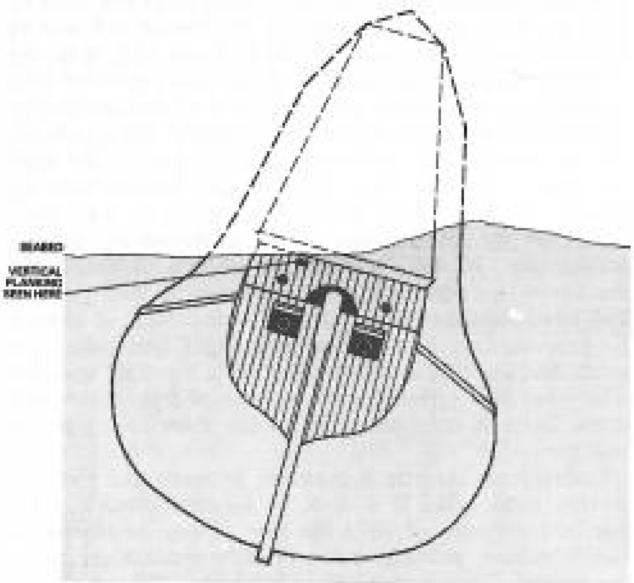
A trench outside the stern of the ship revealed vertical planking, but no other identifiable features. This, coupled with the profile, suggests that there is much of the hull preserved there in the mud: our trench revealed nothing of the rudder or the gun ports which should exist if we had been looking at a portion lower down the hull.

We have found that the strakes in the stern castle, which is of inch-thick clinker-built construction, much lighter than the main hull, are still in position and, as we descend, they thicken. We imagine, although we cannot confirm this until we have excavated further, that this is to accommodate the increased thickness of the hull planking and that at the junction of the castle and the main hull we shall find the thickness of the strakes do match. Outside the castle there is a chamferred vertical wale, and this is rebated to accommodate the clinker planking in position.

The castle structure, which has an internal deck collapsed within it as well as a portion of the companion way still in situ, is liberally interspersed with fragments of wreckage, artifacts derived from the ship, and anchorage material. It is very slow, painstaking work to define and evaluate every single piece of wood before we can establish that it is loose wreckage and finally remove it and, of course, this has slowed down our work on the excavation of the main hull.

So far, excavation has been strictly limited to uncovering the main timbers of the upper hull and the castle sufficiently to verify their function and record them on the plan. Outside the ship, excavation has been limited to that necessary in order to draw a profile. Any attempt to excavate inside the hull at this stage would be vandalism; although the results would probably be spectacular, they would not give us the answers we need. What we need to know is how much of the ship is preserved in the mud, how long the hull is, what is the maximum beam, what is the gross weight in sea water.

Caught up among the superstructure in and around the castle, we have found Tudor artifacts that augur well for the future when the hull is finally excavated in a wet



Conjectural drawing of Mary Rose as she appears to lie preserved in the solent mud. Based on 1972 survey.

Pewter Flagan recovered from the *Mary Rose*.

dock. Stone and lead shot are abundant and clearly derive from the ready-to-use ammunition stores in the stern castle. We have also recovered two small stone shot-moulds and the base and staves of a seaman's cask containing two combs, a thimble, a wooden handle for an iron awl, and a bobbin-like piece of wood the purpose of which is unknown. We also found the wooden handle of a kidney dagger — a thing seldom found on land sites, and a fine pewter flagon which, if it is English, is one of the earliest examples of English domestic hollow-ware to survive. All these objects came from the upper levels of the ship's collapsed structure; nothing from a depth of more than one metre.

We are fortunate in having adequate conservation facilities at present in Portsmouth at the City Museum and at my own laboratories at Fishbourne, and we have set up storage rooms for the treatment of wet wood in the block mills of the Royal Naval Dockyard.

If, after completing our survey, we are eventually able to lift the hull, we hope that we shall be able to bring it into Portsmouth, the only real problem being an embarrassment about which site to choose. Along the Portsmouth shore and adjacent to the harbour are Tudor fortifications built by Henry VIII as part of his great defensive scheme for England: the Round Tower, the long curtain, the square tower and the batteries are all contemporary, or nearly contemporary, with the *Mary Rose*. My personal inclination is to place her in a flooded wet dock here in the camber where she will become part of a display of Tudor naval life — the fortifications, the ship, and the objects excavated from within the hull must evolve into a magnificent museum complex that will be second to none.

Although I am a professional archaeologist — what is called in this country "a dirt archaeoligist" (who has now turned into a "mud" archaeoligist!) so far, this has been a purely amateur expedition and our work has been done on a shoestring, largely financed by private donations and, as Peter said at the beginning, most of us are now broke. For two months this summer we sat on the beach fully equipped, with all the men and equipment we needed, and we did not have the money to pay a professional licensed boatman to take us to the site; we have to have such a boatman to meet the legal requirements, it isn't just one of our whims and foibles. We could not even pay the Third Party insurance — also very necessary when one is going to excavate in the middle of one of the busiest yachting playgrounds in Southern England.

An appeal for £20,000 per annum has just been launched to finance a 16-week summer season of excavation for the next five years, our purpose being to evaluate the ship, and find out exactly what is there. At the end of the five seasons we imagine that we will have all the data necessary for a Feasibility Study to decide whether we do lift the *Mary Rose*, and whether we do have a National Museum of Tudor ships that we can all be proud of here in Britain.

Peter Throckmorton: I would like to tell you a story about Alexander McKee and the *Mary Rose*. He wrote to me a couple of years ago saying "We are doing very well, we have got eleven pounds!"

Presentation

Derek Cockbill: From what we have heard from this morning's speakers, I think you will appreciate the fantastic job that lies ahead on the *Mary Rose*. Obviously, from our point of view, it is the most likely to produce results and, whilst not wishing to labour the point, Margaret Rule did explain that they appear to be a little short of money — it seems sad that they couldn't even afford the hire of a boat. But, on behalf of the B.S.A.C., I should like to take this opportunity of presenting this cheque to Margaret Rule, with our best wishes for the ultimate success of this particular project.

Margaret Rule: Thank you very much; this is a very unexpected pleasure. All of the team working on the project are now formed into a special branch of the B.S.A.C., so we do very much feel an integral part of the Club. Thank you so much for this; I am very pleased I came!

Reg. Vallintine: During Peter Throckmorton's talk he told us a little bit about the *Preussen* the largest square-rigger ever built, and of the old seaman who spent the last 20 years of his life building a magnificent model of it. Peter told me this story about three years ago, since when we have done a little research and found out where the wreck was, and discovered that a branch was already diving on it. As a result, I am very pleased to present to Peter now, thanks to Reg Dunton of Bromley Branch, a piece of the original *Preussen* for the San Francisco Maritime Museum.

Peter Throckmorton: Thank you very much Reg for this miscellaneous piece of bronze! I'm not quite sure what it is, but anyway it is a real piece of bronze that I'm sure Charlie Muller polished in his day, and it will look very well beside his big model in the Museum.

Dr. Nic Flemming: The session this afternoon is concerned with equipment for both sports and commercial divers; machinery and ways of getting work done. Before I introduce the speakers, I have been asked to say a few words myself — it is rather unconventional for the Chairman to introduce himself, but still . . .

Dr. Nic Flemming

Dr. Nic Flemming was educated at Rugby and subsequently gained a BA in Natural Sciences and a Ph.D in Marine Geology at Cambridge. He started diving on oxygen with the Royal Marines Special Boats Section in 1955 and founded the Cambridge University Underwater Exploration Group in 1957. He had lead diving expeditions to most countries on the Mediterranean coast and around the UK, including Rockall, and has conducted commercial and industrial surveys of marine technology. From 1968-71 he was Scientific Consultant of the UK Mission to the UN Committee on the Seabed, and is now consultant to the office of Ocean Economics and Technology at the UN Secretariat.

Machines for the job

I want to talk about the kind of equipment and instruments that the sports diver may be using in 25 years time. You have heard a lot about chambers, S.D.C.'s, underwater houses, diver look-out submersibles, computers and so on and obviously the average club is not going to have that sort of equipment; but let us start from the first principles.

To my mind, there are two kinds of diving: mobile and fixed. It just so happens that the commercial people are mostly fixed: they send down one or two men into a relatively restricted area and work very hard for a long time in that area. Naval divers tend to be more mobile — for things like ship attack and reef surveys. But the most mobile of all is the sports diver. He has light equipment, can go anywhere, and swims freely without any heavy gear or a lot of heavy surface support.

We have to admit that the mobile diver has some very severe problems: he does not know where he is, how fast he is going, when he is going to arrive there, how much to angle off for the current, or how long his gas is going to last. He cannot talk or carry heavy weights; his gas doesn't last very long and if he tries to go faster, it lasts even less time. In the event of an accident he only has a few seconds to save his life or, with a bit of luck, his buddy may get there first.

In the year 2000 it is easy to envisage underwater hotels, safari parks in Indonesia or the Caribbean, people flying round the world with their equipment and living underwater or going to underwater restaurants, or flying around on sports torpedos and all that sort of thing. But still the great problem is how we are actually going to do it. What will the sports diver actually be breathing in the year 2000?

I don't think he will be breathing with his lungs full of liquid, nor do I think he will be breathing from small sets filled with liquified gases. Both of these are much too expensive and complicated for the average club sports diver. On the other hand, there is a piece of kit which has been around for 27 years — it is very efficient, very reliable and absolutely proven: the semi-closed-circuit set, based on the supersonic reducer system used in the Royal Navy. This equipment consists of gas cylinders, a rubber counterlung, and soda lime carbon dioxide absorbent. It isn't very difficult to train someone to use it, but nevertheless everybody agrees that it is too dangerous for amateurs to use. The question is 'why?'

It isn't in fact that it is difficult to use once you have been trained. The point is that there are many ways that it can be dangerous for you even to take it into the water. You can have gas in the cylinders, soda lime absorbent in the cannister, the reducer turned on, and it could still kill you in a few minutes. The only way to make it safe for amateurs is to make it impossible to have the wrong gas mixture in it, impossible to have the wrong reducer flow rate and impossible to use exhausted soda lime cannisters.

With an aqualung, it is immediately obvious when there is no air left or when the valve jams, but this is not so with a re-breather set. However, one could have a sensor package attached to the gas cylinders so that if the gas mixture were not correct for the reducer setting, it would be impossible to turn the bottles on; a sensor in the carbon dioxide absorbent cannister that would prevent the bottle being turned on if the CO_2 absorbent were already saturated.

It is not simply that amateur divers cannot be trusted to use this type of equipment, but that amateur Club branches cannot prevent their untrained members from using a closed-circuit set. However, I am quite sure that we will not be diving with open-circuit aqualungs and a very wasteful gas in 25 years time. Instead, you could put a re-breather set with a few little electronic sensors and several boxes of carbon dioxide absorbent into a mini car and have a week's diving. These are some ideas on what the amateur diver may be breathing with in the future, but how deep will he be able to go?

We have heard all about oxyhelium mixtures; they are very expensive. Oxyhydrogen may not be so expensive, but it is dangerous — not in the proportions that you are meant to breathe, but obviously hydrogen and oxygen mixtures are dangerous for amateurs and I do not see the Clubs using either of these mixtures. I think it is highly unlikely that they will be using pharmacological principles; they will not be taking drugs or putting chemicals into their gas mixture in order to avoid narcosis or bends. I think you have just got to accept that Club diving is going to be limited to the 150-200ft. mark for a good long time to come, but this still leaves us with the problem of decompression.

Decompression meters are difficult to use and not reliable for multiple dives. I won't say any more about the use of these instruments, but it is quite clear that the problem is not solved, not even for the Services, let alone the Club diver. The ideal instrument may come along in the next 20 years: something which actually monitors the diver's physiological state and gives a warning before dangerous decompression symptoms occur.

General safety will be improved in many ways. It is theoretically perfectly possible at this moment to have a set of auxiliary instruments which would come into action if the diver himself passed into a dangerous physiological state or became unconscious. For example, you could have a fairly simple monitor of his breathing or heart rate which would automatically trigger dropping his weight-belt in an emergency. Similarly, one could have an automatic lifejacket inflation system that gave a regulated ascent a forced breathing system — a band constricted around the diver's chest, or electrical stimulation of breathing, in the event of a diver becoming unconscious. All these things can be done with miniature electronics: they are technically possible now, but I admit that we are getting into the field of physiological parameters and their control of mechanical equipment, which is dangerous and difficult to arrange. Yet, I would have thought it possible in 25 years time. And, when the diver reaches the surface: radio aerials, flashing lights, anything you like — all matchbox size, pea size — present no problems.

Having got the diver down for longer, more safely and with increased efficiency, how is he going to move about and know where he is?

A very cheap and very effective diver transport vehicle exists:
with an inflatable bag on the top, and racks along the side that can carry a couple of hundred pounds weight of kit, it tows the diver at one knot and costs about £200. The problem is, how does he know where he is or what course he ought to steer? It is no fun not being able to talk to a buddy, not knowing where you are, not knowing in what direction you are going, etc. and it would be nice for a sports diver to have this information.

If you think that all these gadgets and bits of machinery are going to be too expensive or clutter you up, then just think how a television set has changed during the last 25 years. Think of the electronic equipment, the stereo tape recorders and all that sort of thing, that we now have in motor cars: things are going to change that much, and these pieces of kit are going to become available.

But if you had all the information you wanted on separate dials, you would be finning along behind a square yard of metal supporting electronics, dials and needles.

You wouldn't be able to see where you were going; you wouldn't be able to read all the dials; you wouldn't be able to remember what they meant; and you wouldn't have your hands free to do any useful work.

What we need then, is a computer the size of a small cigar box, that receives and stores the sensory data — measurements of speed, depth and physiology, — communications to the surface, etc., and which is capable of providing a selective data presentation either in sequence or on demand — just like the black box flight recorder system on an aircraft — so that when you come out of the water, you just tear off the piece of paper showing the whole dive profile, and stick it in your logbook.

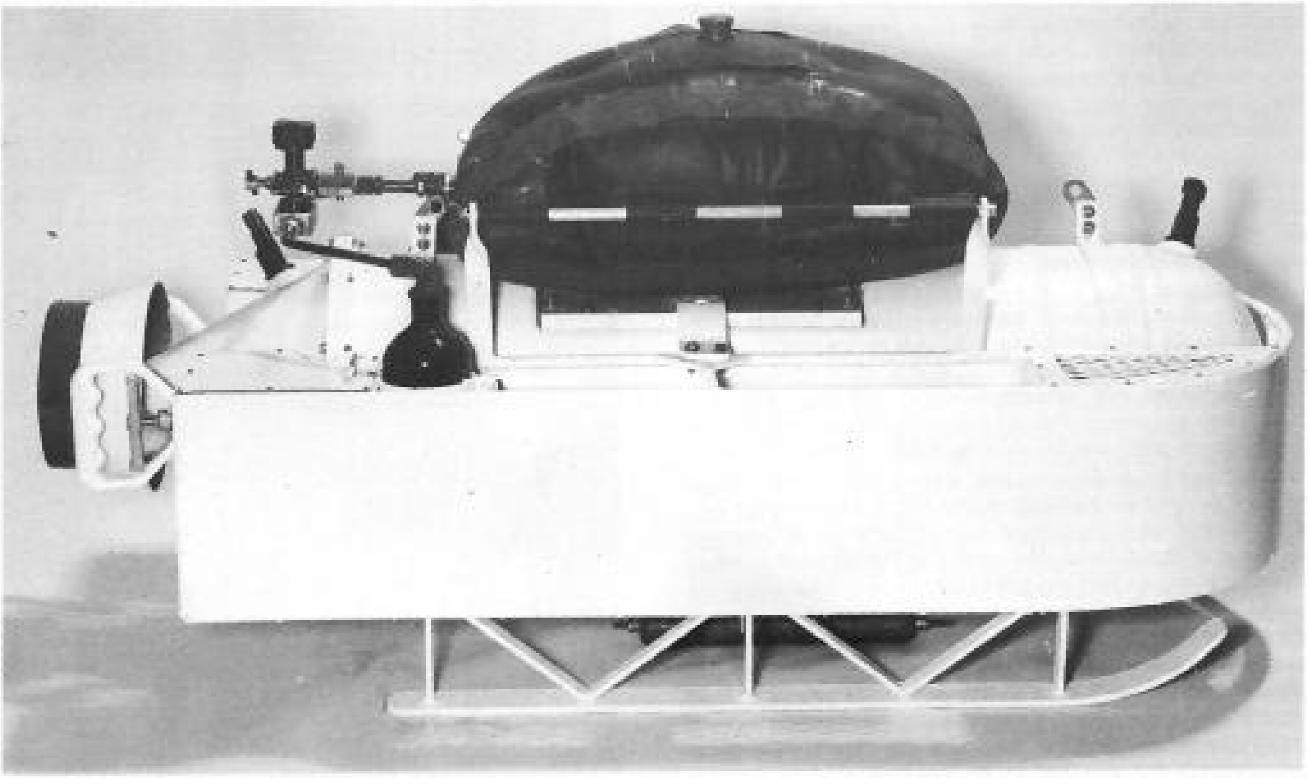
Some of these gadgets already exist: Working on a tri-lateration process of measuring the sides of a triangle, the position-finding equipment invented by John Partridge and developed for Nigel Kelland works perfectly and with great accuracy. But, you have got to use your hands to operate the knobs, and you have to look pretty closely to be able to read the numbers. It gives a good fix and is ideal for present surveying conditions, but in 10 to 20 years time the design of equipment must permit the diver to move, speak and work with his colleagues as freely as he does on the surface.

A recent survey of diving efficiency showed that an individual working in average conditions underwater is probably only 5 per cent efficient as compared with trying to perform the same task on the surface. In addition, if you have three or four men working together underwater, the difficulties of group co-ordination are such that their performance is only 1 per cent efficient when compared with group efficiency on land. It is not surprising therefore that commercial concerns prefer not to use groups of free divers.

On the equipment side, I believe that in the future it won't be necessary to dress up like a Christmas tree. Instead, everything the diver needs will be contained in his backpack, tanks and mask, and it could be made so reliable that all you had to do was to change the batteries every few months.

Well, there are some crazy ideas! I don't know how many of them will come true,-but this is the way things could go.

We are now going to look at two completely different aspects of diving development. First I am going to introduce Dick Tuson who has worked on diver transport vehicles, diver power sources and is now working for *Vickers*.



Electric tug for diver transport and work.

Richard Tuson

Kenneth Richard Tuson joined the RN Scientific Service as Scientific Assistant at the Admiralty Materials Laboratory, Poole, in 1947, and by 1950 was working on instrumentation, high speed photography, the physics of bubble production, and problems associated with diving research.

His work then developed into diving navigational systems, studies in streamlining, the development of breathing apparatus, and trials thereof.

He obtained special leave to work as Project Manager for *DHB Construction Ltd.* on the production, testing and trials of *JIM*, the armoured diving suit.

The cost of power underwater

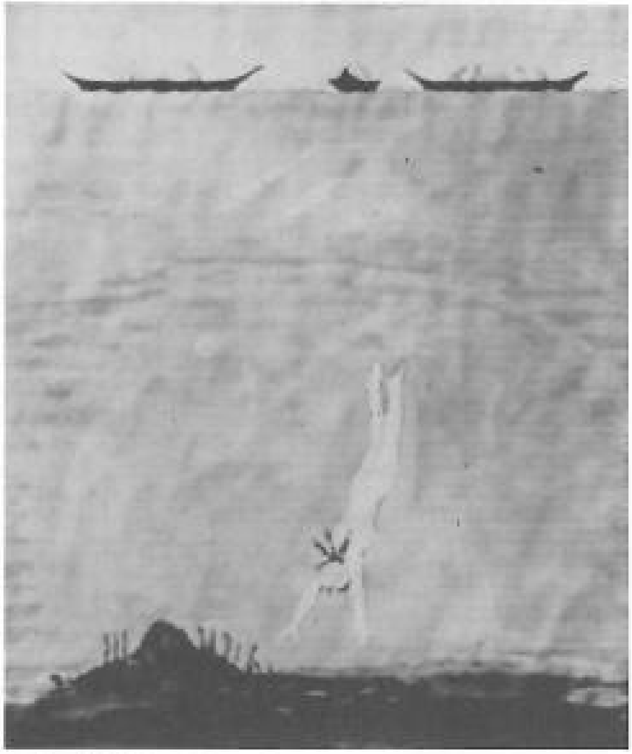
There are at least two principal reasons why people go underwater, they are: to work and to enjoy not working. In most cases where diving is undertaken in conjunction with other interests, as in marine biology or archaeology, the amateur diver probably works as hard as the professional, so it is hoped that some quite general observations on the cost of power underwater will be of value to those main diving interests.

Power is important because any activity, even if it is only moving from place to place, consumes it. One can look further and try to compare various systems from the point of view of cost effectiveness of available power, but any attempt to compare all feasible variations of the available systems would obviously be impossible in a brief paper. Therefore, in order to show the wide range of costs of usable power, I have chosen nine highly stylised and representative operational diving systems for us to consider. In these examples, except where it is shown that the power source is actually a part of the whole system, I have assumed in the first case that only the power output of the diver himself is available.

Of course, there are pneumatic, hydraulic and electrically powered tools available for use by divers and, to power such tools, equally autonomous power packs for deployment on the sea bed, but if the source of power is at the surface, power losses increase with depth of operation, and handling long hose assemblies becomes extremely difficult. Power packs solve this problem but impose other restrictions on the diving system. Generally, the diver uses hand tools of the types developed for surface use but modified to these special conditions, and he is capable of a sustained power output of about a quarter of a horsepower, (probably even only a half of that, but in order to be generous and to cater for the vast differences in conditions to be met, I have in fact chosen a quarter of a horsepower).

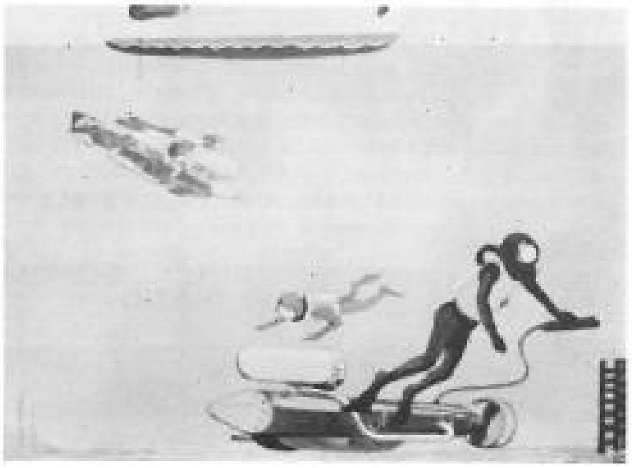
The simplest way to dive is always available and requires no equipment. One only has to swim to the desired place, take a breath and swim down. Simple refinements such as a mask and fins can be added, and a small boat adds to ones comfort and efficiency. This method has been exploited to about the human physiological limits by pearl divers who are reputed to work down to about 45 metres, and by Japanese Amas who, working in shallower waters, achieve 60 to 90 dives per day. They are paid very little, and if one takes these women divers as an example in their diving system, the cost per horsepower hour of their time on the bottom works out at about £5.

The next simplest form of diving is that of wearing an aqualung and minor accessories. The range of equipment that could be included with aqualung diving, and the resulting variation in cost, is so great that only the basic case is considered here. Except in the previous example of pearl divers in which the cost of a boat was included, the calculations for this and subsequent examples of diving systems do not include a boat or ship, but support ships



are included in submersible operations later. In this case, I have assumed a minimal semi-professional team, working a six to eight-hour day at a depth of about 10 metres. With a somewhat doubtful continuous power output of about a quarter of a horsepower, the cost per horsepower hour is about £10.

Standard diving needs little introduction and little qualification except to remark that its main use today is in cold or polluted waters where long hours of heavy work

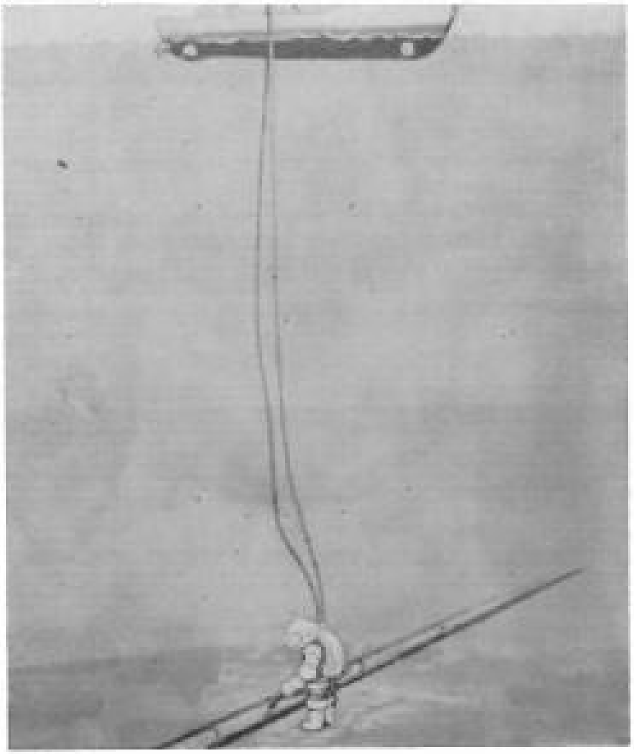


are required. A minimal team is once more considered and with it a long working day in water no deeper than about 10 metres. In this case the cost is about £20 per horsepower hour.

The technique of supplying the diver with mixed gases — either oxy/nitrogen or oxy/helium — from surface demand diving equipment is well-known, and the advantages are, in general terms, increased time on the bottom or shorter decompression schedules compared with when compressed air is used.

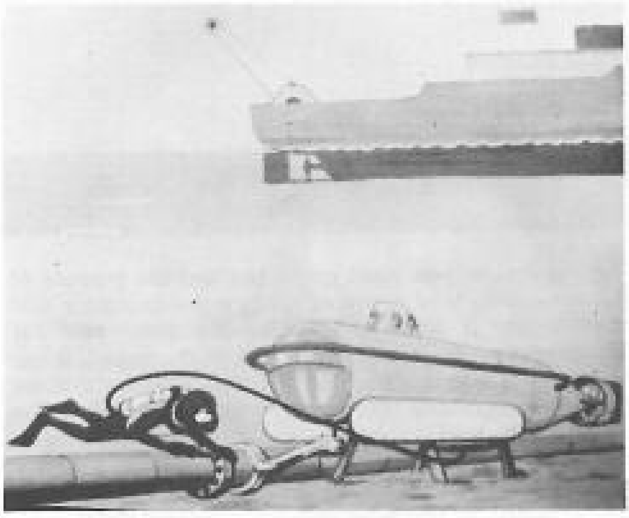
At greater depths — say, down to 80 metres — a much larger surface support team than in the earlier examples will be required. The system demands a high standard of operational procedure, reliability of equipment, advanced diver training and something more than the minimal team. Therefore as depth is increased, conveniently short decompression schedules necessitate a reduction in bottom time: repetitive dives and more divers are required for reasonable work outputs to be sustained. I am assuming the team and equipment necessary to achieve one hour's bottom time per day for a number of bounce dives to about 80 metres. The cost per horsepower hour will be about £1,200, but this is obviously greatly influenced by the exact system used. This is extremely expensive in terms of horsepower hour, and no doubt a more economical system could be devised, but I have chosen to exaggerate yet remain within the bounds of possibility, in order to accentuate the point of this example.

Again considering bounce diving to 80 metres with a total bottom time of one hour per day, if one dispenses with the S.D.D.E. system and instead supplies the diver with a fully mobile power source for his hand tools via a diver transport vehicle with autonomous breathing equipment, a dramatic change in the calculations is possible. If one assumes exactly the same basic costs per day per diving team and equipment and an added cost of £47 per day for a diver transport vehicle which, by the way, allows for a capital cost of £10,000 amortized over about eight years, and £2,000 per battery pack — with 50 cycles life in a battery pack of solar zinc cells — then the cost per horsepower hour can be reduced by a factor of eight on the previous one, which produces a final figure of £150 per horsepower hour.



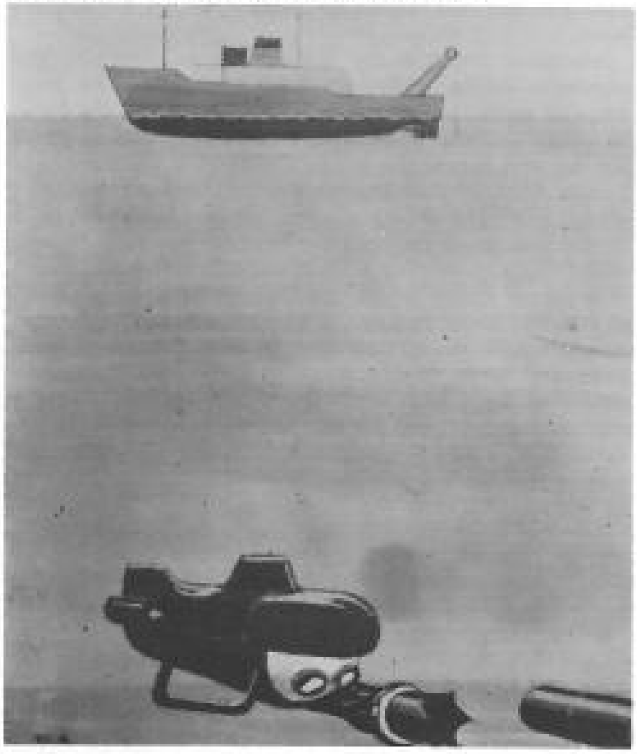
The armoured diving suit provides a special and interesting case: the diver remains at atmospheric pressure within the suit, with the result that the equipment and team can be deployed, and if necessary returned from the diving site, very quickly. Little support equipment is required other than a means of raising and lowering the suit, although operations in water approaching its maximum rated depth may well necessitate guidance systems to the work site. The most interesting aspect of this system is the speed of deployment and possible rates of descent and ascent with no decompression times, with the result that a small team can achieve a six-hour working day on the bottom, and if one assumes that only diver power is available, the cost would be about £300 per horsepower hour.

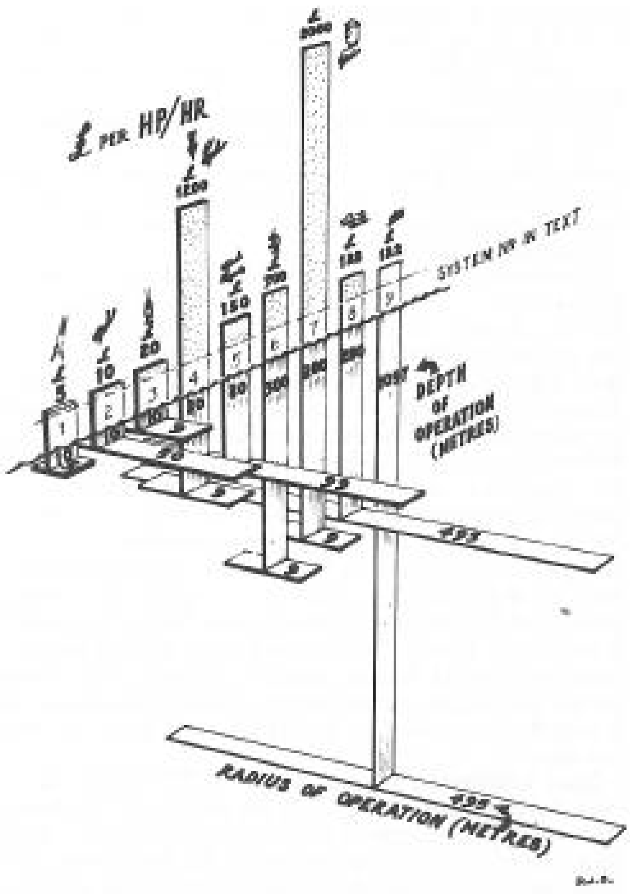
Saturation diving is the most advanced, complex and expensive diving system in these examples. The great range of costs for such systems is dependent on the depth of operation, the amount of underwater work required per day and hence, the size of the team. For this example I have assumed that the requirement is for a sustained presence at the diving site — which could well be a production platform in an offshore oil field — and something approaching a round-the-clock diving schedule in depths of about 260 metres. I accept "round-the-clock" as meaning about two two-hour sorties from the chamber complex each day. I have also assumed that no powered tools are being used and so we only have the power output of the divers themselves to consider. In this case, a cost of about £2,000 per horsepower hour would be the average. It could obviously be considerably more; it could also be considerably less.



A diver lock-out submersible provides a unique feature to diving operations: Only in this case can the diving supervisor, stand-by diver and working diver be within a few feet of each other during a deep dive. The diving control centre is on the bottom in a submersible and, with a good diver to supervise communications, work plans can be modified during the dive and the system becomes very flexible. The diver can be moved from site to site quickly and easily, but the greatest advantage is that power is available where it is required. One can assume that at least half the energy in the submersible's batteries is available for useful work, certainly in depths equivalent to those in the previous example — about 280 metres — and, theoretically, to the maximum operating depth of the submersible which is about 366 metres. The submersible can therefore perform work at a much higher rate than even the divers supplied with power tools. Ideally, if two divers work together from a Perry PC15 diver combination making one sortie per day there would be a total of about 36 horsepower hours on demand. At current quoted charter rates this produces a figure of about £128 per horsepower hour.

With the submersible alone divers are not involved and, although this makes an exception to the general theme of this paper, it is justified because, without divers — as with the armoured diving suits — the physiological problems are removed, and even greater flexibility of operation is achieved. If we consider the Pisces I, II and III family of submersibles, with depth ranges down to 1097 metres and 28 horsepower hours of stored energy available for work and an equal quantity for propulsion, manoeuvering and hotel load, at £122 per horsepower hour, the cost is less than for a diver lockout submersible system.





In conclusion, one must remember that the purpose of this necessarily brief review of diving and submersible cost effectiveness is only to consider the price paid for horsepower hours of work at the site on the seabed. It can be seen that with the more sophisticated or heavy systems the area over which the diver can work is usually quite limited, either by considerations of safety or tolerable umbilical length, whereas, due to the simplicity of the system, the free aqualung diver can move about at will and in safety, as long as he remains in shallow water.

Using a diver transport vehicle increases the bottom area over which a diver can move; the armoured diving suit can be walked around a work site, but if even relatively short distances need to be covered it is probably more economical to move the parent craft and to re-deploy the suit. The submersibles have far greater range, but it is assumed that they would move no further from the parent craft than the limit of their underwater communications system, which is up to 2,000 metres.

Lastly, although it has been shown that submersible systems are very cost effective in terms of power output, there are other equally important factors to consider if an appropriate system is to be chosen for a particular task. The dexterity of the diver is of great value, as was shown in the film that Henri Delauze showed you yesterday: obviously the diver was moving around in a very restricted area, climbing around on a B.O.P. stack, inserting himself in confined spaces and using his hands; examining closely a relatively inaccessible task. Thus, it is evident from the great variety of types of work and the differences in conditions surrounding these tasks, that every system so far successfully developed will continue to be needed.

Michael Burrow

Mike Burrow is Engineering Director of *DHB Construction Limited* — the Atmospheric Diving Suit Company — and Managing Director of *Underwater and Marine Equipment Limited (UMEL)*, which develops underwater apparatus for Government and Industry.

He has been concerned with underwater work for over 20 years, and has specialised in the development of survival and escape gear, commercial diving, self-propelled and towed manned vehicles, underwater habitats and oceanographic instrumentation.

His work in the early days and his support of organisations such as the *Society for Underwater Technology* place him in the ranks of the pioneers in the underwater field.

JIM

During the last 30 years, self-contained underwater breathing apparatus has opened up a new dimension in underwater work: instead of the two-dimensional world of the surface-supplied diver, today's diver is free of surface and seabed ties generally, and has ventured into the third dimension of mid-water. But how free is the commercial diver? He seldom works in mid-water and, in most cases, he is still dependent on the umbilical for survival, gas, warmth, communication and safety. Instead of diving from the surface he works out of a chamber. He cannot be free of the physiological problems of a complex decompression system, and he can never be free, however skilled and efficient he or his back-up may be, of that little bit of fear.

One cannot expect a man to work efficiently underwater if he has to expend a large proportion of his physical and mental powers purely on survival so, what we have tried to do is to "free" the working diver of these problems by filling the gap between the submersible vehicle and the ambient diver. Into this slot fits the atmospheric diving suit (the ADS), and our brand name for this suit is JIM.

It was decided that although the ultimate form of ADS was a suit that a man could wear, our first attempt should be to design a manipulator in which a man could work, a concept which has not changed during the past 250 years; the basic requirement is still that you protect the man from external pressure and allow him to use his arms and legs. In other words, an inside-out space suit.

By the mid-1930's several designs had been tried underwater, but only three types had been used for any real deep diving and, of these, two were restricted by a stiffening of the articulated joints at depth and by trim and stability complications. There are one or two of these suits still in use today, but mainly as observation chambers. The third type, the Peress suit, arrived a little too late on the scene and although by 1937 the British Navy had conducted satisfactory trials with it, they decided that their diving requirements could be met by standard equipment; from that date it was decided that diving was to be a physiological and not an engineering problem.

During our preliminary research into the history of atmospheric diving suits it became apparent that this Peress suit, with its unique hydraulic joint affording no metal-to-metal contact, had gone a long way to overcoming the main problem of joint stiffening and seizing up at depth.

By a series of coincidences, all within a week, we made contact with Mr. Peress and were lucky enough to obtain the original suit which had been dived to 500-odd feet in Loch Ness and which, with Jim Jarrett, had found the *Lusitania*. After two or three months of boiling in paint remover, we managed to get it working again. In fact it was in marvellous condition: the bottles even had oxygen in them and the seals were perfect.

Working with this and with bio-astronautical data from the Royal Aircraft Establishment, we were able to design a configuration that was acceptable to the 99 percentile man. The original joints were tested in our pressure pots and this resulted in a new upside-down, inside-out, about-face joint, which overcame the inherent problems of articulation under higher water pressure differentials.

Visibility: The prime requirement for working is good visibility from the suit and although, as with like submersibles or ambient divers, we cannot do much about bad water visibility, turbid conditions can certainly be improved by intelligent lighting, clear-view containers, image intensifiers and perhaps very high definition sonar. JIM, as he is at the moment, cannot see his feet — standard divers seldom bother to look and divers with fins do not have to — during initial tank trials we fitted him with a foot-viewing mirror, but this has since been discarded.

JIM cannot get his hands very close to his face and although we have had no difficulty so far with working of small complex tasks in turbid water, we are experimenting with various types of attached lighting units. We are also

JIM during trials from *H.M.S. Reclaim*

looking into the use of "finger tip eyeballs" — coherent fibre optic bundles mounted on the hands, and a small work area illuminated by a light guide combined with the coherent bundle. This is viewed by the operator through a monocular and, to a certain extent, helps to overcome the lack of touch and feedback that is inherent with manipulators. The visibility problem is rather akin to the one of working in a current; JIM is essentially a deep diving animal and, luckily, in the depths at which he pays-off, the visibility is normally at a workable level. Normal vision through the present four ports in the lid is excellent and the operator very soon gets used to any aberration caused by the curvature of the Plexiglass.

Mobility: The suit has proved to be extremely mobile over the sea beds so far worked: gradients of about 30° have been climbed and quick descents of such slopes undertaken, normally by a form of abseiling. Although few speed trials have been done, a sustained walking speed of well over a knot seems possible on a reasonable sea bed.

After hilarious experiments, JIM has climbed ladders and has found it possible to hang on to a rung by his toes and to lean back into the near horizontal; it is actually possible to walk sideways along a tight rope leaning either way in the near horizontal! But, an obvious disadvantage in comparison with the standard, helmeted diver is JIM's inability to spindle up and take a leap over an object, however, this is being overcome in the short-term by using inflatable back-pack inserts. One does not fall over in the suit and flail around on the bottom; the operator lies on his face or back and gets up again by basic pelvic movements within the suit, but infact the only way that he could fall over would be if the operator fell asleep in the suit, in which case, he would gradually topple over — forwards, most probably.

The free ascent rate, accomplished by dumping either the front or back 100lbs. weights, is 100ft. a minute. With half or all the ballast gone, the floatation attitude on the surface is extremely good, in fact we have even seen one of the operators doing the breast stroke!

Dexterity: An inexperienced operator using the suit for the first time will undoubtedly soon realise that he is wearing a submersible and not a diving suit, but after a couple of hours most operators are completely mobile and ready to try manual tasks.

Under the heading of "manipulator" we group the units that go together to form the ability to carry out a manual task. So far we have designed three basic types of manipulator or prime mover: a pretty fair fascimile of a human hand, with a swinging thumb; various types of straight-forward pincer, and a rotating shaft. On to these prime movers, one can quickly attach virtually any tool or adaptor by means of a bayonet clip. It is very easy to make up these adaptors out of old gas pipes, with a hacksaw, vice and welding torch; in other words, we end up being blacksmiths!

During the summer we have had two of the ADS working together doing moderately heavy engineering work — moving pipe flanges around, and lifting bolts weighing in the region of 70/80lbs., and nuts weighing about 20lbs., and placing them with great accuracy into the pipe flanges. We have gone back to the age-old system of using a goat's bladder or goatskin as a lifting bag, with a rather neat little control system: one JIM stands off with the control system in his hand, pulling the lever up to make the bag ascend, and down to make it descend. Making up various sets of tongs has proved very useful, in fact one JIM has hooked a bag on to another JIM, blown him up and pushed him over the pipeline and let him down again.

Propulsion: It was never intended that JIM should play the roll of a horizontally roving submersible, and obviously it would be wrong to deploy him in a pipeline or bottom surveying role. However, there do not appear to be any difficulties in deploying him as a passenger riding side-saddle or astride a submersible, either dry or wet. I suppose we will one day arrive at the ultimate of the completely free-roving autonomous submarine — submersible vehicle — at perhaps 1000/1500ft., and of cruising around doing pipeline surveys in sections; not relying on surface support, and remaining at sea for two or three weeks on end. Here, I think, JIM would come into its own inasmuch as we could use lock-in and lock-off systems — and we would not need very large lock-out systems either: the ADS might be fitted with an adaptor ring which would allow just the lid section to be locked on, the lock then being just large enough to take the opened lid.

The use of wet submersibles is attractive; they might carry two JIMs at a survey speed over the seabed and the capital expenditure would certainly be less than that of a pressurised submersible with a complex manipulator. This type of vehicle, or even a bathy-buggy, could act as transport and workbase for JIM, but for individual propulsion one immediately thinks of a form of rocket belt enabling a degree of vertical operation.

Hovering over the owners of large off-shore platforms is the problem of periodic inspection of the underwater structures the complexity of which, with numbers of cross-members and braces, could prove difficult for divers on umbilicals, or for remote-controlled vehicles with cables. However, an adapted version of JIM that is capable of inspection and non-destructive testing could be developed, perhaps along the lines of a magnetic traction unit allowing the ADS to traverse horizontal or vertical members in any attitude.

Into all these activities creep the weak links of navigation, communication and location. But, having put man back into a more natural state within the ADS — at atmospheric pressure, warm and without the physiological and psychological stress — he will be able to give that little extra effort to looking after the operation of navigation, location and communication instruments integrated in the suit.

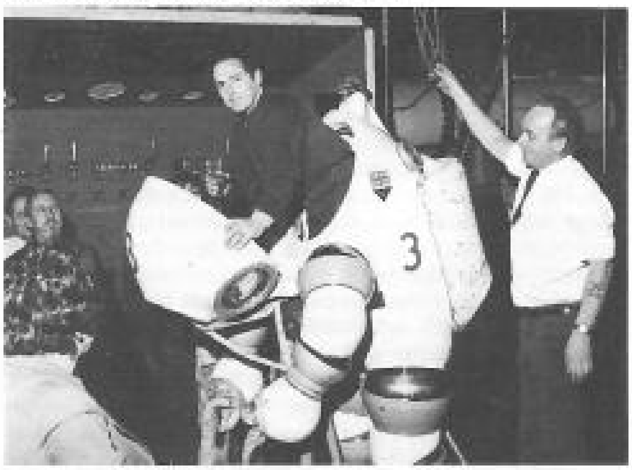
We have experienced the same problems with navigation and location underwater as did the standard diver when working some way from his shot rope, or as divers now working from chambers. So far trials made with a single transponder system — by putting down a datum transponder on the seabed and another on JIM, and by tracking the two together using a digital sonar — have worked out extremely well.

Of course there are plenty of ways in which we could improve the instrumentation presentation: by using a form of head-up system, as they do in aircraft, with which one could project a micro-film of work sites and, eventually, an up-dated system with which JIM is told exactly where he is on the bottom relative to the datum point or work site.

At the moment we are using a very light and flexible telephone cable, but although we are not psychologically quite ready for the idea of complete autonomy, we will certainly rid ourselves of this cable eventually. Of course, if we want three-way open communications, as we have now between diver-diver-surface, we will have to pursue the idea of the multi-frequency acoustic system.

The Future: We do not visualise any radical changes in the deep diving ADS, but in the future he will certainly have a personal propulsion unit. At the moment we achieve variable buoyancy control with an inflatable system, but we could well end up with something like a magnetic traction chest pack which would allow the suit to assume any attitude, and of course we have thought along the lines of a rocket belt.

JIM could have a third arm with a grasper, and might even have four legs/two operators, and look rather like a pantomine horse — it really does not matter as long as it can do the job. But we will have to put in a "get-you-up-and-keep-you-afloat" system, with an inflatable annulus, acoustic and radio beacons — rather like the space capsule recovery system.



Mike Humphrey – Designer of JIM – ten minutes after having been to 1000 ft. – A world record dive in an atmospheric diving suit.

Apart from emergency requirements — deep salvage, for instance — there is no immediate commercial need for diving deeper than 1,500ft. This limit could be extended over the next few years, but much more experience of structures in existing water depths has to be gained before this becomes a commercial off-shore working depth. It really now becomes a question, not of how deep man will be able to work, but of how deep he will be required to work.

The most encouraging thing about atmospheric diving is that although the suit and its fittings might grow in complexity to meet increases in depth and duration, the basic system will not become more bulky or weighty, as does the equipment needed to back-up ambient diving, nor will the cost increase disproportionately. One also has the consolation that physiological problems do not escalate as the ADS goes deeper for longer spells of work.

At the moment our experiments with joints lead us to believe that there is no design limitation as to depth. However, finding suitable materials will be the problem in future, and we will have to look very hard at composites, alloys, ceramics and things like that. The problems remaining are healthy engineering ones which, it is to be hoped, will be overcome by ingenuity, good engineering practice and seamanship.

Since this report was presented, five operators at the Admiralty Underwater Weapons Establishment, Portland, have dived to 1,000ft.

Nic Flemming: I would like to comment on Mike's statement that it takes two hours to become proficient with JIM: I saw a very large geologist climb into JIM for the first time in the tank and within a few minutes he was able to move around without being too clumsy; he had difficulty in picking up a nut and bolt from the floor, but he got the basic feel of it very quickly.

Now, do we have any questions from the floor for Dick Tuson and Mike Borrow?

Question time

Question: I would like to ask Dr. Flemming to expand on his comment that decompression metres are unreliable on multiple dives.

Nic Flemming: Obviously, I cannot quote specific instruments without getting into trouble, but the simple fact is that we do not have a completely reliable theory of multiple decompression with a completely reliable formula that can carry over the loading from one dive to the next. It stands to reason, therefore, that we cannot make a machine that gives us a reliable formula unless it were capable of monitoring the diver himself.

Questioner again: But for multiple diving in industry don't they use decompression meters that work on empirical data?

Nic Flemming: I don't want to get involved in mathematics but the simple fact is that however much empirical data is available, you can still go wrong; we don't have the right formula, so the meters must work on approximations — all of which will work for some areas with some types of divers and give dangerous answers in others.

Question: Regarding the question of monitoring the diver's blood condition directly to determine decompression: is there any technique for measuring, say, the CO_2 content?

Nic Flemming: There are some experts in the audience who can tell you how near this is to becoming possible, perhaps by measuring heart rates, or by trying to detect bubbles accoustically, and so on. I suggest you talk to Dr. Val Hempleman, as this is definitely not my field.

Question: Dr. Flemming, I am rather concerned by the impression you gave that none of the devices currently available to divers can give an accurate representation of the decompression state of the diver — which may, to a great extent, be true — and that the diver should not therefore use any decompression meter, but should simply rely on hoping that he will be OK. If, based on everything we know about decompression, we can produce a simple device that can give us 95-98 per cent safety, then, surely, this is one hell of a lot better than nothing. I think this was not pressed home sufficiently, and I would appreciate your elaboration.

Nic Flemming: This is a good point, but remember that I was talking about 20-25 years hence. Yes, of course the decompression meters that are being developed are very ingenious, and the best theories are being put into them but, nevertheless, they can be baffled by certain sequences of repetitive diving into giving an answer that departs significantly from accepted Tables. From what I know, I feel that the area of multiple dive schedules is still largely obscure and should be treated cautiously. Certainly, the diver should not just hope that he is O.K.; he should always work to the published decompression Tables and published repeat dive Tables, which are much safer than decompression meters.

Surg. Comdr. John Rawlins, O.B.E., M.A., R.N.

Surgeon-Commodore John Rawlins is Director of Health and Research (Naval).

In 1955 he was awarded the MBE for his work on protective helmets while with the RAF Institute of Aviation Medicine and in the same year began work on the problem of escape from sinking aircraft.

In 1961 he was awarded the OBE for this work which culminated in the introduction into Royal Navy aircraft of an automatic underwater escape system.

Two years ago he was awarded the Gilbert Blane Medal of the Royal College of Surgeons for his work on the problem of cold in diving.

Man in The Deep - Part II

It was a great honour to be invited to Chair a panel of such distinguished and internationally recognised diving physiologists and I accepted without hesitation. The task of Chairman is not an onerous one; it has been likened to that of a procurer, namely to introduce the parties, see to the arrangements and then take no further part in the action. But when I received a programme just recently I saw to my alarm that I was also billed to introduce this session on Man in the Deep with a talk on "The Survival of Man in the Extremes".

Survival conjures up a picture of a man marooned on a desert island, or adrift in a small boat, or lost in the Arctic waste; it is the business of staying alive after the equipment or the organization has failed. But, in deep diving, when there is a failure of either the man, his equipment, or organization, his survival is limited to a matter of minutes at the outside and hardly forms a subject for a 15-minute presentation. Indeed, the whole business of diving, whether shallow or deep, is of avoiding the survival situation.

As for embracing the presentations of the other speakers: how do you bring together Swallowable Radio Transmitters (a somewhat uneuphonious term) and How to Dive to 2,000ft. and Return Within the Hour? It is impossible. So, in the face of these imponderables I propose to look at some of the stress-producing problems of deep diving; to consider their interactions and their physiological implications, and then to give some thought to the way ahead.

Owing to the success of the United States Navy in planning working dives to 1,000ft., I think we are all confident that in the future we should be able to dive within the whole region of the Continental Shelf; but the problems of deep diving are basically those of the first 50 or 100ft.: of pressure, respiratory gases, temperature, visibility, psychological stress.

First of all, let us look at the effects of pressure. We know from observation from deep submersibles that quite complex creatures exist in the very depths of the ocean and this would indicate that pressure does not have too much effect on biological cells, and I doubt very much that the effect on mammalian and human cells differs greatly from that of other biological species. But pressure is important when considering creatures with gas-containing cavities, such as man, diving mammals, and indeed fish with swim bladders, because then you get volume changes and the appearance of pressure differentials and physical changes in gases themselves, which brings me to the subject of respiratory gases.

As you all know, pressure affects the behaviour of the respiratory gases as far as the physiology is concerned, so that oxygen becomes toxic as we get deeper, and nitrogen narcosis may be detected at depths as shallow as 50ft., and by about 300ft. most of us are rendered incompetent either physically and/or mentally. Carbon dioxide under pressure does not in itself affect us physiologically, but since the significant partial pressure of carbon dioxide remains the same, when one is diving at great depths and using large volumes of gas, the significant proportion of carbon dioxide is very small and therefore extremely difficult to eliminate, which we have often found to our cost. I might add that pressure increases the density of a gas so that at 600ft. a helium/oxygen mixture is four times as dense as air at the surface, and this doubles the airway resistance which, in turn, increases the effort of breathing, increases oxygen consumption and depletes our oxygen reserves.

Visibility at 1,000ft. is usually zero, but then we can get zero visibility in shallow water where there is much suspended matter — for example, in a harbour like Portsmouth, or a flooded coal mine — and visibility contributes very largely to psychological stress. However, the human physiology is a flexible one and is capable of adaptation and acclimatisation, and is responsive to training. For example, one can work very efficiently in conditions of zero visibility, probably the most classic case being that of the diver Walker who, over a period of five years, worked in nil visibility beneath the foundations of Winchester Cathedral and to whom that edifice probably owes more than to anyone else.

Temperature at 1,000ft. is pretty constant at between two and four degrees Centigrade, say 35/40 degrees Fahrenheit. The reason I want to talk about temperature is, partly because it is my personal interest, partly because it illustrates very well the interaction between different problems of depth, and partly as an example of the hazards that are superimposed on man at depth because of his diving system — it does not have an effect as such on diving mammals.

As a response to cold, shivering is significant to my talk because it has a metabolic cost; it is the primary method of thermogenesis in a human and it costs oxygen, increases carbon dioxide output and increases ventilation. It is significant in the case of the Ama who dives naked throughout the summer to depths of between 60 and 80ft. She demonstrates remarkable physiological adaptation to cold: she can tolerate a lower skin temperature than you or I without shivering. She can also tolerate a lower deep body temperature: this is very important because if she were to shiver she would lose her vital oxygen supply and so shorten her breath-hold dive. Indeed, in the winter she pays some lip-service to insulation by wearing an all-enveloping cotton garment which, by trapping a layer of water somewhere near the skin, may have some effect, but is not an efficient method of insulation.

However, insulation at its best won't get us very far. In an attempt to find out whether by insulation alone one can prevent heat loss, a man wore a total of one inch thicknesses of foam neoprene, and was unable to maintain his deep body temperature in 40°F water. One has to do something more; one has to add heat to replace that which has been lost: either by an electrically heated undersuit, by a closed-circuit warm water circulating suit similar to the cold water cooling suit used by astronauts, or by using the free-flooding warm water suit now largely used by commercial divers, and available off-the-shelf.

However, as you all know, deep diving requires a helium/oxygen atmosphere, and helium has six times the thermal conductivity and six times the heat capacity of air. Thermal conductivity is not affected by pressure, but density is, and hence heat transfer. Now, I have already said that at 600ft. the density of a helium/oxygen mixture is four times that of air at the surface; at 1,000ft. or 40°F, the increase in density and the thermal properties of the gases raises the convective conductance from the skin — that is, the way in which the surface loses heat to a gas — to about 30 times that of air at the surface. These facts not only dictate that the atmosphere in a submerged habitat, PTC, lockout chamber or submersible, must approximate that of the preferred mean skin temperature of 93°F, it also means that although the diver in water may be wearing an efficient heated suit, he will still lose heat steadily unless his gas supply is also heated. During experiments in the U.S.A. one of our subjects breathing 43°F oxy/helium at 860ft. lost 3°F deep body temperature in two hours, and that is very serious. Another subject produced such a copious flow of secretion from his upper respiratory tract that he had to spit out his mouthpiece, and in an actual dive this would of course have proved fatal.

For man to operate at great depth it is essential to heat both the skin and the gas supply, but this necessary equipment adds to the diver's load. How deep is a man going to be able to work effectively as his equipment becomes increasingly complex? Man functions best in an optimum environment, which is why we have centrally heated, pressurised aircraft and, some of us, air-conditioned cars. I believe that in order to exploit the depths, man will need to take his environment with him in the form of sophisticated submersibles with great manoeuverability, navigational efficiency, manipulative skill and strength.

I give you this thought: Man achieves his greatest domination over Nature when he uses his ingenuity to design and build machines. Man has long shown that he has the strength to move mountains — although not always the faith. Bulldozers have proved a great substitute for the sweat of man's brow, and they are a good deal easier to come by than Faith . . .

Ama, — winter dress. (The bottle on her back is for taking back samples).
Photo: Prof. Suk Ki Hong

Ama diving for abalone – summer.

Photo: Prof. Suk Ki Hong

Maximal insulation. Diver wearing 4 x ¼in. foamed neoprene wet-suits was unable to maintain his body temperature in water at 4°C. (The wires are leads to skin thermocouples).
Photo: U.S. Nav. Med. Res. Inst.

Closed circuit warm-water heated undersuit.

Photo: Nav. Med. Res. Inst.

Dr. Joseph B. MacInnis

Dr. Joseph B. MacInnis of Canada has devoted the past 10 years to the study of men living and working in the sea, and in 1968 formed a consulting firm, *Undersea Research Ltd.* in Toronto.

He holds, or has held, consulting contracts with the *US Navy*, *Oceans Systems Inc.*, the *Canadian Government*, *Foundation-Comex Ltd.*, *Perry Oceanographics* the *Smithsonian Institute* and *Oceaneering International Inc.*

Under Arctic ice

Thank you Mr. Chairman; I must say I enjoyed your impassioned speech. More especially because you have now solved one of our critical life support problems in the Arctic. It seems to me that our next trip should include at least a dozen of those lovely Ama divers. Certainly their companionship would do much to ameliorate the post-dive shivering that occurs!

It is a great pleasure for me to come across the ocean that separates my country from yours. As a rather neophite Arctic explorer I feel as though I'm coming home — not, I hasten to add, because of the weather, but because a great deal of the early northern exploration in my country was done by people from this small island. As a matter of fact, the search for the fabled North West Passage to the Pole was conducted from many small ships with origins on your coast. In a few days time I am going to the Scott Polar Research Institute in Cambridge to talk about Polar exploration. It is the finest institute of its kind in the world.

Today, I would like to tell you a little about our work in the high Arctic. First of all, I want to tell you why we go to this ungodly, inhospitable place. Then I would like to take you on a tour of our last expedition in Resolute Bay, where we constructed the world's first undersea polar station.

If we were to go and take a bird's eye view of the globe we would find that on both ends of it there is damned cold water! I am from a country which has a good portion of it — we have a million square miles of cold water in the northern part of Canada, stretching from Hudson Bay, right up to Alert, only 450 miles from the North Pole. Our expeditions have gone to the base of this northern group of islands. Why do we go there, and what do we see?

I will start with the last first. We see an unusual collection of animals. Little is known about their underwater behaviour; most of them have not revealed any of those secrets to us. We also see an incredibly inhospitable country. It must indeed be the most inhospitable part of the planet, because when you combine the difficulty of operating in this endless horizon of ice and snow with the problems of operating in cold water, the combination of the two is a hostile package which cannot be found anywhere else. We go because it is one of the greatest technological challenges of our time.

On our first expedition in 1970, we put a camp site on the shore of Resolute Bay, 600 miles north of the Arctic Circle; temperature about what you have here these days: 45/50°F and about 28/30°F in the water. There were only four of us then. We were interested in making preliminary surveys of Arctic marine biology and geology, and of course we documented everything, feeling that nobody would really believe what we had seen or what we had to say.

Biologically, we saw an impressive amount of life for the remoteness of the site, and were very taken with the ice above us which had unusual characteristics — flutings that had been created by wind and the sea; and a sharpness that could tear a suit.

Dr. Joseph B. MacInnis

We returned again in the following year. It was a very cold trip: the sun was at the peak of its low climb in February. We experienced temperatures on land of 50° below zero. We found that to get into the water we had to cut a hole through six feet of ice. Once this was done, we established a small shed over the hole and commenced 10 days of activity. Again, we were interested in human performance, equipment performance, a survey of marine biology and marine geology.

Going to work down the ladder, we wore an extraordinary amount of weight — 50lbs. — the first 25lbs. to get us down and the second 25lbs. to overcome our reluctance! It was mighty dark down there, but even with the low level of the sun on the horizon, an incredible amount of ambient light came through the ice. Ice having roughly the same transmission characteristics as water, it is the snow on the surface that makes it dark. We carried a lot of hand lights, saw some wild and strange things, and made incredible recordings of the sounds of the Arctic sea. Although I am not a biologist, I certainly understand now why some of you have become biologists: it is a fascinating pursuit, especially in this remote spot where we found so much life.

I am going to interrupt the flow of my talk by telling you a little about another reason for my extreme interest in the Arctic. I am very sympathetic with some of the views that we heard yesterday and today about the preservation of the sea, and about the aesthetic qualities of the sea. I selected the Arctic because it is, in a sense, our last wide-open frontier in the ocean. We have come to appreciate the kind of life that waits for us in the Arctic and to realise that we have a perhaps a final chance to preserve one of the last open ocean areas.

Last March we used helicopters to fly biologists, and two of us who were diving, out over the sea to look for the

Bowhead and Beluga whales, in Alaska. High above the ice we could look down and see the 'open leads' between the new and old ice. We could see eider ducks and bearded seals and we knew we were looking at a part of the world about which man knows very little. Thirty miles offshore we saw our first whales — magnificent, white, Belugas 20ft. long, weighing 1,000/2,000lbs. and just elegant in the water.

One sad thing about man's activity in the Polar Sea is that in the 300 years prior to 1914, the giant Greenland whale was almost eliminated. However, we saw them from the helicopter as they made their northern migration: 60ft. long, the first third of which is all mouth, the size of a small garage. By an extraordinary circumstance, I was in the plankton-laden water with a group of White whales when one of these big ones came by; it was like waking up in a bed and looking over and seeing a black asphalt tennis court next to you.

To get back to the technological reasons for going to the Arctic, let us come up to November 1972 when we stood at an airport in Southern Canada with an Hercules ready to fly 30,000lbs. of gear to Resolute Bay. (I would just like to mention here that all this work is done through a non-profit research foundation which was established in 1969. There is no direct government funding, but we have been provided with excellent logistics, and a great many have loaned us equipment for evaluation. The expedition was mounted on small funds and a lot of energy and support from a lot of people).

We built a small ice camp, again on the surface of Resolute Bay, but this time it was in November and there was no sun at all. The temperature was 35°F below zero, and there was about three or four feet of ice. Again, our interests were in exploring the operational, logistic problems of scientific diving in the far north. To support this we built a small manned station: *Subigloo.*

The idea behind Subigloo was to provide a small safety refuge that offered maximum visibility, did not require a lot of equipment, and which could be built by divers for Polar diving. We built, and tested Subigloo several times in Southern Canada: it comes apart like a large Meccano set, the two hemi-spheres separating at the equator and cradling into each other. This makes it possible to transport it in an aircraft. Once the ballast has been emplaced on the ocean floor, we can build Subigloo in a matter of hours.

As far as possible, we want to avoid any trouble while working under the ice so, on our first expedition, apart from keeping our diving to a modest 40ft. maximum depth (we plan to work deeper on subsequent expeditions), we established four portable refuge telephone booths — *"Sea-Shells"* — in the general area where we were working: they weigh only 50lbs. without ballast, and can easily be rolled into the 4 x 4ft. holes that we cut in the ice.

We also took with us a completely self-contained closed-circuit television, and recorded our work underwater. Since we were analysing human performance, Dr. Berger Anderson studied us at work in constructing the habitat.

The expedition's findings are being published in a series of technical volumes. So far, we have produced about 500 pages on subjects including physiology, biology and geology. We realise that we have, literally, just scratched the surface of the ice: there is so much to learn in this part of the world. It is also an aesthetic experience. One cannot back away from the fact that we are looking straight down the throat of raw adventure.

The Arctic, as you probably know, has a very delicately balanced eco-system. Any pollution stress imposed on this incredible ocean has far-reaching and long-reaching consequences. There are some estimates of tens of millions of barrels of oil in the Arctic islands and we know that we are astride a double-edged sword: an oil spill in the Arctic Ocean could be a disaster.

There is a lot to learn and we have only just begun. We have to study the whole constellation of equipment performance and human performance, and to synthesise these findings in such a way that when we finally walk on those continental shelves, we don't trample, but tread very carefully.

John Rawlins: Thank you Joe MacInnis for a superb presentation, beautiful pictures, and delightful delivery.

We now continue this Session with a report by Dr. Stuart MacKay. Joe was saying that he wishes he were a biologist; Stuart MacKay is a Professor of Biology and a Professor of Surgery, which must be a unique combination.

Dr. Stuart MacKay

Dr. R. Stuart Mackay has held professorships in the health, physical and biological sciences at the University of California at Berkeley, and at San Francisco, Boston University and Boston University Medical School, and Visiting Professorships at Stockholm and Cairo.

He has also been a member of two committees of the USA National Research Council and was Senior Scientist on the Galapagos International Scientific Project.

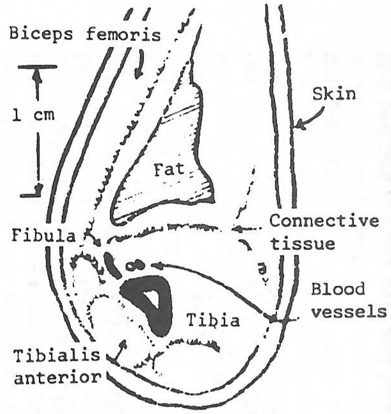
Presently, he is Professor of Biology and Professor of Surgery (Medical Engineering). He has dived throughout the world.

Ultrasonics and the diver

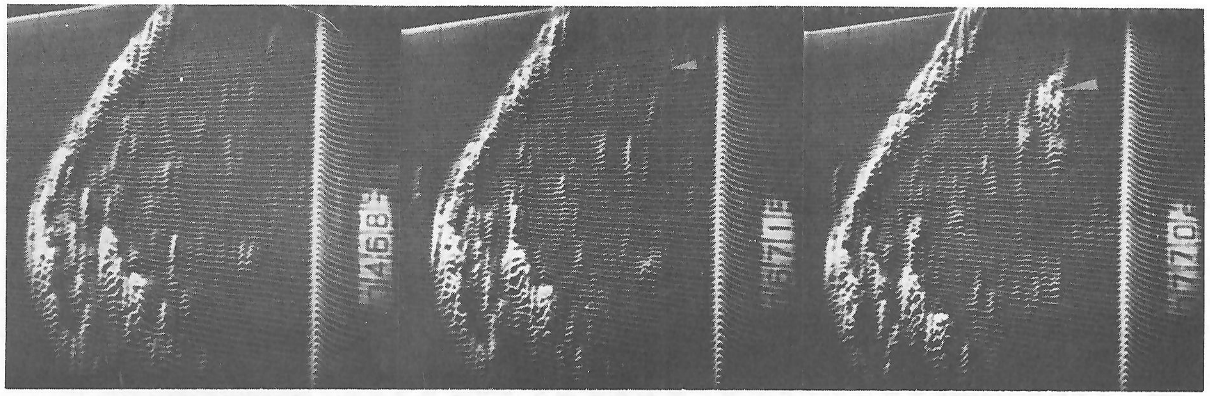
I am going to talk about various systems for monitoring the diver and other animals. Really, this will divide itself into two parts: using ultrasonic methods, and some of the techniques involved in using radio transmitters.

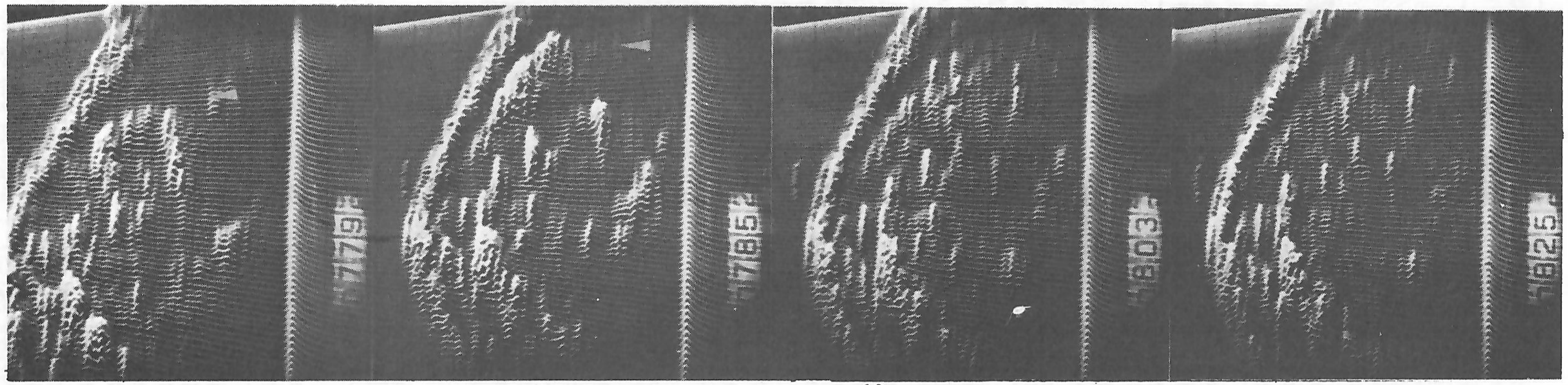
First of all I am going to show you the bubbles of decompression sickness. How am I going to do this? The answer is — by using sound waves. In a system similar to sonar or echo ranging, a "click" sound is sent out, for example, to the neck. Here these sound waves propogate themselves and from the various interfaces the echoes return, are picked up and displayed as a cross-section on a television screen. By this process of "clicking" the scan a complete image of the neck is built up: the spinal tract, vocal cords, various veins and arteries. It looks rather like a person who has been guillotined. (Incidentally, the frequency of the sound waves that are used to build up such an image is more or less the same as the dolphins use in their sonar system so, perhaps this is actually the impression a dolphin has of us).

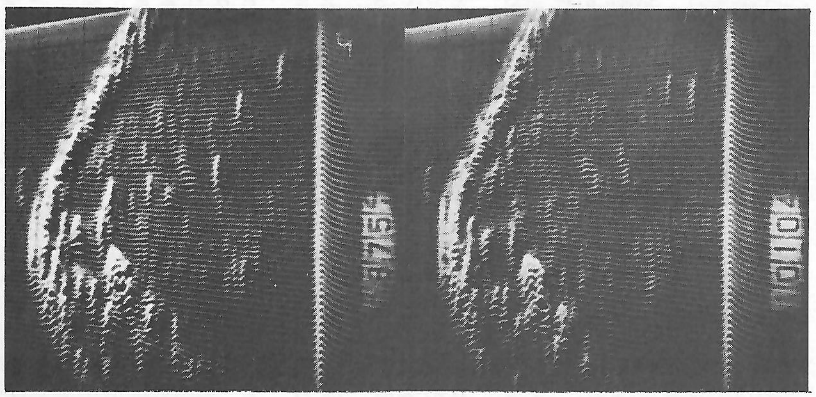
An interface between a solid and a gas is an excellent



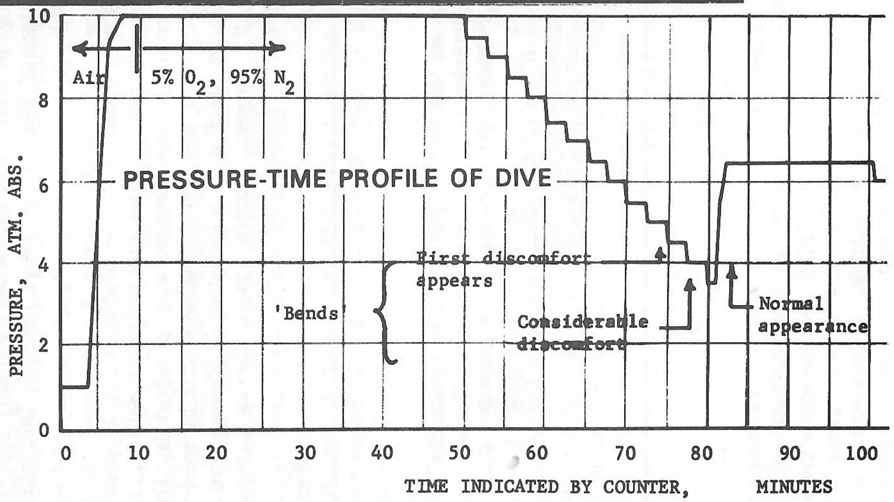
Gross Anatomy of Leg







'BENDS' DEVELOPMENT IN GUINEA PIG LEG



reflector of sound waves and it therefore follows that we can quite easily observe decompression bubbles, even as small as 1 micron (one thousandth of a millimetre). We can look at them; watch where they form; measure their size as they grow and collapse, and influence their size by controlling the ambient pressure. We can actually control the ascent of a subject subjected to high pressure by ultrasonic observation alone, without any recourse to a Table. We have demonstrated this.

Dr. MacKay then presented a short film on ultrasonic equipment, and continued as follows.

There are several things that can now be said: First of all, there is no question that there really are bubbles involved in decompression sickness and, furthermore, there are such things as "silent" bubbles; you can see them. (Ref: *Aerospace Medicine*, Vol.45, pages 473-478, May 1974). We can also confirm that bubbles do form first in the blood in fatty tissue. I might add one interesting point: I am quite certain that these intensities and frequencies of sound waves have no influence on the formation of bubbles, but I am equally convinced that a decompressing diver suddenly hit with an intense low frequency sonar beam could immediately be subjected to the bends. It would be a nice little experiment to try sometime! Let me reiterate this by giving the example of a leg — an interesting spot because it contains such a variety of tissue types: fat, muscle, blood, bone, etc. If one looks into the leg — and one does not necessarily have to have a scanning device to be able to do this, an ultrasonic transducer with a fan-shaped beam that continuously monitors the whole cross-section of the leg would do — and watch for the first bubble to form, and then limit the ascent rate by limiting the size of this bubble to a critical threshold level, one can successfully produce decompression without the use of the Tables.

I would just like to leave you with a charming thought in connection with these matters. Maybe it is by using ultrasound that a mother dolphin knows when her baby has to be burped. You see, if she senses gas bubbles in her baby then she can go ram him with her rostrum. Maybe the social and maternal life of dolphins depends crucially on these matters!

I would now like to change the subject totally, and to tell you about a whole series of tests based on the use of telemetry. It is a fact that radio waves travel through fresh water very well indeed, and through salt water sufficiently well to be useful. It is also true that as a matter of routine we use small radio transmitters (about the size of an aspirin tablet) to monitor all sorts of physiological functions in humans and in animals, so these same radio transmitters can be applied to free-swimming divers.

It is always true that the use of radio transmitters interferes slightly with the subject's activities, whether he be on land, in the water, or going between the two, so I would like to tell you a little about bio-nautical telemetry.

I swallowed one of the first-ever of the ingestible radio transmitters. It sat in my small intestine continuously monitoring core temperature and peristaltic activity; it was capable, even in those days, of monitoring two separate variables and of transmitting continuous information on both. Usually, if you swallow one of these transmitters it appears in the usual way, still transmitting, the next day. Hundreds have passed through thousands of people and, thus far, none has ever gotten "hung up"! But sometimes we wish to extend experiments further and with certain diets it is possible to keep the transmitter inside yourself for about five days. You can also do something else which, although it sounds disgusting, is remarkably comfortable. You can attach one end of a thread to the back of a transmitter and the other end to a tooth. In answer to your next question: You cut the thread. And in answer to your next question: No, it balls-up and comes out as a unit!

We do experiments routinely on humans, but I think it would be more fun if I talk about some of the other animals. In this example, we wanted to know more about the temperature regulation of dolphins; more about the feed-back mechanisms involved. So, I fed a dolphin with a dead fish that had a radio transmitter stuck in its gill. This particular dolphin was very nice: she did not chew her fish so it was possible to monitor her core temperature continuously as she went about her business swimming freely. The alternative to measuring core temperature in this way is to pick the animal up on a stretcher, put it on the side of the tank and shove a thermometer up its rear end every five minutes or hour, depending upon what information one is interested in obtaining. But a dolphin's temperature regulator does not work very well when the animal is in the air. The dolphin's temperature is constant, rather like yours: if you think you are sick the doctor will take your temperature. Actually, there is a rhythm of temperature and the same is true of dolphins; the temperature cycles in the 24-hour period.

To study any interacting system is to disturb it slightly and find out what transient results: this is a way of studying biological, electrical and social systems, etc. So, we decided to disturb the system by introducing a sudden change in temperature. We simply took the dolphin from a tank at one temperature and placed her in a tank at a slightly different temperature and, as she swam around, so we monitored her temperature continuously.

As a result of our monitoring we were able to establish that the dolphin has quite a stiff regulator: there was a transient change in temperature, but this was returned within approximately an hour. From a careful analysis of such a temperature curve, one can get an idea of what must be going on inside the dolphin to have produced this transient; the point of all this being that only by being able to monitor the animal without disturbing it, are we able to make such an analysis.

Besides such controlled experiments, we also go out and do fieldwork. On one occasion I went to the Galapagos to study the only lizard in the world that enters the ocean to feed. It is a cold-blooded animal that has to deal with the cool Humbolt current; it does not go out very far — I think it is afraid of sharks.

In this particular case, a small external radio transmitter was placed at the base of the animal's tail so that whatever it was doing, whether crawling over land or swimming underwater, it would be possible to keep track of its temperature. Incidentally, do realise that the only way that this cold-blooded animal can regulate its temperature is by going in and out of the sun, in the lava crevices.

The usual method of studying such an animal is to go out and catch one every hour and put a thermometer up its rear end. After a few hours of this it doesn't care what its temperature is; all it wants to do it to get away from the biologist. Yes, it is very important that the thermal activity pattern is not disturbed.

Of course, we are not only interested in monitoring temperature; we have monitored human divers swimming around in salt water, with a little radio transmitter about the size of my thumb conveying a signal that is reproduced on an electro-cardiagram.

In some cases we convey signals ultrasonically, but there are many instances when we prefer to use radio transmitters through the water. We have produced electrocardiagrams of fish; in this case one can see the respiratory movements of the fish, and we have sometimes noticed a strange snychrony between heartbeat and respiration — a matter to which we have devoted some study. Some of my students have studied fish using radio transmitters. All I am saying is that there are many variables in studying freely swimming animals, be they human or otherwise.

Because it brings up several interesting points, I would now like to give you another example of temperature regulation. Shortly we will hear from Dr. Kylstra, one of the pioneers in the liquid breathing experiment, but I would like to discuss these experiments from a slightly different aspect and that is, what happens to the temperature of some of these animals when they breathe liquid. Specifically, I will be discussing a mouse with a radio transmitter inside it, but do keep in mind a couple of questions: Why are fish cold-blooded, and why are all the aquatic mammals without gills?

In this experiment a mouse breathes a liquid at room temperature; down in his tummy is a radio transmitter that sends a signal from the abdomen, through the liquid and up to a few turns of wire that serve as a receiving antenna. The signal then goes to an ordinary radio receiver to be de-coded and subsequently traced out as temperature.

When you jump into a swimming pool your skin may get a little bit cold, but this is meaningless. What we are really talking about is the temperature deep down in the body, and this does not change until our mouse takes his first breath of liquid. The lungs provide a large surface area for the exchange of gases, and it follows therefore that they are also a large surface area for the exchange of heat so, when the animal takes its first breath, its temperature starts to drop precipitously, even though it is a warm-blooded animal; even though it should have a constant temperature. Its temperature regulator simply cannot cope with these conditions. This means that the problem with a lot of schemes for artificial gills, etc. in which you have this great gas exchange, is that the body will try to warm up the entire Atlantic Ocean — not the most practical thing to attempt!

We have all sorts of transmitters — big and little. This is a radio transmitter on the tip of my finger. It does not require any fancy laboratory for its construction; it is made out of standard commercial components that are simply slotted together, and anyone in this auditorium could build a transmitter like this in one day. It senses and transmits temperature, is small and could be tucked into a mask. We can monitor quite a number of variables, and all sorts of ranges of transmission allow quite a variety of physiological monitoring in the free-swimming diver where the problems of monitoring are especially hard to solve by the usual laboratory methods.

I have not speculated about anything at all; I have merely told you some very routine present-day facts which, I hope, you may have found as interesting as any speculation.

I hope that you now understand one good reason why no aquatic mammals have gills: it would couple them too closely to the ocean.

Surgeon Commodore Rawlins: As a matter of fact, in its study of hypothermia the Royal Navy uses the same transmitters. I was intrigued with the liquid-breathing mouse and its respiratory heat loss because of its relevance to deep diving, helium-oxygen at 1,000ft. having the same heat transfer properties as water.

Dr. Val Hempleman

Dr. Val Hempleman is Superintendent of the Royal Naval Physiological Laboratory.

In the 1950's, he and his team were called upon to produce new decompression procedures for the Navy, and tests finally resulted in the successful dive to 600ft. by Wookey in the late 50's.

Later research was carried out on decompression tables for saturation diving, and it was due to this that the "helium barrier" was broken.

This was proved by the 1500ft. simulated dive by John Bevan in March 1970.

The transfer of man's capabilities to deep underwater tasks

It is always a difficult task to foresee what will be happening in underwater physiology in the next 20 or 30 years, but 50 or 60 years ago some early workers predicted that men would live in undersea houses with lock-in and lock-out facilities, and although the diving dress they designed is somewhat dated, we will be doing very well if we can be as accurate as this with our predictions.

Less than four years ago, 335 metres was taken to be the safe depth limit and yet, as you know, the French diving group *Comex* have just safely reached 600 metres (2,001ft.) So what went wrong with the 335 metre limit idea, which was made in good faith, and as a result of a lot of hard work?

To examine this it is profitable to return to the previous Congress when a young man named Hannes Keller startled the diving world and set in motion a real impetus to deep diving work by extending ordinary conventional diving. By this, one means that he was descending to great depths quite rapidly, staying down there 10 or 20 minutes and then returning as quickly as possible, consistent with safety, to atmospheric pressure. (I watched a dive of his to 700ft., with 10 minutes hard work on the bottom, followed by return to atmospheric pressure in about 100 minutes).

We in Britain at that time were the only group properly equipped to take advantage of this technique because we had a submersible chamber and so we could put a diver into this chamber, bring him up from the depths at full diving pressures, and transfer him on to the support ship where he could be locked on to a large deck pressure chamber. This technique of transferring under pressure is now of course well-known and well-used. So we set off to try and extend conventional diving to greater depths and, like the ordinary conventional air diver, descended to depth at 100ft. a minute.

When we studied this technique of going to the depths rapidly, several facts began to emerge. We already knew from a lot of submarine escape experiments we had done that descending rapidly on air to 625ft in 25 seconds presented no untoward problems, but when we went to compress people on helium to 500ft. at only 100ft. per minute, some hand tremor appeared on sensitive men. At first this was ignored; it was felt that the men were slightly psychologically affected. But when, later on, we then compressed on oxy-helium to 800ft. in eight minutes, marked hand tremors were observed in nearly all the men and when stripped to the waist in the pressure chambers the musculature of the back and upper arms of many of them was moving about in a most unco-ordinated and disturbing manner.

Then to the laboratory came Professor Buhlmann from Zurich, who did some rather splendid pioneering dives with us, as a result of which we learned that if we took an hour to get to 1,000ft. there were very small changes in hand tremors, and, only small EEC changes — i.e. electrical activity of the brain.

Compression on oxy-helium to 1,000ft. in 24 hours was accomplished by the Americans, and this appeared to cause no detectable changes at all. Finally, the observation that diving ought to end somewhere about the 350/360 metres mark was due to an experiment on oxy-helium with compression to 1,200 ft. in approximately two hours which caused some hand trembling but marked changes in the electrical activity in the brain, which were quite rightly regarded as sufficiently serious to prevent any attempt to descend deeper.

From all these observations the conclusion was reached that if you want to put divers deep in the ocean, then you must give the body time to adapt to the markedly changing environments that are being experienced during the descent.

As you know, the French groups have now moved into the forefront of work in very deep diving and it was they who put together all the untoward signs and symptoms seen when going to depths, and called them the "High Pressure Nervous Syndrome". We now know that although one can reach 1,000ft. fairly quickly — in about an hour — once one goes much beyond this depth then in order to avoid the high pressure nervous syndrome one must descend very slowly. In fact it is necessary to descend more and more slowly, until it is taking several days to reach 600 metres depth, and one would estimate that to reach 800 metres would represent an impracticably long period.

Yet another problem presents itself during the second phase of a dive, i.e. the period when the diver is at full depth. From our own observations we have been able to establish that although it is possible for a diver to do fine work with his hands at, for example, 1,500ft., the electrical activity of the brain is partially suppressed and this inevitable change becomes progressively worse with greater and greater pressure. The *Comex* group has confirmed these observations with their own very deep dives and established that around 800 metres (2,600ft.) these changes would reach such a magnitude as to become unacceptable.

The other major problem that occurs at full depth concerns the breathing difficulties. Once again at 1,500ft. we did a number of respiratory experiments to see if people could work; we did not ask our volunteers to do a great deal of physical work because it was a pioneer experiment and one must not press people into more and more stressful situations in case it turns out to be dangerous. It was quite clear that although light work was quite feasible, these men were not breathing normally, which is hardly surprising when it is realised that the density of helium at such levels of pressure is quite great, equivalent to air at about 220ft. As a result of our early observations we would have concluded that our divers could probably not sustain physical work.

Quite recently, some more complicated experiments have been completed in the United States at a depth of 1,600ft. and as a result of their measurements they reached the conclusion that although the tasks were performed efficiently, 1,600ft. (500m) may represent the approximate limit at which, using our present diving procedures and equipment, sufficient physiological reserve remains to deal with emergencies. The theoretical conclusion is that if a diver is asked to descend 50 per cent deeper he would only be capable of performing light work. Here again the same value of 800 metres or 2,600ft., at which the practical breathing limit will be reached is estimated.

This afternoon we have heard a good deal about thermal balance and the difficulties allied to maintaining it: divers working with life support systems on oxy-helium are very sensitive indeed to small temperature changes. In our experience at 1,500ft. it was really quite difficult to keep both our divers comfortable, a shift of a degree or two either way affected them both quite markedly, turning one over to shivering and the other to sweating. From this you can see that maintaining a suitable thermal environment in these pressure chambers is difficult, and descending much deeper would increase the technical problems enormously.

Finally, we come to the third phase of diving which is the decompression phase, and here again for illustrative purposes I shall refer to our own 1,500ft. dive, during which, in various stages, we tried to overcome the effects of compression and the HPNS. We then started to decompress fairly rapidly. Now, the term "fairly rapidly" will make you smile when I tell you that it was at 40ft. or 12 metres an hour which by ordinary standards of diving is absurdly slow. But, as a result of attempting to maintain this rate of decompression we encountered serious trouble with one of our volunteers, and had to recompress him to overcome it. From this, we could confidently state that one cannot decompress at this rate from such depths and eventually we established a safe rate of decompression at 10ft. or 3 metres an hour. The point I wish to emphasize is the colossal time it takes, perhaps 8 or 9 days decompression, to get back to atmospheric pressure, and if you were to ask to go to nearly double that depth the running time would be in the order of weeks. I am not saying that you cannot make such deep dives, but certainly the times involved become impracticable and, curiously enough, most of the figures seem to indicate that somewhere in the region of 800 metres or 2,600ft. lies the practical limit to deep diving for unmodified men.

One therefore asks whether there is anything we can do about this. We have heard about pharmacological agents for overcoming the effects of pressure, but I am not sure how acceptable these will be and there is still a great deal of work to do. Some form of power-assisted breathing would seem to be helpful yet, if you have this, a good number of the advantages of using men on the ocean floor begin to disappear.

With regard to decompression, I am sure we have not reached the optimum answer and perhaps something like the previous speaker's method of monitoring the diver would yield better results, although one cannot see it altering the order of time of the decompression, it will merely trim it and make it more individual.

Various other solutions to the problems of decompression have been suggested, such as connecting people to kidney machines and thereby washing the inert gas from the blood, but all these are really macabre solutions and one would think they represent unacceptable ideas.

So, we are faced with the fact that on the available knowledge to date, an unmodified man will not descend much deeper than 800 metres and yet, here we are, human beings with the best computer available, able to transmit complex messages even balancing on one foot! Perhaps our best plan would be to combine our unique properties; the brain, central nervous system and muscular co-ordination, in some way with machinery, so that we get the best of both worlds. Such an attempt is being made; that is to key into the main muscular areas, and perhaps into the nerves themselves later on, so that when a man moves his arms and fingers there are corresponding arm and pincer movements on a complex undersea device. I am not able to comment on the efficiency of this method, but at present this demands a large undersea machine and has certain obvious disadvantages.

Another somewhat less clumsy answer to this type of problem is JIM, about which you have just heard. We at the physiology laboratory are not concerned with the engineering of this device, but we have been making some tests on the "bio-mechanics" of it, and it is very apparent that this piece of equipment is very operator-dependent by which I mean that not just anybody can get into it and immediately operate it efficiently. After a good number of lessons the operator can bend and use the human body properly and although the device doesn't have a great deal of strength in its manipulators, JIM will certainly cope with some quite dextrous work.

I would like to emphasise how mobile this man can make himself. He can be pushed over and stand up and get himself into all sorts of manoeuvres; a very dextrous piece of machinery which can work on two carrots and a beefburger! JIM has a great many features in its favour, but it is clumsy at the present time. Obviously, for example, it will not be able to crawl down the propeller shaft of a ship but nevertheless it impressed us when operated by a well-trained man. We are now attempting to see what sort of currents JIM can walk into and, rather like a moon suit, the way this man walks need not necessarily be orthodox, he can walk sideways, or backwards, and we are trying to establish the most effective methods.

So JIM represents one sort of solution to the problems of decompression. It is not an ideal solution as yet, but if we are to go deeper some fusion of man and machine such as this will have to take place.

Prof. Johannes A. Kylstra

Johannes A. Kylstra, widely known for his liquid breathing experiments, is Associate Professor of Medicine and Assistant Professor of Physiology at America's Duke University.

Born in the Netherlands — he received a medical degree from the University of Leiden in 1952. From 1952 to 1954 he was an intern at Albany Hospital in Albany, NY, and from 1955 to 1958 he was a Lieutenant in the Royal Netherlands Navy Medical Corps.

In 1958 he obtained his PhD in physiology from the University of Leiden, and after three more years in the US, he served from 1961 to 1963 as Assistant Professor of Physiology at that University.

Liquid Breathing

As some of you may recall, during the second World Congress of Underwater Activities held in London in 1962, Jacques Cousteau startled his audience with a vision of the diver of the future — homo aquaticus — a human creature with liquid-filled lungs, breathing like a fish, with a surgically implanted gill. Homo aquaticus would be free to roam the oceans from the surface to great depths, protected against decompression sickness by an incompressible liquid in his lungs. As all of you know, one of the main hazards in diving is the presence of compressed air in the lungs, which prevents the chest from being crushed while, at the same time, sustaining life. The pressure causes gases to dissolve in the blood, with potentially serious consequences. At heightened concentrations in the blood and tissues, most gases are toxic: oxygen can cause lung damage and convulsions; nitrogen can produce a state of altered consciousness, and usually incapacitates a diver at a depth of 300ft. or thereabouts. These complications can be avoided by using helium, which is not narcotic at high partial pressures, and by minimising the fractional concentration of oxygen in the inspired gas mixture so that the partial pressure of oxygen remains within safe limits.

However, regardless of the gas mixture used, the inert gas dissolves in the blood and tissues and, whenever a diver surfaces too rapidly from depth, releases bubbles that result in decompression sickness. Theoretically, decompression sickness and gas toxicity could both be avoided by filling the diver's lungs with a liquid instead of compressed gas. This liquid would resist the external pressure without a change in the volume of the chest and, at the same time, no gas would dissolve in the blood flowing through the lungs since there would be no gas in the lungs in the first place.

To supply the diver with enough oxygen and an avenue for the disposal of the carbon dioxide that is continually being produced in his body would necessitate the use of a device similar to the ones now being used by surgeons to keep patients alive while repairing their hearts: an artificial lung, but this time fashioned after the gills of fish, et voilà — homo aquaticus.

The essential feature of homo aquaticus is the incompressible liquid in his lungs. The artificial gill — a technical and surgical "tour de force" — is necessary to protect him from drowning, or is it? Could not the diver's liquid-filled lungs be made to function like gills? As it turns out, the answer is "Yes", and the advantages over the surgically implanted artificial gill are obvious.

Animal life on our planet began in the sea in an environment in which oxygen is relatively scarce. Early forms of animal life, making the best of the conditions imposed by the environment, evolved breathing organs such as gills that are capable of extracting adequate amounts of oxygen from water. Eventually the evolution of lungs made it possible for animals to emerge from the sea and to benefit from the physical characteristics and advantages of an oxygen-rich gaseous environment. Throughout the span of evolution, however, the function of the respiratory organs has remained basically the same: in both gills and lungs oxygen diffuses from the environment, across thin membranes, into the blood, and carbon dioxide coming out of the blood diffuses in the opposite direction to be discharged into the environment. Nevertheless, to reverse evolution and to resume water breathing presents formidable problems for a mammal. I have already mentioned one: the fact that under normal conditions, at ordinary atmospheric pressure, water contains too little dissolved oxygen. Another problem lies in the fact that natural water, be it fresh or seawater, usually has a composition which is very different from that of blood. Hence, when such water is inhaled it causes lung tissue damage and, provided enough of it is inhaled, fatal alterations in the volume or composition of the body fluid.

Now, it is a simple matter to prepare a liquid that overcomes both of these difficulties. Suppose we take an isotonic salt solution that is like blood plasma in composition, and charge this solution with oxygen under greater-than-normal pressure: the solution's similarity to the blood will prevent any alterations in the volume or composition of body fluid by diffusion or osmosis. Under pressure, the solution can be charged with about the same concentration of oxygen as is normally present in air at sea level. Could a mammal breathe such a solution?

Using a small pressure chamber partly filled with an isotonic salt solution, I performed the first experiment, with a mouse, at the University of Leiden in 1961. The mouse was introduced at the bottom of the pressure chamber through a lock like the escape hatch of a submarine; the chamber had transparent walls so that the mouse could be observed. In the first few moments after entering the chamber, the animal tried to swim to the surface of the water, but was prevented from doing so by a grid below the water level. After a short period the mouse quieted down and did not seem to be in any particular distress; it made slow rhythmic movements of respiration — apparently inhaling and exhaling the liquid. It moved about in the chamber occasionally and would respond to a rap on the wall. Some of the mice so tested survived for many hours, the length of survival depending on the particular conditions of the experiment such as temperature and the chemical composition of the liquid. In each case, however, the mouse eventually ceased his respiratory activity.

From the results of variations of the applied environmental conditions, it appeared that the decisive factor limiting the survival of the mice was not the lack of oxygen — which could be supplied in ample amounts simply by increasing the oxygen partial pressure in the liquid — but the difficulty of eliminating carbon dioxide at the required rate. The mouse that survived for the longest time — 18 hours — was assisted by the addition to the solution of a small amount of tris(hydroxymethyl)-aminomethane, which is a substance that minimizes the untoward effects of carbon dioxide retention in animals and man. Lowering the temperature of the solution to 20°C, about half the mouse's normal body temperature, also lengthened the survival time by cooling the animal and thus reducing his metabolic rate, and consequently his rate of carbon dioxide production.

Now, with mice in a small pressure chamber it is difficult to determine how much oxygen is actually taken up by the lungs, how well the arterial blood is oxygenated, and how much carbon dioxide the animal retains. Consequently, my associates and I resorted to more elaborate procedures using dogs in a large pressure chamber provided with additional equipment.

The entire chamber was pressurized with air and an anaesthetized dog was lowered into a tub of oxygenated saline. The animal was kept cool at about 32°C in order to reduce his oxygen requirement. While submerged, the dog continued to breathe, and jets of water rising from the surface showed clearly that he was pumping the solution in and out of his lungs. At the end of the observation, the dog was lifted out of the tub and his lungs were drained of water and re-inflated with air. One of these dogs was later adopted as a mascot by the crew of the Royal Netherlands Navy vessel *HMS Cerberus*.

We had now shown in measurable terms that under certain conditions a mammal could indeed maintain respiration by breathing water for a limited period of time. The blood pressure of the dog was slightly below normal while he was breathing the oxygenated liquid, but it remained stable; his heart rate and respiration were slow but regular and his water breathing kept the arterial blood fully saturated with oxygen. However, the carbon dioxide content of the blood steadily increased, indicating that the dog's vigorous respiratory efforts were not enough to remove sufficient amounts of carbon dioxide from the body.

I continued my studies at the State University of New York at Buffalo, using apparatus that makes it possible to measure the actual exchange of gases taking place in the lungs of water-breathing dogs. As before, an anaesthetized dog breathed the salt solution oxygenated under pressure. This time, however, the animal did not have to move the water into and out of the lungs on his own, and it was possible to measure accurately the gas content of the inhaled and exhaled water. Oxygenated liquid was delivered to the dog via a tube from a reservoir, and was drained back into a reservoir underneath the dog. A motor-driven valve system regulated the respiration. The amount of oxygen taken up from the liquid in the lungs, and the amount of carbon dioxide discharged into it, was measured by comparing the relative amounts of these gases in the inspired and expired liquid. Samples were taken, so we knew the oxygen content of the liquid going into and out of the lungs; the dog was not cooled, and it extracted about the same amount of oxygen from water as it normally would have from air. However, in spite of the mechanical assistance to its water breathing, the animal did not eliminate sufficient amounts of carbon dioxide in the exhaled water, so that the partial pressure of carbon dioxide in the arterial blood gradually increased. At the end of the period of water breathing, which lasted up to three-quarters of an hour, the water in the dog's lungs was drained by gravity through a tube in the trachea and the animal's lungs were inflated with a few breaths of air blown into the tube. Several of these water-breathing dogs later became healthy and pleasant family pets.

It was now abundantly clear that inadequate elimination of carbon dioxide was the main problem in water breathing. There are two reasons for this. First of all, we now know that when a breath of fresh air or water is drawn into the air sacs of the lung, the oxygen molecules are at first concentrated in the centre of the sacs and have to traverse a substantial distance by diffusion before they reach the walls to enter the bloodstream; this distance is many times greater than the thickness of the membranes that normally separate air from blood in the lungs. If the breathing medium is air, the situation is of little consequence: oxygen diffuses in air so rapidly that freshly inhaled oxygen is distributed homogeneously in a matter of milli-seconds. However, when the medium is water, in which the respiratory gases diffuse about 6,000 times slower than in air, a gradient of oxygen tensions persists over the distance between the centre of the air sacs and the walls at the periphery. Throughout the cycle of each respiration the oxygen tension is greater at the centre than at the walls; the same being true of carbon dioxide discharged from the blood: it is more concentrated near the transfer membranes than at the centre of the sacs. Thus, at a normal resting respiratory frequency, the average carbon dioxide partial pressure in exhaled water is considerably lower than in exhaled air, at the same partial pressure of carbon dioxide in the arterial blood. Furthermore, the situation may be expected to get worse as the respiratory frequency increases and less time is available for carbon dioxide to diffuse during each breath.

Secondly, at normal body temperature, the solubility of carbon dioxide in water is less than in air, which is to say that water contains fewer carbon dioxide molecules than an equal volume of air at the same partial pressure. Hence, an increase in the partial pressure of carbon dioxide in the arterial blood, and consequently, in the air sacs in the lungs, would eventually restore the balance of the production of carbon dioxide in the body and elimination through the liquid-filled lungs. Unfortunately, the body tolerates only minor variations of carbon dioxide partial pressures in the arterial blood. Obviously then, if we put all these factors together, we find that in order to maintain his arterial carbon dioxide partial pressure within tolerable levels — to prevent a sense of suffocation or even loss of consciousness — a water-breathing diver would have to move a substantially greater volume of water per minute in and out of his lungs than the air-breathing diver moves air. At first sight this would not seem to be an insurmountable problem, since a suitable motor-driven pump could relieve the diver of the extra work of breathing but, unfortunately, the maximum rate at which air or water can flow out of the lungs is effort independent: the flow initially increases with the increase in expiratory effort, but only up to a point, after which the flow no longer increases no matter how much pressure is applied to the lungs. The reason for this is the pliability of the walls of the airways so that they collapse once the critical expiratory flow has been reached.

David Leith and Jerry Mead at the Harvard School of Public Health, Boston, have measured the maximum expiratory flow of water from the lungs of dogs, and on the basis of their findings predicted that the maximum minute ventilation of a saline-breathing diver would be approximately 3.5 litres. If one realises that a resting man must breathe normally almost twice this amount of air per minute and much more when he is performing work, then it becomes clear that the water-breathing diver could not possibly eliminate carbon dioxide at the necessary rate, even if he remained absolutely at rest in the water.

Now does this mean that we must find other ways to eliminate carbon dioxide from the body such as, for instance, an artificial gill? Not necessarily. Theoretically, the problem could be solved by using a liquid in which carbon dioxide is more soluble than in water, or by adding a substance which chemically binds carbon dioxide; the effect of either of these measures would be the same, namely to increase the number of carbon dioxide molecules present in the exhaled liquid at a given partial pressure.

We are mainly interested in the solubility of carbon dioxide at a partial pressure of 40 millimetres of mercury; that is a partial CO_2 pressure normally found in arterial blood. Under these conditions, one litre of saline contains approximately 30 milli-litres of carbon dioxide, while FC80 — a synthetic fluorocarbon liquid — contains 84 milli-litres (almost three times as much), whereas one litre of air at the same partial pressure contains approximately 60 milli-litres. A solution of tris(hydroxymethyl)-aminomethane in a 0.3 molar concentration and adjusted to a ph. of 7.4 contains 320 milli-litres of carbon dioxide per litre.

Since, in normal resting conditions a man produces about 250 milli-litres of carbon dioxide per minute, it would follow that carbon dioxide elimination might not be a problem if a diver were breathing a tris buffer solution, even if his maximum minute ventilation were no more than 3.5 litres, as predicted by Leith and Mead. In fact it can be shown that such a diver would be able to perform work requiring up to 1,300 milli-litres of oxygen per minute — that is, approximately four times as much as under resting conditions — and still have a normal partial pressure of carbon dioxide in his arterial blood.

Unfortunately, the solubility of oxygen in a tris buffer solution is no different from that in normal saline, thus an inspired oxygen partial pressure of approximately 18 atmospheres would be required to provide the diver with the 1,300 milli-litres of oxygen per minute. If our diver were to breathe fluorocarbon liquid instead, his maximum oxygen consumption at a normal arterial carbon dioxide partial pressure would only be about 300 milli-litres per minute — barely enough to support him while completely at rest. On the other hand, only one half of an atmosphere of inspired oxygen pressure would be needed to provide him with the necessary amount of oxygen.

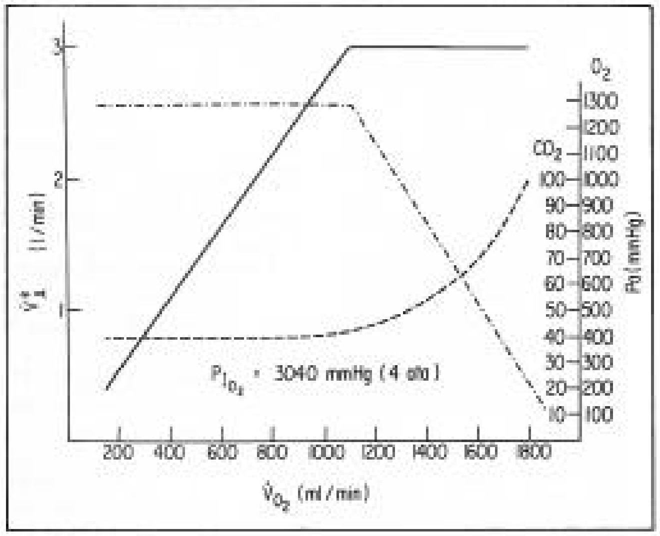
In general then, the high carbon dioxide-carrying capacity of a tris buffer solution would allow productive physical activity of a liquid-breathing diver but, with the oxygen solubility being so low, prohibitively high partial pressures of inspired oxygen would be necessary. The solubility of oxygen in a fluorocarbon liquid is high enough to provide the diver with sufficient oxygen at safe inspired partial pressures, but the solubility of CO_2 in fluorocarbon liquids is still not good enough: even at complete rest in the water and while breathing at his maximum capacity, the diver would barely be able to maintain a normal carbon dioxide partial pressure in his arterial blood.

Would it be possible to combine the advantages of a fluorocarbon liquid and of a tris buffer solution by mixing the two in suitable proportions? Fluorocarbon liquids do not mix with water and are in general very poor solvents for all but a few organic substances. However, it is possible to make stable emulsions of fluorocarbon liquid droplets in physiological salt solution containing tris buffers. Such emulsions have been prepared as a blood substitute, the fluorocarbon liquid droplets functioning as liquid blood cells to carry oxygen from the lungs to the tissues.

We can now estimate the maximum oxygen uptake through human lungs filled with different liquids at various arterial carbon dioxide partial pressures. The calculations are based on the known oxygen and carbon dioxide solubilities of various liquids, on an estimated maximum effective alveolar ventilation of three litres per minute, a minimum arterial oxygen pressure of 100 millimetres of mercury and a gas exchange ratio of 0.8. On the basis of such calculations one can predict that the maximum oxygen uptake of a saline-breathing diver could be no more than one third of his resting oxygen requirement at a normal arterial carbon dioxide pressure, that is to say, he could not survive under these conditions. In order to be able to extract the minimum required 300 milli-litres of oxygen per minute from the oxygenated saline in his lungs, the partial pressure of carbon dioxide in his arterial blood would rise to 110 millimetres of mercury and cause him to lose consciousness. As you may recall, these predictions are in accordance with the experimental findings in saline-breathing animals which I discussed earlier.

If a diver were to breathe FX80 fluorocarbon liquid instead of saline, the situation would be somewhat better: the estimated maximum oxygen uptake would be slightly greater than his minimum oxygen requirement at a normal arterial carbon dioxide partial pressure. However, the slightest amount of physical activity, raising his demand for oxygen by no more than about 60 per cent, would cause an increase in his arterial carbon dioxide partial pressure to 60 millimetres of mercury, and give rise to a sensation of impending suffocation. For this reason a fluorocarbon-breathing diver would not be of much use in the water.

If we estimate the maximum uptake of oxygen through the lungs of a diver breathing an emulsion of fluorocarbon liquid in an isotonic tris buffer solution, the prospects brighten considerably: the diver would be able to perform work that requires an oxygen uptake of 1,100 milli-litres per minute, at a normal arterial CO_2 pressure of 40 millimetres of mercury, and he could increase his oxygen consumption to almost 1,500 milli-litres per minute before he would be so short of breath that he would have to stop. The diving women of Korea, who harvest abelone and oysters and other materials from the seabed at depths of up to 60ft., require about 1,200 milli-litres of oxygen per minute while they are working underwater. So this would seem to be a reasonable figure for a reasonably active diver.



Relationship between oxygen uptake, effective alveolar ventilation, and oxygen and carbon dioxide partial pressures in the arterial blood of a hypothetical fluorocarbon emulsion breathing diver.

I have prepared a Graph showing the relationship between oxygen uptake, effective alveolar ventilation, and oxygen and carbon dioxide partial pressures in the arterial blood of a hypothetical fluorocarbon emulsion-breathing diver. As you can see, the effective alveolar ventilation increases linearly with an increase in the oxygen consumption, while the arterial carbon dioxide and oxygen partial pressures at the end of an expiration remain 40 and approximately 1,300 milli-metres of mercury, respectively. Once the maximum alveolar ventilation of three litres per minute has been reached — which occurs at an oxygen consumption of approximately 1,100 milli-litres per minute — a further increase in activity and consequently in the oxygen consumption, causes a rise in the arterial carbon dioxide partial pressure and a drop in the arterial oxygen partial pressure. An inspired oxygen partial pressure of approximately 4 atmospheres was chosen to prevent blackout as a result of arterial hypoxaemia before the diver's arterial carbon dioxide tension rises to a value that would force him to rest. In spite of the high inspired oxygen partial pressure, the partial pressure of oxygen in the arterial blood remains within acceptable limits, at least for a dive that would not last much longer than an hour or so. With liquid-filled lungs that would be long enough to descend several thousand feet into the water, work at depth for perhaps half an hour and return safely to the surface — all within an hour.

Granted that it has been shown that animals can breathe oxygenated salt solution or fluorocarbon liquid; granted that my estimate of the respiratory capabilities of a hypothetical fluorocarbon emulsion-breathing diver is approximately correct, what evidence is there that a real diver could tolerate the sensations arising from the presence of a liquid instead of air in his lungs?

During the past six or seven years my colleagues and I at Duke University Medical Center have been treating patients suffering from a variety of lung diseases by rinsing their lungs with a physiological salt solution in order to remove harmful secretions.

The patients are anaesthetised and a double tube catheter is inserted into the trachea: one lung breathes anaesthetic gas and oxygen while the other has its air replaced by physiological salt solution at normal body temperature. Once all the gas in the lung has been replaced by liquid, the rinsing procedure, which more or less resembles the normal breathing process, begins. A tidal breath of 500 milli-litres of saline is made to flow into the liquid-filled lung and immediately after this the same volume of liquid is siphoned off. We continue this treatment for up to two hours and may use as much as 10 gallons of salt solution on one lung; so far we have done this on about 200 occasions, and the patients have suffered no harmful effects.

The same procedure was performed on a healthy volunteer whose windpipe was anaesthetised to introduce the catheter; he otherwise received no medication and was wide awake throughout the entire experiment. He told me afterwards that the liquid-filled lung had not felt noticeably different from the gas filled one, and that he had experienced no unpleasant sensations arising from the flow of saline in and out of his lung. Of course, such a test is very different from trying to breathe liquid with both lungs, but it did at least show that filling the human body with liquid will not necessarily damage the tissues or produce unacceptable sensations, provided a suitable liquid is used and provided the proper technique is employed.

With the advent of this volume-controlled lung lavage technique it has also become possible to measure accurately the rate at which a saline solution can flow out of the human lung. We have been able to drain 500 c.c. of saline from one lung in 7 seconds, so it should be possible to exhale twice that amount, that is one litre of saline, from both lungs in the same time and, since inhalation and exhalation normally require about the same amount of time, it should be possible to move more than 4 litres of saline per minute into and out of both lungs. This is slightly better than Leith and Mead's estimate of 3.5 litres per minute.

The total amount of liquid inhaled and exhaled per minute will always be greater than the effective alveolar ventilation since part of it is wasted in ventilating the dead space. Consequently, the maximum effective alveolar ventilation may be expected to be somewhat less than 4 litres per minute, depending upon the size of the anatomical dead space, the respiratory frequency, the distribution of the flow of inhaled liquid and blood in the lung, and the presence or absence of partial gas pressure gradients within the liquid-filled gas exchange units of the lung.

During volume-controlled lung lavage in patients and again in a healthy volunteer, my colleagues and I found that diffusive mixing in the liquid-filled gas exchange units of the human lung is complete, provided that the respiratory frequency is no more than two or three breaths per minute. In addition, we found no evidence of a gross imbalance between the flows of inspired liquid and blood in the saline-filled human lungs which, by the way, is in complete agreement with observations in dogs' lungs made several years ago by John West and his Clinical Research Physiology Group at Hammersmith Hospital in London.

It seems therefore safe to conclude that at a respiratory frequency of two or three breaths per minute the physiological dead space in a liquid-breathing man would not be much greater than the anatomical dead space of some 200 milli-litres. Thus, with 4 litres ventilation per minute the effective alveolar ventilation of a liquid-breathing diver could be as high as 3.5 litres per minute. As you will recall, my predictions were based on the assumption of an effective alveolar ventilation of 3 litres per minute, so they are in fact a little bit on the safe side.

This is in essence what is known now — 12 years after it was first shown that mice could be kept alive breathing on their own in oxygenated salt solution, instead of air. Many questions remain unanswered and much work remains to be done. Nevertheless, looking to the future, it seems likely that some day — soon, perhaps — some courageous man will take a deep breath of specially prepared liquid and that, by the turn of the century, divers with liquid-filled lungs will carry out critical rescue and salvage operations at great depths in the oceans, where gas-breathing divers would have failed.

Surgeon Commodore Rawlins: I think our last speaker gave an extremely interesting and erudite presentation, but I have always personally felt that homo aquaticus could be equated with man-powered flight: extremely interesting but not too practical. I could be wrong about that.

Question time

Question: There seemed to be some disagreement between the speakers on the subject of temperature. For example, a severe drop in the temperature of divers breathing gases was dangerous, yet, while breathing liquids the cases were deliberately kept cool — I don't understand the significance of that.

Surgeon Commodore Rawlins: I think the answer to this is that the liquid cases were in an experimental situation. You can cool people significantly during surgery, but that is very different from cooling them in a practical condition where you cannot tend to their respiratory requirements.

Professor Kylstra: It was only during the initial liquid-breathing experiments in which the animals were breathing unaided and were not mechanically ventilated that they were kept cool. It was done deliberately to decrease their oxygen consumption and consequently to prolong their survival. In the subsequent experiments they were kept at normal body temperature which requires that the liquids they breathe be of approximately the same temperature as that of the body, otherwise they would lose body heat very rapidly. So, preferably, one will not cool down liquid-breathing man.

Question: As far as I can see from the data on the fluorocarbons, the solubility of oxygen and carbon dioxide, these refer to the equilibrium values. Would it not in fact be necessary to correct these for the rate at which equilibrium was achieved, and to take into account their diffusion co-efficient?

Professor Kylstra: That is correct. They are based on the equilibrium condition. Perhaps I did not make this point sufficiently clear, but I did mention the lung lavage experiments in man, in which it became apparent that this equilibrium is reached within 20 or 30 seconds, so that we can indeed apply equilibrium conditions, provided that the respiratory frequency does not exceed two or three breaths per minute.

Arthur Clarke: In 1952, Haldane told me as a sort of aside that he had decided that one could breathe liquids, his reason being that he had observed that it was very difficult to drown baby mice, and he thought they were deriving oxygen from the liquid. He then made a remark which I thought was very poignant, he said: "if ever I knew I was dying of cancer I would try this experiment, but I think it would be rather painful". Well, of course, he did die of cancer, but he never had a chance to try the experiment.

Professor Kylstra: I am glad you brought this up, because one has to be very careful to state the age of a liquid-breathing animal. It is quite true that if you put a new-born rat or mouse under water, it will survive for 20 or 30 minutes at least. This is not due to the fact that the animal is born with a special capacity for extracting enough oxygen from the water — in fact, I am not sure it is breathing it — it is because it is capable of metabolising anarobically, in other words, living without using oxygen. This has been very elegantly demonstrated in experiments in which this anaerobic capability was poisoned with various drugs. I am glad Haldane did not undergo the experiment.

Question: Doctor Mackay, is it possible to destroy bubbles that form in the body ultrasonically?

Stuart Mackay: No, not that I know of. The suggestion is to detect the bubbles, to study them and to control their formation, but not to destroy them. Ultrasound can be used to cause bubbles to coalesce, or it can be used to pump up bubbles — these are two separate matters, and in some cases it can be used to disperse bubbles. I think it could probably be used to age Scotch whisky rapidly too, but I don't know that it can be used to eliminate the bubbles.

Question: I was just speculating that if the sound wave had a wavelength of approximately the same size as the bubble, it might perhaps break the bubble up. And if the bubble were broken up into smaller bubbles, because of the greater surface area, it would dissolve more rapidly.

Stuart Mackay: As it turns out, when the frequency is such that the wavelength is about the size of a bubble, you can actually pump up the bubbles; as the bubbles pulsate in response to the compressions and rarefactions of sound, you find that more gas diffuses in than out on each full cycle. So you can get into trouble and actually have the exact opposite effect to what you want. This is part and parcel of why I suspect that a decompressing diver hit by a low frequency sonar beam might actually be given the bends very suddenly.

There may be some arrangement that you can think of which might do something useful, but do remember that the bubbles must be so small that they cannot even plug capillaries; a matter of a few microns.

Incidentally, over the decades it was predicted that there might be bubble showers; people suggested that when recompressing a bent animal/diver, all the bubbles trapped in the capillaries and the lungs, for example, might suddenly be released and circulated through the body. Now we have actually observed this to be true — much of what people have talked about or thought about has since been proved to be true.

Question: Dr. MacInnis, I was interested to see that you were using Unisuits under the ice. I wonder if you could tell me whether you did any evaluation reports on these, and, if so, are they available?

Dr. MacInnis: We made some 205 dives over a period of 30 days and during these used the Unisuit almost exclusively. In summary, we found that we were able to dive to depths of 40 and 50ft. for durations of up to an hour-and-a-half at low-to-moderate work loads — which is critical — without the onset of shivering. To go deeper and, certainly, to get into more exotic gas mixtures than the air we were breathing, would definitely necessitate supplementary heating.

Surgeon Commodore Rawlins: Ladies and gentlemen, I think we all agree that we have had an absolutely fascinating afternoon, with a tremendous range of speakers, and it only remains for me to thank them all on your behalf and to ask you to give them a very big hand.

I would now like to call on Mr. Derek Cockbill, the Chairman of the British Sub-Aqua Club, to close the proceedings formally.

Closing remarks

Derek Cockbill: Before I close the proceedings, I would like to call on Jacques Dumas, President of the World Federation, who has asked to say a few words.

Jacques Dumas: Mr. Chairman, ladies and gentleman, the Third World Congress of Underwater Activities is coming to its end. During this past week, delegates, speakers and experts, representing over 50 countries, have met here, thus making London the capital of the underwater world. We have heard papers of the highest interest and, within the framework of the CMAS, many important decisions have been taken affecting the future of our activities.

The year 1973 and this Congress mark a new step in the history of diving and in the conquest of the sea by man. I want to thank most warmly all the participants of this Congress, some of whom have come from very far away.

This Congress has enabled us to meet one another on a human level, to renew old friendships and to establish new ones, and has taught us to know which are the better and, especially, to realise how much the sea is a link that unites all of us.

Finally, I do not know if you are aware of the enormous effort and work necessary to organize a Congress as important as this, but the merits of the British Sub-Aqua Club are great since it was they who also hosted the Second World Congress here in London in 1962. They have held this Congress for us, for the benefit of the underwater world, and for the future of man in the sea. I therefore ask you to be upstanding and to give a big hand to the British Sub-Aqua Club and to the organizers of the Congress.

Derek Cockbill: Thank you very much indeed, Jacques.

We now come to the rather sad part of the World Congress: the end, at least of the official part, of a programme which I think even the most critical would agree has been an unqualified success. I know you would not wish me to let this moment pass without paying tribute to those who have made this occasion possible and that, as Jacques has said, is the Organizing Committee of Oceans 2000. I feel that I would like to name them, particularly those who were responsible for the various functions that have resulted in such an efficient presentation.

They are:

Colin McCleod, Chairman
John Meredith, Vice-Chairman
Kendall MacDonald & Bernard Eaton, Publicity & Press
Harry Gould, Chairman Finance Committee
Geoff Briggs and his Marshals
Maer Burr, Initial Registrations
Jan Curd, Entertainment & Prize Draw
Nic Flemming, Scientific Programme
Mike Busutilli, Sales Promotion
Mike Todd, Exhibition Organizer
BSAC HQ Staff, headed by Reg. Vallintine
The girls of the Conference Management
The Projectionist
The Speakers, who made this occasion possible

It only remains for me to wish you "God Speed" on your journey home and even better diving for the future. We look forward to seeing you all at the next CMAS General Assembly, in Sweden in 1975.

£2.50

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