

off and so on but he was back in diving in three months whereas the young man will never dive or do much else. When the supervisor of the operation was asked, "Why did you let him do something like that?" he said, "There is nothing wrong with that, we do it all the time." At that point the person who asked the question turned around and laughed. There was no sense continuing the conversation. That is the type of extreme that chamber fires come from. That includes the US Navy but most of the chamber fires occur in the commercial diving industry.

One is working in a very dangerous environment in a chamber and to me it is essential to avoid taking known risks.

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## DIVING ACCIDENT MANAGEMENT

### THE CATALINA CHAMBER AND ITS CLIENTELE

**Andrew Pilmanis**

#### **The Chamber**

Our chamber at Catalina<sup>1</sup> is a 7.3 m (24 foot) long, 2.7 m (9 foot) diameter, rectangular door, double lock, 7.8 ATA (100 psi) chamber. It was donated by the Lockheed Corporation. It was brought over by a tug boat company free of charge which was very nice of them. They lifted it off and placed it on the railway and said goodbye. The thing weighs 22 tons and we had a great deal of fun in installing it. Getting it into the building was interesting. It is large. There are pros and cons to large chambers. My original reason for getting the chamber was research and size is a big plus. One can put a great deal of equipment and people and so forth inside a large chamber. We have

had four simultaneous patients, 3 or 4 tenders inside in comfort. Whereas in a 1.3 m (54 inch) chamber one simply could not do that. We also do a tremendous amount of training. When one can put 10 or 11 people inside the chamber it saves a great deal of time.

We have a fire suppression system, which many chambers do not. I am a firm believer in such a system. Once a year we have what we laughingly call a chamber party. One of the exercises we do is we pressurize 4 or 5 people down to 50 msw (165 feet) and let them have a water fight and use the fire system. It does several things. It clears the pipes of any rust, or anything of that nature. It builds confidence in the crew because they have used the system. It proves the system works. And at 6 ATA, narcosis level, having some fire hoses going is a lot of fun.

The negative side of a large chamber is that it is in need of a great deal of machinery, machinery meaning large compressors, high pressure gas and so on. Compressor maintenance, size of compressors and so on, that is where the expense and time is. Our chamber interlock is approximately 28,000 lt (1,000 cubic feet) and to pressurize to 6 ATA takes a lot of gas. We put all the plumbing for the chamber together ourselves. We did not contract it out as we did not have the money. Being a physiologist I did not know the first thing about plumbing. However after a year of plumbing the chamber, I think I can plumb any chamber anywhere. It can be done, I cannot say inexpensively, but certainly for a lot less than what manufacturers quote.

#### **The patient and staff**

We are isolated. There is no hospital on the island. We treat all the local diving accidents. We do no hyperbaric oxygen therapy (HBO), although we have treated about 8 people with carbon monoxide poisoning off boats where the individuals were cold at night, left their gas stove alight and closed all the windows. In the morning they were found unconscious. They were right next to us and we did treat them but routinely we only treat diving accidents. In that sense we are somewhat unusual as far as large chambers go.

We have no physician in residence on the island. The medical support comes from the University County Hospital Emergency Room. They have a very active training programme in emergency medicine and as part of that twice a year we give a one week diving medicine course and then those residents are put on call. When we treat a case, a resident and a nurse (we give diving medical courses to nurses in the same department) are flown over by the Sheriff's

Department helicopter. We are lucky that we have access to an excellent helicopter organisation and because of that some twenty odd miles across the channel really does not impact on us very much. Some of the helicopters can be over in 15 minutes. It is not the helicopter flight that is usually the delay. The delay is finding the physician, beeper or no beeper. Our paramedic base station often has a very difficult time locating the resident who is often moonlighting in some other emergency room and we have to run all over Los Angeles trying to find him. On the average a physician arrives at the chamber between an hour and a half or two hours after the call.

We operate in a labour intensive way with a crew of five, three outside and two inside. It is a manually operated chamber and we need the extra help outside.

The majority of cases probably 60 plus per cent, come from Catalina Island. It is the most dived area on the West Coast and is probably one of the most often dived areas in the world. In one three day weekend we counted 2,500 dives just at Catalina. This goes on year round, not just in the summer. We also get patients from the mainland, shore diving and the various channel islands, but the majority come from Catalina itself.

In the twelve and a half years we have been in operation the patient load increased fairly linearly until 1985. In 1985 two things happened. Two other chambers opened up in the general area, therefore the patient load was diffused somewhat. And for whatever reason there was a very low incidence of diving accidents. That was reversed itself and this year (1986) by the end of May we had already done more treatments than we did the whole year last year (1985).

We treat almost entirely sport divers, both for air embolism and decompression sickness. With air embolism many were under training. That is now in the past. In the last two years we have rarely seen an embolism from training, whereas 10 years ago that was the number one source. I think that the training agencies are gradually increasing the level of instruction.

We have treated abalone and sea urchin divers. They are probably very similar to Australian abalone divers. They work a 6 to 8 hour day under water. They make just enough to buy some beer and then they are back underwater. The industry has decreased radically over the last few years because there simply are no abalone left, so they have switched to sea urchin diving. They take the sea urchin roes, freeze them

and send them to Japan. It is quite lucrative. Sea urchin divers work very shallow whereas abalone divers were working very deep. We treated one individual who that day had made 13 dives to between 39 and 42 m (130 to 140 feet). He did not see anything wrong with that. He did it, he had the bends, but that population has decreased so now we only see about two or three in the course of the year.

Few scientific divers needed treatment. In the 12 years we have treated maybe five scientific divers.

We have treated a few wreck divers, who are very enthusiastic and to them decompression is a tremendous nuisance. For some years they were working a First World War destroyer at 140 feet, pulling bronze portholes off and working very hard, never leaving enough air, or having any spare tanks, to decompress with. One fellow was treated three times in the chamber. Towards the end of the last treatment we said "OK, Pat that is it, either you give us a bronze porthole or we are not going to let you out of the chamber". We had to give in, he refused to give us the bronze porthole. We finally let him out.

We do treat some commercial divers from the Los Angeles Harbour, these are usually one or two men operations which cannot afford a chamber. They clean ship bottoms and that sort of thing. We have only treated two offshore oil industry divers in 12 years because most of the companies have their own chamber. They take care of their own as they do not want anybody to know what it is that they are doing anyway. The two that we did treat came from a 54 m (180 foot) air dive. They had a chamber on the oil rig, both divers were bent and both refused to go into the chamber. They considered it unsafe. The interesting thing is the Diving Supervisor agreed with them. So they were brought to our chamber and we treated them. We have done, up to last weekend, 555 treatments. Of those about 40% were air embolism and 60% decompression sickness.

Air embolism cases generally have come from either charter boats or the beach with some from private boats. Decompression sickness used to come from abalone divers or other similar individuals and a great deal from private boats. Since then things have changed. The private and charter boats would be a much larger proportion now.

Beach diving produces air embolism and near drowning but almost never decompression sickness because one cannot get deep enough diving from the beach in southern California. There has been one interesting case where going through very large surf,

an individual had an air embolism. He was using his regulator and apparently held his breath as the swell came through.

The majority of divers at Catalina can see the chamber location at the Marine Science Center. I would say at least 60 if not more per cent of the patients we get were diving in sight of the chamber. The seven miles to the west end of the island, with its offshore rocks, is the lee side of the island. It has beautiful visibility and it is a most popular spot. So the location of the chamber is ideal from that stand point. There are a few cases that come from a wreck at the other end of the island and a few from the other side.

There was an incident a couple of years ago, where four divers died in one dive to 36 m (120 feet). They went down, they all ran out of air and they all drowned. No cause other than nitrogen narcosis or perhaps they simply did not know what to do. They simply were not used to that kind of depth and they were not used to their single tanks running out so fast and when the tank ran dry they simply drowned. Southern California divers are used to 9-12 m (30-40 feet) diving and the shallowest you can dive from a boat at Catalina is 18 m (60 feet), but that is unusual. Most people end up diving to 36-39 m (120-130 feet) just going down the anchor line, some get down to 60 m (200 feet).

### **Diving Accident Management**

Communication is one of the most important aspects and we have gone to great lengths in Southern California to establish communication with the diving community and with the emergency services. We have a pretty good system, there is one phone number to call and the whole system is put into operation.

The US Military Services and the US Coast Guard jointly operate what we refer to as rescue co-ordination centres in a variety of places around the United States. There is one in Hawaii, two on the West Coast and one the East Coast down to the Caribbean. They have tremendous communication and transportation capabilities and even in the remotest site if they can be reached they can do a lot. They know nothing about diving accidents, one has to instruct them specifically what is wanted. Interestingly enough the US Coast Guard is not at all educated in what to do with diving accidents.

We constantly re-educate the helicopter pilots and crews in our area about oxygen and all kinds of other

things. They simply do not train their people at all. But these Rescue Coordination Centres have tremendous capabilities.

### **Transportation and pre-chamber care**

Our standard policy and party line to all the community, both medical and diving, is oxygen first. One hundred per cent oxygen for both air embolism and decompression sickness. We are not necessarily trying to give oxygen, we are trying to exclude nitrogen and in order to do that one has to have true 100% oxygen. A leaking mask allows dilution with air so that nitrogen is not being excluded, which is why the local rescue organisation uses a demand valve to give oxygen to conscious patients. And for embolism only we use the head down on the side position. I have some misgivings about the head down position. Certainly I would never suggest a person be sat up but when we receive some of these patients who have been head down for about 2-3 hours, they have a hell of a time clearing their ears and their lungs are congested. So we generally recommend one hour head down and then put them level but never head up. I would like to see some better basic research done on this whole aspect as we are functioning on very weak information. However the diving community as a whole, after 10 years of effort has finally been educated and head down is standard practice. I would be very hesitant of changing it now. I think we would create chaos.

The main reason that we do put a patient head down on his side is not for buoyancy or bubbles. It has to do with the much more practical matter of vomiting. Most of these patients will end up vomiting. If they do not have their head to one side or the other they are going to inhale vomit and have more problems and that is the main reason we utilise this position. It is very difficult to maintain incidentally and it is one of the problems in transport.

### **Rescue boats**

The Baywatch is a rescue vessel that is based about a mile from the chamber. It is operated by the County of Los Angeles Life Guards. They operate very closely with the US Coast Guard. The Coast Guard generally operates more offshore and Baywatch takes care of the in-shore emergencies. They respond to all kinds of emergencies, including fires and boats sinking. They tow boats, they do the standard sort of thing that you would find in any boating community. They also recover people or bodies from aircraft.

Surprisingly there are a lot of aircraft going down in the waters around Catalina. It is a favourite place for weekend private pilots to fly about 3 feet off the water and sometimes they misjudge and take a tumble.

The Baywatch operates with a crew of two paramedics. They have all the standard paramedic gear on board. The individuals we have stationed at Catalina have had about 10 or 12 years experience with diving accidents. In some cases they have transferred patients to the chamber within about 5 minutes of them surfacing.

A recent paper on Baywatch statistics on pre-chamber care<sup>2</sup> is of interest. This was a series of 58 severe air embolism patients, all except one using scuba. Fifty five were sport divers and three were commercial abalone, sea urchin divers. Fifteen of the sport divers were in their training checkout dive, there was a wide range of symptoms from alert and oriented with neurological deficits to a few coma and full cardiac arrests. All symptoms occurred in these 58 cases upon surfacing or very shortly after surfacing. The mean arrival time of Baywatch to the dive site was 18 minutes (range 2-55 minutes), so they had very good care within that time frame. The mean transfer to the chamber was 31 minutes. They were all treated with oxygen and head down on the side. They used a demand valve for the conscious patient and a ventilation mask for the unconscious. Thirty-one patients were started on Ringers lactate. Thirty four of the 58 improved during transport, 20 patients remained the same and four deteriorated. Out of the 21 patients picked up unconscious, 12 regained consciousness before the arrival at the chamber. Thirteen patients were in full arrest and were given cardiopulmonary resuscitation, nine of the 13 regained vital signs before arrival at the chamber. Four remained in full arrest at the chamber.

### Helicopters and aircraft

There are tremendous problems, especially with heavy weather conditions, in lifting patients having CPR up to the helicopter. They do accomplish this by using a basket with the person doing CPR straddling the patient and continuing it into the helicopter. It is a rather hairy situation, particularly when the basket starts spinning. Sometimes the person doing CPR wonders if he is going to make it, but they try very hard not to interrupt the CPR.

The Sheriff's Department has an airforce of its own and they often transport our physician and nurses and the patient. We also get the Marine Corps and the Navy involved at times.

They have search and rescue missions and they will go out to some of the other islands and even on occasions bring their own people in.

The Navy is not supposed to dive without a chamber on site. Yet about three times a year we get a call which goes something like this, "Are you on line?" ... "Yes, we are on line." "This is ... we are doing diving operations at such and such." "Did you say the US Navy?" "Yes, that is correct sir." "Well don't you have a chamber on board?" "No sir, can we use yours?" .... "Well yes of course!" I do not think regulations are always followed, in any event they do transport some of their own people.

In Los Angeles we have the Life Flight organizations, three companies competing for business. These have wonderful machines, they are quick with just about everything and they have emergency room personnel flying with them and they can do a tremendous amount. They have a 15 minute response time to the island from Long Beach, very nice. Somewhat expensive but in all our critical cases we transport in the Life Flight helicopters rather than the Coast Guard or Sheriff's Department. The Sheriff's Department would rather arrest the patient than treat him and that is not pleasant in some cases.

We work with the Coast Guard as closely as we can. It helps us, it helps them. They come out to all our courses and demonstrate their talents and we try to educate them on diving accidents in turn.

### Air embolism

A few comments and a few statistics about our experience of air embolism.

Recently at a boy scout camp on the island, the instructors decided that it would be tremendous experience for the boy scouts to see marine life under water. They found an old diving helmet and placed it about 15 feet underwater and pumped air through it. They had the boy scouts swim down, put their head up inside the helmet and look around and have a good time and then take a breath and come back to the surface. Without getting unduly excited we convinced them to discontinue the practice, they were totally ignorant of what the consequences might be. That type of problem does occur. I will not say frequently but it does occur. One of the saddest cases was a 10 year old boy whose parents for his birthday put a scuba tank at the bottom of their swimming pool and had the kid swim down, breath from it and then surface. The birthday boy came up with a classical air embolism. They went to a

succession of five emergency rooms and nowhere was it diagnosed or treated. To this day he is in a wheel chair with severe brain damage.

Currently the primary cause of air embolism in Southern California is running out of air. It used to be training, or lack of it. Now what is happening is people run out of air and then they have to do something. It is what they do that causes the air embolism, but the ultimate cause is running out of air. That is why I emphasise to all training agencies, over and over again, that these casualties can be avoided if they train their people to watch their pressure (contents) gauge. Some make ascents and do not make it, some try buddy breathing. Of course they have not done it since their training course. They do not know what to do. They hold their breath while the other person is breathing from the regulator, and both are ascending. This is the sort of air embolism that we see now. The other sort is inexplicable, that is everybody swears that the diver did everything right. One cannot find a cause, whether it is cysts in the lungs, whether it is something that he did that nobody saw. We had one of these last weekend in someone who obviously dives a tremendous amount, who had been looked over thoroughly medically yet during a very mild and simple dive suffered a severe air embolism.

In my mind the primary reason for buddy diving is if someone comes up with an air embolism and the buddy is not there they drown, that is the end of the story. This happens on a regular basis in Southern California because the death is not air embolism, it is drowning. The worse cases are the near drowning and air embolism combination. They are very difficult to manage. There are many reasons for buddy diving, I suppose, but there is nothing more important in my mind. We have had two cases where an individual came to the surface. Nobody was there. He became unconscious, sank down to about 9 m (30 feet). Somebody came along, saw him, and brought him to the surface. The underwater time was judged anywhere from 5 to 10 minutes. The rescuers did CPR, the patient had spontaneous respiration in about 2 or 3 breaths but were unresponsive. With aggressive treatment both individuals survived. That is a long time underwater. The San Diego chamber has three out of three such cases survive with no residual problems. The lesson there is not to give up.

Over approximately the last eight years we have had a series of assumed air embolism cases which by the time they arrived at the chamber have been having CPR anywhere from a half hour to two and a half hours, one might say, "Why bother to treat them?" We all know the medico-legal problems in the United States and there is the additional problem that the

information one gets when one receives such patients is not always very reliable. Ask the helicopter pilot how long has this been going on and he says, "Hell, I don't know. I just fly the aircraft." One tries to contact the boat but they cannot be contacted. One cannot ask the patient, so one does not really know what has happened. As a result, with what we call "heroic efforts" we do pressurize to 50 msw (165 feet). If there is no response within a half hour then they are pronounced dead. Then we have to decompress our tenders. Out of about 30 such cases, not one has survived or even had any indication of life. I would like to terminate this procedure, however our medical supervisors are very reluctant to do so. The reason I would like to terminate it is that we are putting our tenders at risk and we go through some elaborate decompression for them afterwards.

Incidentally, I think the only autopsy done under pressure in a recompression chamber was done at Catalina. Los Angeles has a coroner who when informed that we had a dead diver in the chamber said, "Hold him there. I'm going to do a post mortem in the chamber under pressure." He did not want the artificial bubbling that occurs on decompression. I said "We can't very well hold it there. Our tenders are inside and I know you don't care about them because they are living, but I do, one of them happens to be my wife. You can get out there as fast as you like and go in and do it, but I'm going to start recompression." He flew out at night in the Sheriff's helicopter and went inside, did a post mortem and that determined it was a heart attack, not an air embolism that killed the diver.

Most people with air embolism survive if you can get to them. There is a myth that goes around that if you get an air embolism you are dead. It is just not correct and I keep trying to emphasise that.

There is improvement during transport in a very high percentage. Often there is no deterioration with proper care, and many are asymptomatic when they arrive. There is a classic situation of a person unconscious from air embolism, who wakes up and on examination appears to be totally normal and is sent home. In our experience at that point the trouble starts. I cannot say how many relapses occur because we get a selected population, but we have seen quite a few. We try to educate people, especially those in emergency rooms and life guards and so on, that if someone is suspected of having air embolism they should not be sent home, they should still be sent to the chamber even though they appear to be perfectly normal. To get this message across is very difficult.

I am very happy to see research being done on air embolism. When I first got into this business I asked about air embolism and was told, "Well it's due to holding your breath as you ascend and you rupture your lungs and you die and that's it." Des Gorman's lecture last night was the first time, other than Hallenbeck's articles in the last few years, that somebody is doing something about finding out exactly what is going on. It is necessary because patients do not fit the picture that is in the text books or in the training manual. For example, I have never seen frothy breath, or bleeding at the mouth and nose in air embolism, yet every text book has that and it is said to be the primary thing to look for. We have been on the radio and the boat skipper argues with us and says, "Yeah, but he does not have frothy red bleeding at the mouth and nose therefore he cannot be an air embolism." That is a very unfortunate situation. I do not know the source of this misinformation, possibly it was the US Navy, but I have never seen it with a patient.

Again I would agree that it is very strange that one does not get pneumothorax and mediastinal or subcutaneous emphysema with air embolism or even two of the three together. It doesn't make sense, there is something more to it than the standard explanation. I do not know what is happening. We have had only three or four embolisms who also had a pneumo-thorax and we have had maybe two air embolisms that also had subcutaneous or mediastinal emphysema, that is all.

It has been suggested that perhaps the explanation is the effect of a small volume of air in the cerebral circulation is much more noticeable than the same 5 ml of air in the mediastinum or in the pleural cavity. That could be true, but we do actively look and try to find air in the mediastinum and pleura and yet do not demonstrate it.

Very often by the time they arrive at the chamber they only have headache and chest pains. We go by their history extensively and diagnose air embolism that is asymptomatic if the history is strong enough in an air embolism direction. But very often headache and chest pain are the only things present and I would suggest that that is something to look for. Nausea and dizziness are also quite often present, and many more types of things occur. We have had a number of seizures and the immediate reaction in the chamber during treatment is to blame oxygen toxicity. We have had three patients fit in the chamber during treatment. All three occurred at 9 msw (30 feet) not 18 msw (60 feet) and I believe all three were due to air embolism not oxygen.

### **Decompression sickness**

What causes can I point to in Southern California in cases of decompression sickness? One of the causes is very simple, tables are not used. Not which tables or any of that, they simply are not used in the majority of our patients. They simply ignore decompression procedures. There is no magic special reason. It is a very straight forward reason. Why are they not used? The majority do not know how to use them. Those that do will give you answers like, "Well it is just too much trouble", or "I don't think it's important." And that is the cause in the majority of our cases. Twenty eight per cent of our cases are directly due to exclusive reliance on the SOS decompression meter. In the last two years we have not had a single case because of these, I think they are on the way out and I am not very happy about that. They are very dangerous gadgets as far as I am concerned. In many cases the watch and depth gauge are not used. Many divers wear them but do not use them. We have a very difficult time extracting dive profile information from the patients.

Delay in seeking treatment is a disturbing feature of sports diving cases. Our average delay on bends cases is over 24 hours and yet they do well. We have had a three week old case that we treated successfully.

### **Question**

Unknown speaker

Where I come from the sports divers use tables and the abalone divers do not, yet they do not seem to get bent. What is your experience and what is your explanation.

### **Dr A Pilmanis**

We have had many, many hours of discussion along these lines. I think first of all you have to question what a particular diver means when he says he does not get bent. How do you know he does not? Have you done a neurological examination on him? I have sat for hours with abalone divers and have been told, "I'm fine, I'm fine," and suddenly three minutes later he says, "Hey, that pain just cleared up." My response is, "What pain, you said you were fine." We put people in a chamber who say they are asymptomatic and they tell us, "Oh boy does that feel better." The pain has gone, this is resolved and that is dissolved. Human nature dictates that in certain situations people deny. That is number one comment.

I am sorry, I will not accept that statement without further elaboration. I do not believe that abalone divers' physiology is different from sports diving physiology, nor from Navy divers' physiology nor from commercial divers' physiology. The laws of physics apply to all. I question the basic premise. I certainly accept there are certain individuals that are "more susceptible to the bends", or less susceptible. There is a distribution curve people are on, certainly. But one cannot define that curve individually. One cannot pick out one individual and say you are here on the curve. It is almost an impossible thing to do. I am not answering your question basically because I cannot accept the question or the premise.

### Financial problems

We make no money from the use of the chamber. The patients usually do not pay. The collection rate is almost non-existent and as a result it is a publicly supported facility. Most other chambers that depend on diving accidents are either closing or are somehow supported publicly. They cannot exist on the income from divers. Divers will not pay their bills in the United States. Most of them have insurance and still will not pay.

However our chamber operation has never been successfully sued. I said successfully, that is nobody has collected a thing. There have been six law suits during our 12 years that the patient or relatives initiated. In all six cases they named everybody in the world except our chamber. We feel grateful, we thank them profusely, but I do not know how much they collected. This is a constant threat, the number one reason why our chamber will probably, or could possibly, close is because of insurance rates. The University insurance went up from \$200,000 last to \$2.5 million this year. Rates like that mean you can't operate.

### SUMMARY

I feel in diving accident management the easiest part is after you get to the chamber, the hardest part is getting patients to a chamber adequately and I think communications and transportation are the key. I would put a patient on true 100% oxygen, in order to exclude nitrogen, and transport him on his side, also head down for suspected air embolism cases, as soon as possible as close to sea level pressure as possible.

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### DECOMPRESSION TABLES AND DIVE COMPUTERS

**Andrew Pilmanis**

#### Decompression Tables

I firmly believe that the Standard US Navy Tables when used to the limit cause bubbling in the body in 100% of the population. This has been shown by Doppler studies, years of them. So what do you do? What we have done in our own facility and are encouraging around Southern California and Canada is to switch to other tables.