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# THE IMMEDIATE MANAGEMENT OF THERMALLY UNBALANCED CASUALTIES IN THE FIELD

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From listening to the previous lectures, I have come to some conclusions. The first one is that “Man was not meant to fly”. I think that man was not meant to dive, either, after what we have heard for the last day and a half. I gave it some thought last night, early this morning and during lunch, and I have concluded that perhaps we should adopt Dick Longs’ “System Approach”. Man is very poorly adapted to diving, but women are apparently much better adapted to diving. It is my feeling that those of us here who are involved in professional diving should simply supervise and leave the diving to women. No, I’m serious. Women have a much better distribution of subcutaneous fat and also those areas have been demonstrated as high heat loss areas - the hands, the head and the feet - are proportionately smaller. Also the genital region doesn’t have as much surface area, so maybe this is really the answer to some of our questions. It should make life happier on the rigs and barges, at any rate, and that allows both a physiological and an anthropomorphic reason to justify my “Systems Approach”.

During this session we want to focus our attention on practical problems and find ways to apply known physiological principles. It will be our responsibility to apply these facts to diving operations in order to save lives. We also want to stimulate the imaginations of the divers in the field. They may see opportunities which researchers or physicians or engineers are not aware of, for the application of scientific principles to solve practical problems.

I want to take the speaker’s prerogative, before I get into “nuts and bolts”, and address one of my pet subjects: the preventive aspect of diving medicine. One of my interests has always been preventive medicine, and one of the reasons I have chosen to remain in diving medicine is that I feel it is an area where preventive medicine and preventive engineering can be applied with greater benefits than other fields that I am familiar with today. In diving and aviation, the preventive medical aspects have certain parallels. Most people today, even many pilots, do not realize how much physicians and engineers worked together in the late 1930s and throughout World War II to solve an awful lot of problems in aviation similar to the ones that we now face in diving. It was a genuine co-operation and exchange between these two professions.

One of my concerns is environmental control and, in my opinion, environmental control in the diving industry today is inadequate. There are lots of different systems, and there has been a lack of communication among the people who design the various systems. Every time a diving company wants an environmental control system, it decides to design its own, so we end up with a hodge-podge of things. For instance, within our own company, we had sixteen environmental control units on sixteen different rigs, all inoperable for sixteen different reasons during the month of August.

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Another point, which Paul Webb touched on earlier in this meeting, is the fact that we spend thousands and thousands of dollars, and incalculable amounts of pounds and guineas and cents, trying to send a man down into this hostile environment to perform work which demands two unique human qualities: judgment and psychomotor skills. We continually compromise both of these qualities, man's judgment and his psychomotor skill, by either overheating him or underheating him. You have seen physiological evidence that, whether too hot or too cold, the first thing affected is the brain. Such men cannot make good judgments and they cannot perform well. I just reviewed the design of a life support system for a device that is supposed to enable men to work effectively at 3000 feet. As proposed, this life support system would have placed the men inside the device into a situation of severe oxygen toxicity well before the calculated duration of the life support system had been exceeded. This kind of thing just goes on over and over again.

But let me back my first point about prevention. To prevent accidents, which is fundamentally why most of us are here, we must maintain the man's cerebration, his judgment and his manual dexterity. Many, if not most, accidents begin because of judgment errors. Perhaps the most common factor compromising judgment in diving operations is chronic fatigue. I want to cite an example which I saw recently on a rig which shows how the lack of a systems approach can cause problems years later. This happened aboard a drilling vessel in the Adriatic off the coast of Yugoslavia. During the design of the diving system, it was assumed by the people who were putting it together that "Gee, it's going to the Mediterranean and that's a nice sunny place." We have all seen the travel brochures. Constructing a control shack - a control van, and having air-conditioned or heated, was just ignored entirely. In fact, it was brought up at the time, but management said, "Man, you guys are going over to the Mediterranean. We don't have that stuff in the Gulf of Mexico and you don't need it there." We had always gotten by without them before, and so away it went.

Well, if they had asked me, I probably would have said the same thing, if I had been in the same situation of allocating dollars and making those kind of decisions. But in fact, the Adriatic off Yugoslavia in November is subject to 70 and 80 knot winds, and temperatures of freezing and slightly above. I don't recall the wind chill factor on that, but it is pretty cold. To expect people to stand saturation decompression watches outdoors, or wrapped up in a jury-rigged tent, is asking a hell of a lot of them. To put a man on watch in one of the most dangerous situations possible, one of extreme boredom in watching gauges where a slight deviation of one could be significant or foretell a disaster, where he is expected to make quick and accurate judgements because incorrect hasty judgements can be fatal - and then expect him to be able to manipulate a series of valves with half frozen fingers - this is extremely poor planning. We got trough that all right, but only by standing short watches. It was just too cold to stay alert and awake for longer periods. Dutchy and I happened to be there to add two more people to the crew, but in the usual situation there might have been only two people available, three at the most, to man those watches. So, in addition to exposure factors, you have the fatigue factors that mount up over the days to give you an intolerable situation from the standpoint of potential accidents.

Nobody in the diving industry is quite ready to accept this yet, but I think we are going to have to look at crew size. You might have to pay more at the gas pump as

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a result, but I think that, in general, we operate with too small a crew, particularly for longer duration saturation dives. I think someone who has expertise in this area should look into the situation and define optimal watch-standing periods. Now, that is not a terribly esoteric physiological problem, but there has been some work done on it by NASA. A spacecraft would have its crew in a similar situation, sitting on one position and watching gauGes. They say that the maximum time that you can expect a man to be able to perform optimally under such cIrcumstances IS about four hours. HowevEr, in the diving industry, twelve hours is the common watch period. Simple little things like that, I think, can be highly significant.

I was a bit angry at Glen for starting off by talking about how it is better for divers to be a little chubby, because one of the problems that I have is trying to promote physical fitness among commercial divers. In general, they are among the most unfit people in industry, and understandably so because, at least in rig diving, there are hours and hours of boredom and inactivity punctuated by rare interludes of panic. They sit out there for two weeks without diving and are subjected to a very boring situation and denied most of the niceties of life. The only escape is to go to the galley every six hours, and eat too much. We tried an experiment in the North Sea of putting bicycle ergometers on rigs, and offered rewards to the crew that pedalled the most miles during a two week tour of duty. Things like that are worth trying because poor physical condition decreases tolerance to the type of things we are here to talk about: hypothermia and hyperthermia.

Adequate nutrition and hydration certainly are significant as well, not only simply in the long term, either - they are damn significant in the short term as well. No commercial diver, I imagine, has ever come back from a dive without being in a relatively dehydrated condition. No effort is made to see if that man is at least adequately hydrated before the dive. One thing which I have advocated for years is having something to drink in the bell so that, when the diver gets back inside, he can drink water, or lemon squash, etc., preferably something with electrolytes and all those good things in it. These things can make a difference and can influence decompression. It can influence your resistance to heat stress and cold stress that we have talked about.

We have talked about the types of build, and to look for symptoms earlier as far as the hypothermia is concerned. One of the problems that still plagues us is the inside tender of the bell; he is the one who is getting decompression sickness more often than the diver who is out in the water. There are several speculations as to why. It could be that he is colder inside the bell than the diver is outside. Also it could be that they neglect running their scrubbers because of interference with communications. Simple operational things like this do matter. In general, we are too sloppy in our operations and we need to improve. A diving company should be able to say: “OK, we have taken a systems approach, and we have looked at it, and we think there are several little things that we can do that might significantly influence our accident rate, and by God, all you guys in this area for the next six months are going to do it this way. Period. And we’re going to gather the data on it and see whether it makes any difference”. Maybe the guys in another area don’t even know about the “experiment”, but that kind of thing needs to be done. We have talked about laboratory experiments but this is an experiment that can be done offshore. This

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is a very simple experiment. It is an operational experiment.

There is one more area, which we did not quite touch upon, which concerns nutrition and preparation for a dive. I have seen one near casualty that I think I can attribute to this, and I just want to bring it up to warn others. People ask about alcohol. We know what it can do in short term. One of the things it can do in the long term, however, is cause hypoglycaemia. In addition to hypothermia, and quite often I think in conjunction with hyperthermia, a contributory cause of accidents has been alcohol induced hypoglycaemia. Divers by tradition are spree-drinkers. They do not drink on the rig, but when they go ashore they often stay in a mild degree of inebriation for about two weeks. Occasionally in the North Sea they arrive at the helicopter pad and have to be helped onboard the helicopter. I have known several occasions where they arrived on the rig and were immediately asked to dive, have admitted later that they were actually drunk when they did. Now, that is one situation which is bad enough to begin with. What is worse is a guy who is a little more conscientious, who says, “Well, I’ve been having a right good run ashore, and I’ve got to go offshore about three days from now, so I’m going to taper off”. Well, he does!

This is a perfect situation for reactive hypoglycaemia. This man doesn’t even have to be an alcoholic. He just has to have been drinking a fair amount over a week. If he has been ashore longer, that just makes it more likely to happen. This is something the FAA recognized years ago. It happens to doctors and lawyers who make a lot of money and spend it on airplanes. You know, they have three drinks, three cocktails at night for a month, and then they get two weeks off and they decide to fly to Catalina or the Grand Cayman or somewhere in instrument weather conditions, and the second day out they start to get a little shaky and they are sweating. They might end up in a thunder storm, and under the stress of the situation they become hypoglycaemic, pass out, and then crash. This is a result of something that happened days earlier. Let me warn you that divers set themselves up for this particular situation every crew change - either the situation where the diver has stopped all alcohol intake three days before, or where he stops when he arrives out on the rig drunk and is called to dive. Alcohol and exercise really aggravate hypothermia.

We had a mysterious occurrence which turned out to be a near accident, where a diver was doing a 400 foot dive off Vietnam. He came back to the bell after the dive and was getting up into the bell when he just lost consciousness. There was never an adequate explanation for it, although, when he got back to Singapore, he had EEGs and a really good neurological workup. When I got the history of it, I found he had taken three days to get from Singapore to the rig. It probably was not his fault- he had to go on about three different short haul airplanes and never checked into a hotel, although he did spend the night in Saigon before going offshore. This man’s entire diet probably consisted of alcohol in one form or another for three days, and within an hour and a half after arriving on board the rig he was locking out at 450 feet. And, gentlemen, that is not a good situation for several non- medical reasons. But for sound medical reasons as well, it is very dangerous. Be advised, and beware of similar situations.

To sum up this section of my talk, I propose that every diving system that requires prolonged decompression watches, say, more than eight hours, should have a control

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van. The van should have an environmental control system as well as the DDC, which means it should be airconditioned or heated so that the man inside on watch stays awake and comfortable, mentally and physically prepared to make the necessary decisions. Someone should consider a look at our watch schedules in the light of safety and efficiency, and be aware of the point I brought up about diving and alcohol, and the post hypoglycaemia.

I want to tell you a sea story. It is a true one and most of the people involved with diving will recognize a lot of the things that went wrong and why. I want to tell you a bit about the Johnson-Sea-Link submarine entrapment, tell you some of the things that may seem peripheral, but really are significant to the overall situation. I was there, and two of my friends died in the submarine, and I know the background quite well. I want to tell you some of the errors that we made. I share the responsibility for becoming lackadaisical in our attitude toward submarine operations. We had been operating for nearly a month very successfully, training a team in shallow water. We had gotten down to a smooth operation, had gotten into a bad habit of allowing joy rides in the submarine as well. It was the seventh dive on that wreck when we got entangled. The fatigue factor was there, I know from personal experience. Submarine operations generally require an 18 hour day because you are up at dawn and charging batteries and running two or three missions, then there is always a mechanical problem to correct. By the end of the day everybody sticks together and works on it until it is over. The fatigue had been allowed to accumulate. In fact before that dive we had been up until 2:00 in the morning. Nobody knows and nobody can quantify how much that applies to things.

The original dive plan did not include divers in the after compartment. It was a mission to go down and pick up fish traps, and afterward we planned to go down and do a lock-out dive on the wreck. We had done one lock-out at that depth. We knew it was cold, but we relied upon the diver’s judgement, and we did a lock-out at 350 feet in bathing suits. We were going to wear wet suits the next time, even though we knew we would not get much additional protection. It was colder than we had expected. We had actually measured the temperature on the previous day for scientific purposes, with a recording device that we had attached to the submarine, and I am ashamed to admit now that we were so unconcerned that we didn’t even look at it. We knew it was somewhere around 55° to 60°F.

During the pre-dive briefing, we decided, “Well, a couple of guys want to go along on an observation dive. No lock-out. Just ride along for familiarization with the sub”. Clayton was only there for the weekend. It was a last minute decision, and they walked back and got into the submarine wearing sport shirts and short pants and tennis shoes. It was stupid for us to allow that, but we had done it so many times and gotten away with it, just as all of you have in various diving operations, that we simply were not concerned.

There was some lack of foresight in design. The acrylic sphere in the forepart of the submarine was an excellent insulator. In fact, I nearly died of hyperthermia in it in another episode, where I got trapped on the surface and couldn’t be picked up after the air-conditioner failed, but that’s another story. Aluminium, even if it is very thick, is a very good conductor. That was something we had really not thought about. The after compartment - the diver compartment - should have been

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insulated, but we had never felt any discomfort before because it had usually been operated at one atmosphere or pressurized only with air.

We all knew of the loss of efficiency of sodasorb scrubbers as temperature decreases, but we really had not thought a lot about the consequences. We knew the sea temperature was 55° to 60°F, and we knew we had plenty of sodasorb to last the duration of the dive we had planned. The suggestion had been made that we should use lithium hydroxide or at least carry lithium hydroxide for emergencies, but it had been turned down on the grounds that it is too expensive. It costs $7.00 a pound versus 65¢ for sodasorb. You know that is an easy kind of situation to get into when making those kinds of decisions. Lithium hydroxide costs several times more, and we had always used sodasorb. Lithium hydroxide is toxic, as well. Let’s not bother. The fact is that, if you look at the overall cost of a diving operation and count the capital investment and the depreciation on it and things of that sort, the difference between sodasorb and lithium hydroxide in any situation where you may be exposed to cold is simply insignificant. So you ought to consider having lithium hydroxide available for an emergency entrapment situation. I am sure you are all aware that the scrubbing characteristics of lithium hydroxide are very good. Between 70° and 35°F the efficiency falls off very little, whereas sodasorb falls off to practically nothing at 35°F. These were all things we could have done earlier.
We had thought about the possibility of entrapment, and, in previous operations with diving bells, I had always insisted on having bolt cutters on board when I was in the bell. But we had not done it; we had promised to do it the next time we were in port.

Little things like that creep up on you you know. One of my pet tenets of philosophy is the well known “Murphy’s Law” and I think at sea it applies one hundred percent of the time: if anything can go wrong, it will go wrong. And if there is a possible chain of bad events, it probably will occur in that chain and not just one at a time.

Well, the submarine went down on a routine mission, tried to pick up the fish traps, got entangled in a wire from a radar target on the ship, and that is where “Murphy’s Law” came into play - the moment that the submarine became entangled.

The submarine had three motors aft, mounted vertically. The pilot had a red light on his control board indicating a top motor failure. The submarine was hung up and the pilot knew he had fouled a wire. He could look back and see the wire, but he could not quite see where it was going. And just then, practically simultaneously, the motor goes out. So everybody assumed that the cable was fouled in the propeller. We found out later that the wire was not in the propeller. It was fouled in a snap hook, a snap hook on the starboard side of the submarine. The hook didn’t even need to be there. At one time there was a necessity for that snap hook, but when that necessity ceased, since it was a potential hazard, that snap hook should have been removed. But that is the overall thinking I am trying to stress. It needs to be applied to these kinds of systems. From that point on, everything went downhill.

The men in the forward compartment, even though their scrubber motor failed, were able to improvise a scrubber. They took their shirts off and lay sodasorb onto them to fashion emergency scrubbers which performed adequately for the entire 36 hours or so that they were trapped. They had acrylic to insulate them from the cold. The

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people in the after compartment, who were in an air atmosphere initially, started to get very cold, they started getting $CO_2$ buildup. As the $CO_2$ buildup became more and more severe, the only alternative was to go onto the BIBS. One of the things we had neglected to really think about operationally was, “What happens when you go on a BIB system when you’re at 350 feet and you don’t have an overboard dump?” Well, the exhalation starts to pressurize the compartment. It is all very easy to see after the accident, and perhaps someone else has thought of it, but I had not really thought about it up to that time. Within an hour and a half or so, they had pressurized by exhalation alone to over 80 FSW. Nearly 100 FSE, we thought. It turned out to be 100 feet because the gauge, the Caisson gauge inside, had gotten out of calibration. At that point, we switched the BIBS to heliox which made the situation worse. We switched the BIBS to helium to protect the people from nitrogen narcosis and to reduce decompression time when the rescue vessel arrived.

Well, the colder they got, the faster they breathed. And the faster they breathed, the more they pressurized the compartment. Within about four hours the bottom hatch open equalized at 350 feet. They were trapped in a predominantly heliox atmosphere in shorts, tennis shoes and shirt, and they were really cold, really suffering all this time. Their judgment probably was starting to be affected, because at that point one rescue attempt had been made and had failed, and I estimated from $O_2$ partial pressure that they had from 45 minutes to maybe an hour and a half of consciousness left, but probably not more than 30 minutes of effective operational time. I suggested to Jock Menzies that they lock-out and try to free the submarine and we discussed this back and forth for a while. There was no way we could force them to get out, and they elected not to get out because they were under the assumption that there was a wire in the propeller and they did not have the tools and doubted they would be able to free it. They felt that their functional decrement was too great. They had the diving gear to do it, which was something that was misrepresented in the reports. They could have made a lock-out. That was the real tragedy of the situation in retrospect. There was one wire hooked under the snap hook, a hook with a spring mouse on it. Had they known, I still believe that, at that point, they had sufficient and physical power left to do a breath hold dive from the hatch up to that wire and, with one hand, press in that spring- loaded mouse and pull that wire down and then get back into the submarine. But that is not the way it turned out.

So. Let’s review one more time some of the things we neglected. We did not review our operation in a systematic manner. We were too optimistic. We did not anticipate all the possible bad things that could happen. Well, unless you do those things you are going to get caught by “Murphy’s Law”.

Hypothermia

To introduce the immediate management of hypothermia in a friendly spirit of disagreement, I will jump right in where Larry Raymond left off yesterday, saying “Well, it’s not really an emergency anyway. Get the guy back into the bell, bring him up on deck and transfer him into the DDC and you’ve got plenty of time to rewarm”. Based on my experience, I should say first of all, you will have a lot of trouble getting the diver into the bell. Secondly, once you get him into the bell, you are going to have trouble closing the hatch; the “O” ring probably will drop out, better have a spare. And in the third place, after you have surmounted all these obstacles

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and gotten the diver into the bell, the winch will probably fall. So, what I want to focus on are the ways to treat these casualties and others that require immediate treatment. In my feeling, acute onset hypothermia, of the degree that is possible at 1,000 feet breathing helium, is a real emergency that requires immediate treatment if it is available. I will take that stance for the sake of the discussion.

Now, what should we do? The first thing to do is to remove the victim from the cold environment. You should at least remove him from the water. That is a colder environment than in the bell. A lot of the bells I have seen are not even adequately equipped to remove a diver from the water if he is unconscious, and unable to assist. First of all, you've got to have a harness. You've got to have a harness that picks him up in a position so that he is able to breathe, assuming that he is still able to breathe, or, if he is not able to breathe, a harness that assures an open and accessible airway so that you can breathe for him. I would be willing to wager that something like 60 percent of your harnesses will not allow for the fact that you are going to pick the diver up by a simple chest harness with a pick up point in the back, and the diver's head will be held forward and down by a heavy helmet or mask in such a manner that his airway is shut off automatically. So the practical solution to this problem is to devise a harness that picks up from some point on the front of the chest.

You've got to have a harness on the diver, you've got to have the pick up point in the right place, and you've got to have a winch to lift him. We have rigged tackles, all different sorts, and you end up with lines running everywhere, all tangled up, and the blocks capsize. It really does not work. It works in the dry, it works in the drills, but "Murphy's Law" applies here, too, and in a genuine emergency it will fail. A very nice device does exist: I don't even know the trade name of it, but Dick Long probably sells it. It really works and it is one of these aircraft cargo winches with a ratchet drum. But you don't take rope and put it on the drum with the ratchet, that's too slow. You run the rope through it for four turns, so that you have a tail on it that you can pull to get the diver up and into the bell hatchway. At that point you can crank the ratchet to help pull him up into the bell.

The second thing, if you do not have a winch or if the one you have does not work, is to get him inside the bell by flooding. Practice it. Have your scrubber out of the way so that you can flood the bell halfway, and then float the diver through the hatch. It really works well when all else fails.

Once you get him in there, assume the worse possible situation. His heating system probably has failed. He is at 1,000 feet and both his suit and his respiratory gas heating systems have failed - despite the fact that you have redundancy through the entire system, ie., you have two pumps and two heaters or at least an alternate source of heat.

One should be enough, but Dick Long has been granted immunity from "Murphy's Law" so you can just get by with one of his, but we try to have one Dick Long unit and one alternate system for heating water, just in case.

Open- circuit hot water suits are the greatest thing that has come along, but I would like to see some more emphasis and ingenuity devoted to closed-circuit hot water

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suits, because they can continue to work inside the bell. The bell tender is the guy who is now getting the cold exposure. We could eliminate some of the variables from our decompression and other things by having both divers at the same temperature, both the bell tender and the diver, and they could even stay at a constant temperature during the adiabatic cooling during decompression. When you consider lock-out submersibles, I do not see any practical engineering possibilities other than closed-circuit suits. We would welcome them from anyone at a reasonable price.

Now remember if you have a total hot water failure, you have about 20 minutes before the body core temperature starts to fall off rapidly, so you have time to get back into the bell and get things squared away. But you must also remember that respiratory heat loss begins immediately, so if you do end up with a closed-circuit suit and there is a failure in the water, don't say, "Well, I've got to finish the job. And they told me I had 20 minutes before my core temperature starts to drop because I've got a dry suit on". Don't do it, man! While you have the chance, get back in the bell before you start to be affected by respiratory heat loss.

OK, we've got the diver back in the bell. We have overcome all these simple seamanship problems, and he is back in there and the hatch is closed and there is an "0" ring under it and you've got the hose taken care of - cut it away, let it go so it won't be in your way. You don't know the core temperature because we don't have monitoring systems yet.

The patient is unresponsive; he doesn't have any detectable pulse. You are looking for a carotid pulse which, if you have a backlift harness, you are not going to be able to reach. What are you going to do? Here is a cookbook approach: first thing you ought to do with the diver, when you get him up into the bell and his head out of water, is to give him immediate mouth-to-mouth resuscitation. That is the warmest gas you have around at the moment and he is not breathing very well, so don't hesitate. As soon as you get him out of the water, breathe for him and then proceed with all these other details, and every chance you get, stop and give him a few breaths because his brain cells are dying all the time.

OK, let's look. What assets do you have, now that you have the diver in the bell? If you had to flood the bell, you now blow it dry. Let's hope you have a situation that will allow you to blow it dry. What do you have on hand that you can use to revive him? Maybe the hot water is back on line. Probably, if you had a failure, it was somewhere topside and by now perhaps it is repaired. You should have your system manifolded so that you can now use your hot water suit, open-circuit or closed-circuit, in the bell. We discussed controversies about warming the extremities, etc. You don't have a whole lot of choice in the bell because they are very small, and for you to get into a position where you are able to perform cardio-pulmonary resuscitation, you are going to have to have him lying down on top of the inner hatch and probably on top of a coil of hose. You are going to have to have his legs and arms out of the way and that probably means throwing a hitch around his ankles and trussing him up somewhere so that you can get to him. You will be rewarming him in almost the position described for use in a tub, ie., keeping the extremities out and elevated. But frankly, it doesn't really make a damn bit of difference. I would not worry about the acidosis; I would not worry about the blood in the extremities; I would try to get hot water going over him, because the alternative in this

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circumstance is almost invariably death, and almost anything you do is going to be correct. It is going to help him. I hope that the hot gas method is going to be a lifesaver in this situation, although I admit that more work needs to be done and more and more measurements made. I hope that somebody will start making them soon. But you have the apparatus to administer hot gas; you have a diving helmet, or a mask with a heat exchanger, and your heat is back on line, so start giving him hot gas again. You want warm gas to go over his head, because 40 percent of the heat loss can occur from the head. This is exclusive of respiratory loss, which is the main thing we are concerned with in a hyperbaric situation. Take advantage of any avenue to warm the victim, and if you have a helmet, put it on him. You do not have to fasten it down, but just put it on him loosely so that you have a constant flow of warm breathing mixture over the victim's head, as well as into his lungs.

Well, what are the liabilities in this situation? You are probably at least a half an hour away from that DDC, even in the best operational situations. I am talking about after you have gotten the diver into the bell, gotten a seal, left bottom, passed through the interface, gone through the problems of transfer, etc. Now, suppose you have a total heat system failure, and the hot water does not come back on line? This is where I would think that central rewarming is going to be the most valuable emergency device, beside the well-trained diver, that we can have in the bell. I do not think a device exists yet in any respectable form. Studies need to be done to see if any damage is done. The two people who have done work with central rewarming are Lloyd in Scotland and the people in Vancouver.

The data from Vancouver does show the after drop in core temperature with central rewarming. They did not use the same device that Lloyd did. They were cooling the subjects in sea water, and they had them out on a ship where they had a tub to put them in, with a respiratory rewarming device. These subjects had to climb up the side of the vessel when they got down to 34° or 35°F $^{\text{rectal temperature}}$. They climbed out of the water by themselves and walked across the deck and got into the tub and began to use the central rewarming device. It is possible that the difference in the data on the afterdrop could occur from their exertion and movement in climbing up and going across the deck.

We have heard Dr Raymond talk about the disadvantages and the possible danger, so bear them in mind and don't go running out and jury-rig these things and use them unadvisedly. We really require further research on it. However, I would be willing to say, given Lloyd's cases in Scotland plus the work in British Columbia, that if you have no other source for rewarming a diving casualty outside a bell, the tub of warm water is an acceptable emergency form of rewarming in this acute situation and I would use it. But I may regret these words one day.

Dr Lloyd found no after drop in core temperature, so you do not have the rewarming collapse. He feels like this form of rewarming warms the brain earlier than putting someone in a tub and running hot water over him. It has not been proven in humans, that I know of, but there have been dog experiments in Germany which claim that the vasomotor centre in medulla ceases to function at about 81°F. Cold-triggered impulses from the skin may keep the blood pressure elevated in an acute hyperthermia situation. There is a danger here of dumping somebody into a tub who has been through all this cold and hydrostatic pressure effect, and who now has an inadequate circulatory

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volume. These investigators feel that the central rewarming might heat the brain first and wake up the vasomotor centre, thus allowing the body to get a little edge on the situation by peripheral vasoconstriction. This could avoid, or at least help offset, the hypotension that may occur if a hypothermic person who is volume depleted is rewarmed peripherally instead of centrally.

Are you familiar with Lloyd's device? It is different, I think, from the Canadian one. The mountain rescue teams in Scotland use it. It is just a simple canister. This is in cross- section. It is called a watters canister, a to and fro anaesthesia circuit, with an oral nasal mask. There is a $CO_2$ cartridge which BOC produces to pressurize beer kegs. The canister is filled with sodasorb, and you fire the $CO_2$ cartridge off and the exothermic reaction of this $CO_2$ reacting with the sodasorb jacks up the canister temperatures to around 60°C. They were so incautious in regard to temperatures that they did not measure them initially, but they found that this is within the temperature range which the hand can tolerate without much stress. So they just fire off a couple of $CO_2$ cartridges and, if they're out there up on the mountain top and they still don't feel the canister is warm, they fire off another one. They already have the victim breathing oxygen anyway, and the highest the $CO_2$ level reaches in a mask is about 5 percent.

They continue on with this, and if the thing starts to get cool by touch, they fire off another cartridge. It is a pretty simple little device. We already have the makings of that in the diving bell. We have scrubbers in there, and some of the more advanced companies have devices that you can put on the scrubber, so that you can breathe on it in a passive mode. All you have to do now is bravely add some little $CO_2$ cartridges to your system. You would not want to use pure oxygen, of course.

I understand that the US Army has one of Dr Lloyd's devices at Natic now, and they are running some tests on it. If I can get hold of one, I want to run some tests at Duke on pigs. We will get a pathologist to take a look and see what we are doing. Lloyd did report, in his first series of eleven patients, that two cases presented laryngeal problems. I think one case was laryngeal oedema and one case of "scalding of the trachea". That is kind of imprecise, and I don't know how scalded it was or just what they meant, but I suppose they got that conclusion on autopsy.

I will read something to you of what Lloyd says in his paper. The reference is Lloyd, et al. Conrad and Walker. It is called, "Accidental Hypothermia - Apparatus for Central Rewarming as a First Aid Measure," *Scottish Medical Journal*, 17:83.

A general summary is that heat should be applied centrally to warm the body selectively. The equipment should be compact and lightweight to enable it to be carried by rescue teams. That means it has to be small if we are going to allow it to be carried in a diving bell, because it is going to take up space. We are not so concerned about the weight, but space is at a premium and we don't want anything in there that we hope we will never have to use. It should be simple to use as well as safe, since people that are using it are likely to be non- medical.

That is all I have to say now on the subject of hypothermia - no, wait. I have one more thing that I forgot. Let us suppose the winch did not fall this time, and we did get the diver all the way back up into the DDC. Now we have a choice of using

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a hot water suit in the outer lock, or simply filling up the entrance lock part way with hot water.

If this had been a routine cold water dive, the diver probably is going to be relatively dehydrated, and despite the low metabolism in the periphery, he probably is going to have some mildly acidotic blood trapped in his extremities. He is going to be sort of anaesthetized from the cold, and this is an excellent opportunity for the medic to get in there and practice starting an IV of warm lactated Ringer's solution, 1,000 millilitres. One thousand millilitres of warmed (which means body temperature or slightly above) lactated Ringer's does not mean a great deal in relation to the whole blood volume, but it becomes a more significant percentage if you consider that this man is still in acute hypothermic state and completely vasoconstricted in his legs and arms. What you are doing is trying to dump one litre into the central volume. It may not be highly significant, but it serves two functions: it adds a few calories, and it allows access to his circulation. In mountain rescue situations, they have to consider this problem all the time because, when they start their IV's, they often find them frozen. They are trying to resuscitate a hypothermia victim and they are giving him extremely cold intravenous infusion. I think we ought to try to give our diving casualties warm infusions, and I think there are enough data that we can assume a relative dehydration that will allow the safe administration of at least 1,000 millilitres of lactated Ringer's solution on a purely empirical basis. You will not have any laboratory data or anything else until you get the diver to the point where you can start to monitor his urinary outputs, and listen to his chest, and be aware of things so you do not overhydrate him. That is where I was going to stop on the hypothermia side. While I do not really welcome it, those who have strong criticism of the intravenous recommendations are invited to speak forth now and later.

I think the standard things that come in the little handbooks about treating hypothermia anywhere are applicable if you have gotten the diver through the decompression phase.

Remember, when you look at the fact, you say that is a rather insignificant amount of heat to add, but let us go back to the principle of removing him from the hostile environment. He is still in a cold bell, and if he is breathing at all, he is still going through a decreasing but very real respiratory heat loss. So, assuming you are still with him, you can at least slow down his rate of loss by eliminating that factor of respiratory heat loss. Beyond that, I am open to suggestions.

Hyperthermia

Now I am going to talk about hyperthermia. The other speakers have covered the physiological aspects of hyperthermia and heat stroke very well. I have just searched the literature, and Dr Webb has sent me all kinds of good things over the past few months, but on my way out here on the plane I discovered in the March 1976 issue of *Aviation Space and Environmental Medicine*, this article: "Heatstroke: A Review," by Civelete, Lancaster and Bannon. This was an update of an earlier article by the same authors. It is about 17 pages long and quotes 270 references. So I really wasted a lot of time last week. These authors seem to feel, as I do, that the distinction between heat cramps, heat exhaustion, and heat stroke is over emphasized. Maybe it is a philosophical point, but I think they are all in a continuum of a syndrome that

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is developing, and they should not be looked upon as single clinical entities. Once you start to see the signs and symptoms of the most innocuous one, you should be advised that the more serious ones may well be on their way, and you should take appropriate action. Again, to add to what someone else said earlier, a heat exhaustion casualty is a candidate for evacuation from the rig, as far as I am concerned, because he needs to go ashore for medical evaluation. A heat stroke victim, no matter how mild, needs to get off that rig and be hospitalized for observation, because his thermo-regulatory system has been compromised. You do not want a recurrence either on your hands or on your conscience. Besides, he may have malaria masquerading as heatstroke, so get him off the rig.

Dr Webb discussed the accident on the Waage where two people died, and I am going to cover that in a little more detail because several things have been published which do not portray the situation as it actually happened. I am going to read through an interim report which I wrote after the investigation of this incident. Please remember this is an interim report, not a final one. It is an impression we had shortly after the accident, and after gathering considerable data through interviews with everyone involved, including some of the people that were observers from the crew on the rig.

As I have said, very few diving accidents are the result of a single factor. In this situation several factors which occurred previous to the incident contributed to the death of these two people. One of these factors was the operational practice of monitoring the bell (Submersible Decompression Chamber) depth by means of a master gauge, which is a common operational practice, not only in Oceaneering but in other companies as well. I do not necessarily condemn it, although it is not the way I would do it. I feel that every pressure vessel in a system should have its own independent pressure gauge, and this one did actually have that, but because some gauges are better than others, the supervisor had adopted the practice of using the master Heise gauge to track bell depth in the water.

The focus in the North Sea had been on hypothermia. Everybody there worried about hypothermia. We have heating coils and insulation and the like, and the practice had become routine on those types of dives to preheat the DDC (Deck Decompression Chamber). When they knew that they were going to make a dive, they turned on the steam coils underneath the deck plates in the main lock.

Ordinarily, after arriving on the deck, the chilled divers transferred under pressure from the bell into the entrance lock, and undressed. The entrance lock was not heated. The diver stepped into the main lock and warmed up. He could tolerate this for a time, and meanwhile some heat exchange was going on. But if it was too hot, if he was uncomfortable, all he had to do was to step back through the hatch and return to the entrance lock. He could cool off for a while, then re-enter the main lock. Meanwhile the system is equilibrating. Besides, this is a crude environmental control unit for dehumidification. With cold steel in the entrance lock, and all this hot steel in the main lock in a heliox atmosphere that is saturated with water vapour, a convective flow is created which precipitates water out against the cold steel of the entrance lock.

They were a little delayed in beginning the dive this time (they had a longer

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observation dive than usual) and the temperature climbed to over 105°F in the DDC. I do not know exactly how hot, but at least 115° to 120°F in the last time anyone looked. That would not have been significant if all systems had retained operational as they had been in the past. It would have meant that the divers spent a shorter time in the DDC before returning back to the entrance lock to cool off, and that equilibration between these two compartments might take a bit longer.

The bell arrived on deck and they prepared to transfer under pressure. On the first attempt, there was a leak at the mating flange. That is a common occurrence. So they pulled the bell back and over-hauled the seal and brought it back together, and this time there was no leak, or maybe just a slight leak at the mating flange. It was nothing to be alarmed about.

The diver transferred into the entrance lock. One of the divers was instructed to re-enter the bell and bring the gear out and transfer it as well, because they wanted to pull the bell away and clean it up for the next dive. At this point the diving supervisor, alone in the control van, noticed a drop on his master Heise gauge which ordinarily reads the main lock because it is the biggest compartment. He saw the pressure begin to drop and he thought, “Well, we’ve got a leak”. He instructed the divers to get out of the bell, into the entrance lock, and close the hatch because he thought that gas was escaping through the mating flange.

The divers entered the lock, closed the hatch and leaned against it to effect a seal. But closing the hatch did not seem to cause much difference in the leak rate. So the supervisor said to the divers, “Well, don’t panic. Get in the main lock and shut the hatch to the entrance lock”. So they transferred into the main lock and shut the hatch. One diver said, “Hey, it’s kind of hot in here”. But nothing seemed unusual. And the supervisor replied, “Don’t worry. We’ll take care of that in a minute”.

In order to get a seal on the main lock-entrance lock hatch, the supervisor bled down the entrance lock. This is the normal thing to do if you want to ensure a seal. And if you think you have a leak elsewhere in the system, you want to make sure you get a seal. He opened up the exhaust valve a little bit and he bled pressure off. I do not know how much.

At that point, the divers were trapped in the main lock. The supervisor was watching the pressure drop in the bell while presuming that the gauge represented pressure in the main lock. The gauge had been representing the pressure drop over the whole system until the main lock-entrance lock hatch had sealed. After that, it indicated the pressure in only the entrance lock-bell complex. Since the same leak was now draining a significantly smaller volume, the gauge indicated a greater leak rate than previously, about six times the rate. The volume had been decreased to one-sixty so the rate of indicated leak on the gauge went up six times.

There are very few emergencies in commercial diving operations in which you cannot just stop and analyze the situation and figure it out, but, when you see a six-fold increase in a gas leakage rate in a manned compartment, and you do not know where the leak is coming from, that is one situation in which you want to react quickly. And there is only one thing to do: start pressurizing and make up for that gas loss, and that is what the supervisor did. He pressurized.

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They were at 510 FSW and he pressurized to 650 FSW. The divers could sense being pressurized and they tried to tell the supervisor, but he did not understand. His sensory system was overloaded. He was watching gauges and adding helium while the crew on deck scurried about looking for a leak which did not exist. And then suddenly he looked up, switched gauges, and realized what he had done.

All the while, the divers in the main lock had been trying to indicate that they were being compressed. They were not unconscious. I am sure they felt an intense adiabatic heat load in addition to the 110° or 120°, but it probably did not exceed the short term heat loads that people can accept even considering the respiratory heat load factors. The divers in the main lock opened the equalization valve to the entrance lock which started reducing the pressure in the main lock, while the supervisor responded by repressurizing the entrance lock to make sure that they did not come up too far. The main lock and the entrance lock equalized at 504 FSW. This was within the safe upward excursion distance and they had no decompression problems.

Our policy for the past two years has been to tape-record the conversation of all divers. We do this for two reasons: one, to improve communications discipline by reviewing the tapes after the dive; and two, so that we might have a record of the sequence of events in case anything abnormal occurs. This particular dive had been taped up to the point of transfer under pressure, but after starting to transfer they felt there was no longer any reason to tape the conversation. So we do not know the exact time frame in which these events took place.

The divers appeared to act irrationally. One man left the DDC and one got on the bunk and they said some words to the supervisor and then they started holding their heads and they were noticed to be sweating profusely. They went rapidly through the entire clinical spectrum of acute heat stroke, culminating in dry, red skin, sweat glands exhausted. The holding of their heads probably would indicate severe head pain. They also had some bleeding from the mouth and nose which would go along with some of the reports of clotting problems and disseminated intravascular coagulation in heat stroke.

Up to this time, no one had recognized this as a hyperthermia problem. John Boyce really deserves most of the credit for first recognizing what had occurred. We analyzed the sequence of events and felt that what we were looking at was heat stroke, hyperpyrexia, as a result of heat loading from the high temperature of the main lock. The fact that they were recompressed in hot helium probably accelerated the onset of the fatal hyperpyrexia.

The UK Department of Energy investigators did not accept that diagnosis at first, but we had an autopsy at the University of Aberdeen which confirmed our initial impression.

Let me just read part of this report as a summary:

"Commercial working divers in the waters of the North Sea are a common occurrence, and the dangers of cold-hypothermia-are well recognized. To overcome the hazards of hypothermia, hot water suits, breathing gas heaters, thermal regenerators, and diving bell/DDC heaters have been developed. With the emphasis on hypothermia in deep diving, compounded as it is by the high thermal conductivity of helium, we have tended to overlook the danger on the opposite end of the temperature scale - hyperthermia. The hazard is there, compounded again by helium's physical properties, plus the complications introduced by high humidity and low flow velocities in the chamber micro-climate, factors which preclude the loss of body heat by evaporation and lead to heat loading with every respiration.

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"Once the body temperature begins to rise, cellular metabolism increases, producing greater than normal quantities of heat. Roughly speaking, at 108°F, the rate of metabolism of the cells is doubled; at 114°F, the rate is almost quadrupled. The hypothalamus, the part of the brain acting as the body's thermostat, functions poorly if overheated, and a vicious cycle occurs: elevated temperatures cause an increased rate of metabolism, which causes increased heat production, which elevates the body temperature and further damages the hypothalamus. Once the body temperature exceeds 107°F to 110°F, the body's thermostat fails and the body temperature may continue to rise until death occurs unless rapid and extreme measures are taken to artificially lower the body temperature.

"Man's tolerance to elevated temperatures is directly related to his ability to remove heat from his body core by increasing blood flow to the skin surface and then lose heat by evaporation of sweat. It is only the evaporation of sweat that makes short exposures to extremely hot environments tolerable. Should the ambient water vapour pressure approach the 44 mm Hg (ie. a dew point of 36°C (97°F) value which is typically found on a man's skin while sweating, heat tolerance is drastically reduced. The partial pressure of water vapour at 120°F (the temperature at which the DDC may have reached prior to the accidental pressurization) is 88 mm Hg.

"Humidity control in the decompression chamber complex aboard the WAAGE 11 was normally accomplished by allowing the atmosphere to circulate by convection between the main chamber and the transfer chamber where the moisture condensed on the transfer chamber walls. When the divers inside the main lock closed the door to the transfer chamber to protect themselves from a suspected sudden loss of pressure in the transfer chamber-bell portion of the chamber complex, humidity control stopped.

"If the divers started to sweat at a maximum rate inside the DDC, a vapour pressure of 44 mm Hg would be reached very rapidly and practically no further skin cooling due to sweat evaporation could occur.

"A heat storage by the body of 80 kcal (320 BTU) with a rise in body temperature of 1.4°C (or 2.5°F) represents the voluntary limit in the average man. Collapse can occur at a heat storage capacity of 160 kcal (640 BTU) with a 2.8°C (or 5°F) rise in body temperature. Moderately active men will produce heat at the rate of 180-300 kcal/hour (800-1400 BTU/hour). If all this heat is retained by the body, a heat storage of 160 kcal can be reached in half an hour. If heat is being added through the lungs and skin, collapse can occur even sooner.

"A man breathing helium/oxygen at 300 feet with a ventilation rate of 1 cubic foot per minute and a gas temperature of 120°F will add heat at more than 0.5 kcal per minute. As his body temperature increases, so will his respiratory and heart rate, adding heat at ever increasing rates. This respiratory heat was retained, along with the ever increasing heat of metabolism, driving the divers toward an irreversible and fatal hyperpyrexia".

(Question): In addition to an awareness of the problem which is the first step in prevention, what are some of the actions we might consider in response to heat emergencies?

(Answer): The objective is simple: cool the victim as rapidly and efficiently as practicable. Achieving the objective depends on your own ingenuity.

Let me tell you another sea story which might point out some of the possibilities.

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It just so happened that on my way back from the WAAGE 11 accident, I ran into an old friend in London who was homeward bound from a job off Dubai in the Persian Gulf. He had not heard of the accident, and he was talking about the rough job he has had out in the Persian Gulf. Their main chamber had an environmental control unit consisting solely of a tarpaulin to shield it from the direct rays of the sun. On several occasions, the main chamber had been occupied when my friend arrived on deck for his surface decompression in the chamber. This meant he had to use the standby chamber which did not have even a tarpaulin environmental control unit. “Man”, he said, “it was really hot in there. I just got to feeling so weak and crampy. I just felt dizzy, you know, like I was going out of my head”. He said, “Particularly between my O2 periods. Get back on O2 and it really made me feel better for a while. That O2 is really good stuff. I don’t know what was the matter with me, but it happened every time. You know, I’d get off that O2 and start feeling nauseated and bad and I’d get back on it”.

Think about that. The temperature in a chamber out on deck in the Persian Gulf is probably around 120°, 130°,140°F, and the ventilation does not always meet the diving manual standards even in Oceaneering, so I began to wonder why he felt so much better when he was on oxygen.

Well, he was breathing oxygen from a high-pressure tank, and as it expanded from its compressed state, be was getting effective central cooling. Each time during the air breaks he was drifting right up to the edge of a heat problem, and by going on oxygen he was pulling himself away from it as a consequence of breathing cool gas. So I think that is one thing we can do in a heat emergency. We can breathe cool gas as long as it does not get too cold and cause excessive bronchial secretions. Remember, any time you reduce a gas from high pressure to low pressure, it cools. So you have an advantage right there, if you can work out a way to take advantage of that pressure reduction.

Or maybe you could devise a heat exchanger for the breathing gas, say, an oildrum on that side of the chamber with a bunch of copper coils in it, and a lot of ice and salt over them when you need a cold gas, or hot water when you need warm gas. It would not cost much, but of course there may be simpler and more elegant ways to do it.

There is another little device that we have found which I think might have some application. It is called a vortex tube. You can put high-pressure air in the middle, and you get hot air out one side and cold air out the other side. You can either heat or cool. Obviously, you cannot violate the laws of thermodynamics, and if you have thing operating inside the chamber, you are not going to have any overall net change. But you can control what we call the micro-climate around the man. There is an off-the-shelf device that hooks up to the vortex tube which could be useful. Foundry workers use them. Foundries have a hot room where pigs of metal are poured. Something like 35 seconds was the maximum time that the toughest guy in a Houston foundry had ever been able to stand working in that room. But they got this vortex hood, put it on, and just ran plain old compressed air through it.

Using the hood, a worker could enter the hot room and work for 20 or 30 minutes. Remember 40 percent of heat loss occurs from the head and neck not counting the respiratory tract. The vortex hood can be a very effective means of protecting the individual in a hot environment. Now someone needs to determine if it will function in a hyperbaric chamber.

For cooling a chamber in tropical areas, I would suggest putting burlap, blankets and stuff like that over it, and running the water over that, so it will increase your heat loss through evaporation.