The similarity of scan results in the CAGE and neurological DCS groups may indicate a similar etiology. While the presence of autochthonous bubbles cannot be ruled out, the pattern suggests a microembolic event of homogeneous nature affecting selected areas of the brain, primarily the regions supplied by the anterior and middle cerebral arteries.[4] This does not preclude the presence of spinal cord involvement but, rather, expands upon our understanding of the often vague cerebral manifestations. In CAGE, the cerebral insult acts alone to cause clinical manifestations while in DCS, it may be that spinal and cerebral insults act alone or in combination.

Astrup and Symon proposed a model where cerebral hypoxia, due to decreased cerebral flow, could lead to reduced or absent function without cellular demise. Reversible and non-reversible areas of damage occur depending upon the degree and duration of the hypoxia.[5,6] Hypoperfusion, caused by either CAGE or DCS might lead to reduced function with subsequent symptoms and/or signs. Recompression with increased perfusion may lead to clinical resolution of a diver's symptoms whilst subclinical cortical hypoperfusion remains.

Follow Up Studies

In a follow up study of 18 of these divers, it was shown that the perfusion deficits shown on initial scanning were remarkably persistent.[7] While some improvement occurred, and indeed complete resolution in a number of cases, it was not uncommon for lesions to worsen or remain unchanged over periods of a year or more. Several divers showed worsening scans with apparent extension of their initial deficits. These findings increase concern that neurological damage caused by diving may be more significant than previously believed and may be of a more permanent nature despite prompt and clinically effective therapy. Underlying damage remains and raises the question of what further diving will do to an already damaged brain. Are these divers at increased risk of further incidents? If injured a second time, will their injury be harder to treat or is it likely to leave greater residual damage? No one can answer these questions at the present time. People have been diving for years following repeated incidents of CAGE and DCS without revealing any definite trend. Long term neurological changes have been documented in the spinal cord[8] and have been suspected to occur within the brain for some time. As our methods of studying these divers becomes more sensitive and accurate, these questions may be answered.

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TESTING THE RECREATIONAL DIVE PLANNER

Raymond E.Rogers

Summary

In phase 1 M. R Powell, PhD, tested 911 dives, 518 in the chamber and 393 in open water. The broad cross section of subjects had wide variations in dive profiles. All dives were past RDP limits. There were no cases of decompression sickness and minimal bubbling. The increase in vacation diving paralleled development of the Recreational Dive Planner (RDP). As multi-day diving was largely unstudied Diving Science and Technology (DSAT)

imprinted warnings on RDP and did the phase 2 study.[1] The test plan covered 4 dives per day, to mimic resort activity, two dives in the morning, one in the afternoon and one dive at night, with the dive day spanned over about 13 hours. Each dive was to the limit of the RDP (except for the last). The last dive was shallow, for about one and a half hours and was single-level. This was to elevate gas pressure in slow tissues.

Phase 1 testing

The point has been made that no new tables and no new equipment should be introduced without adequate testing. That is a relative term. How much is enough? We tested it a lot. Probably there can never be "enough" testing, but one strives for adequacy.

The first phase was chamber testing, with Dr Michael Powell as the principal investigator, at the Institute of Applied Physiology and Medicine (IAPM) in Seattle, Washington. This was followed by open water testing. All divers were Doppler monitored after the dive.

There were 911 dives done, 518 in a chamber, 393 in the open water. There was a broad cross section of subjects, from old people to young people, inexperienced to very experienced, fat, thin, male, female. They were volunteers, and we took whatever we could get. There was a variety of variations in the dive profiles. We tested a total of 25 different profiles across the whole spectrum of the recreational range. Every dive was tested beyond the no-stop limit of the Recreational Dive Planner, and beyond the no-stop limit of the US Navy tables, and probably even further beyond the limits of DCIEM tables or the BS-AC tables. No decompression dives were done.

Phase 1 results

In all these 911 dives, there was no case of decompression sickness, and only negligible bubbling. There were no bubbles detected after 92.6% of the dives, 6.3% of the dives had bubbles in the grade one range, while grades 2 or 3 were found in fractions of 1% of the divers. There were no grade 4 bubbles nor any decompression sickness.

Slow tissue compartments which have extended half-times can play an important part in recreational diving, but only in multiple long shallow dives with short surface intervals. Obviously if one defines a slow compartment as one which reacts very slowly across the time spectrum one has to talk about long dives. The only time when long dives are permitted in no-stop diving is in shallow water, and even then there is the problem how long can anyway one tank last? If one keeps going back to the boat and getting another tank, and repeats this long enough, eventually one can push up the pressure in the slow compartments. It is only with this pattern that the theoretical model says that one might have a potential problem. The combination of short surface intervals and long, shallow dives, randomly selected, would eventually cause some compartments to pass their theoretical limits. Once we established what these dives were, we then asked the computer how to prevent overpressures. The answer was two simple rules.

The first reads:

"If you plan three or more dives in a day, beginning with the first dive, if your ending pressure group after any dive is W or X, the minimum surface interval between all subsequent dives is one hour."

The second rule is almost identical:

"If you plan three or more dives in a day, beginning with the first dive, if your ending pressure group after any dive is Y or Z, the minimum surface interval between all subsequent dives is three hours."

These rules are simple. They are so simple they might have been made up artificially. That is not the case. They are based on huge numbers of computer calculations which examine all sorts of profiles that recreational divers might use.

Slow compartments have little influence on most dives and bottom times have to be very long, and the dives shallower than 60 feet, to achieve repetitive groups W, X, Y and Z (Figure 1). It takes multiple dives and one really has to work at it, but if one tries hard enough, one can get down into the "magical" W-X-Y-Z groups. But notice how few time boxes there are down there, hardly any at all. For dives to 70 feet and deeper, one could not do it. Before the 60 minute compartment pressure can get too high, the no-stop limits of the faster compartments get one out of the water. These groups can only be reached after a repeated sequence of closely spaced long and shallow dives.

Divers very seldom finish in these high pressure groups, but if they do, the long surface interval causes pressures in the slow tissues to decrease to acceptable levels before the start of the next dive. I am not suggesting that there is no gas in the slow compartments, of course there is, there always is, but time gets it down to a tolerable level.

With these rules in place, can the model be exceeded if all the rules are observed? If one follows the W or X or Y or Z rules if they apply, if one monitors one's ascent rate and one does not go too fast, if one takes a safety stop, if one does all these things, can one break the model? Yes, one can. But one has to work at it. I found an example of how one can do that. If one goes to 35 feet for 120 minutes and then has a surface interval of 66 minutes, then repeats that, the operational rules now require a safety stop at 15 feet, and the table requires another 66 minute surface interval, etc. The reason

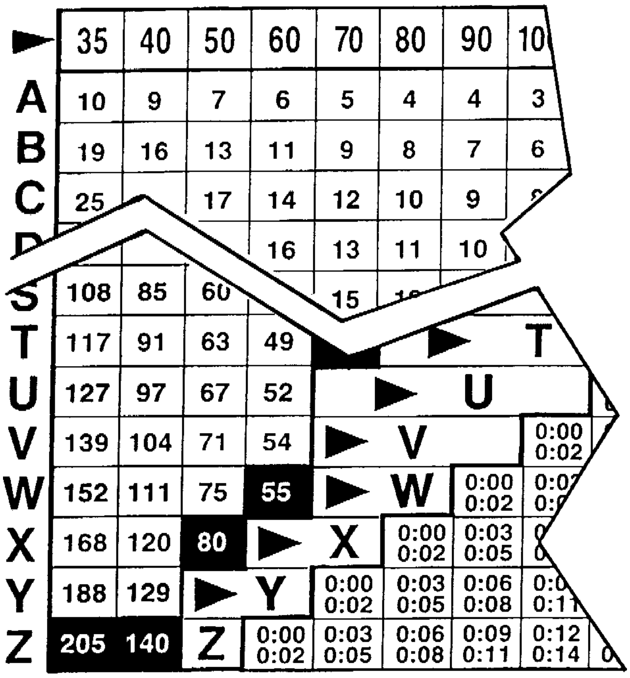

FIGURE 1 Taken from the PADI Recreational Dive Planner. Depths are across the top line. Bottom times have to be very long, and the dives shallower than 60 feet, to achieve repetitive groups W,X,Y and Z.

I used 66 minutes is that it sets up a cycle, between pressure group X and pressure group H and according to the RDP one can do this for ever, for days if one wants to. But when one surfaces at the end of the sixth dive, after six consecutive dives of 2 hours each to 35 feet, one would be slightly over the theoretical limits in three of the slow compartments. But to achieve that feat, one would have been in the water for over 12 hours of the previous 18. I consider that sort of diving a trifle on the unrealistic side, so I am going to ignore it.

Multi-day diving

But it was good that we included these procedures in the model as it came along, because it takes time to develop things, and from the moment the idea popped into somebody's brain until the product was actually available to the public, something interesting happened, quite coincidentally. Out of nowhere, we had a brand new issue, vacation diving.

Divers are everywhere. People are jumping on aeroplanes and going all over the world to all sorts of exotic places, and when they get there they want to dive as much as possible. And many people advertise "unlimited diving".

What was really known about multi-day diving? The answer is essentially nothing. Two facts were known, that a lot of people were doing it and that most were getting away with it. But there was no data and no research had been done. No one knew whether it was safe or risky.

TABLE 1

THE DIVE TO BEAT THE RDP RULES
(Feet / Minutes)

Dive	Stop	Surface interval
35 / 120,		0 / 66
35 / 120,	15 / 3,	0 / 66
35 / 120,	15 / 3,	0 / 66
35 / 120,	15 / 3,	0 / 66
35 / 120,	15 / 3,	0 / 66
35 / 120,	15 / 3,	0 / 66

About the time this issue came to notice, PADI introduced the RDP. It carried this warning: "Note: Since little is presently known about the physiological effects of multiple dives over multiple days, divers are wise to make fewer dives and limit exposure toward the end of a multi-day dive series". In 1988 that little was known about it.

We know a lot more than we did then. Not as much as we would like to or are going to know. That warning looks extremely vague, and deliberately so, because so little was known about the subject, we could not be more specific than that. Repetitive diving is considered to be a risk factor, but most recreational diving is repetitive diving. Also it has been surmised that it may not be the gas uptake of multi-day diving which is the problem, but giving the diver more opportunities to make a mistake.

When multi-day diving became popular the warning was in place. DAN said that we had adequately tested for three dives a day, but what about doing this day after day?

Maybe we could have left it alone, with just the warning, but we were were not willing to have it left unexamined. So it was back to the chamber. In the interests of those who might be using the RDP, and in the interests of those who might be doing recreational diving anywhere we decided to research the subject.

Phase 2 testing

We set up a test program of four no-stop limit dives per day, for six consecutive days, 24 dives for each subject. This test program used 20 different subjects which meant a planned total of 480 different dives.[1] There were a few incidental ear squeezes, but we did 475 dives out of the planned 480.

Table 2 shows the subject data. We had 12 men and 8 women. The men ranged in age from 21 to 61, with an average of 39 years. The women had an average age of 36, ranging from 24 to 45. The weights were all over the place, some of the men were almost twice as heavy as the others. Body fat was all over the place too. We were not selective. We did not just use young, athletic-type males. We supplied a TV set up outside the viewing port and there was a rowing machine in the chamber to stop people from going "stir crazy".

TABLE 2

AGE, WEIGHT AND % BODY FAT OF THE SUBJECTS (12 MEN AND 8 WOMEN)

		Age		
Male	39.08	±	11.62	(21 - 61)
Female	36.38	±	7.76	(24 - 24)
		Weight (kg)		
Male	78.3	±	14.76	(59.1 - 111)
Female	61.5	±	7.96	(50.0 -75)
		% Body fat		
Male	20.54	±	5.90	(15.5 - 36.0)
Female	26.74	±	5.28	(21.6 - 35.3)

Table 3 shows the actual test profiles. You can see that it is a combination of multilevel diving and single level diving. We (I do not know where one would find an an open sea environment that would let one do this) tested three levels, four levels, two levels and, as a matter of policy, we decided we would finish every day with a long shallow dive. The last dive the first day was 90 minutes at 40 feet. I have to confess that when I said that every dive was to limit, it was not entirely correct. 90 minutes was an arbitrary cut off point, as it was probably long enough. We set out to mimic resort-type diving, two dives in the morning followed by an afternoon dive and then a night dive. We tried to simulate reality, as well as to do another thing. Finishing with a long shallow dive, tends to elevate the tissue pressures in the theoretical slow compartments as well as to reduce the overnight surface interval. The dives spanned about 13 hours from start to finish. The surface intervals between dives are shown. The last number each day is very large, it is the overnight surface interval.

There were some very long dives with total bottom times (surface to surface) of 106 minutes and 91 minutes. These are very long dives. Most of the dives one could not do with a scuba cylinder but a chamber, of course, has an unlimited air supply.

The last dive on day two was to 45 feet for 92 minutes. The natural limit of the system was 92 minutes, so we went ahead with that for 45 feet instead of rounding it down. In the second group, it was not too much different. The pattern tends to repeat in order to increase the rigor of the test. When we got to dive number 24, the last dive in the series, we threw in an extra 10 minutes to round off to 100 minutes for the final dive.

If the surface interval was long, the subjects were monitored several times. The practice was that if there was any doubt about whether a bubble was observed, it was a Grade 1. If there was any doubt as to the magnitude of the grade, it was always scored as the higher. Every monitoring was taped, for confirmation by an independent observer, and this later confirmation revealed that Dr Powell was anything in the world but conservative. The true grades were probably lower than he reported.

Bubbling in phase 2

Over 90 per cent of the readings, despite the arduous diving, were Grade 0. We did not get any Grade 4 bubbling, and only small numbers of Grades 1-3. The most important thing of all is that there were no cases of DCS.

There are various ways to define how to score Doppler Grades. Table 4 is probably the most popular one world wide, the one we actually used. The definition of no-bubbles in 10 cardiac cycles for grade 0 is a little bit restrictive. Typically, if no bubbles were detected, Dr Powell would monitor somewhere between one and two minutes with his test probe and try to elicit the sound of a bubble. He was not checking for just ten heart beats and then taking it off.

TABLE 4

DOPPLER BUBBLE GRADES

Grade 0	No bubbles in 10 cardiac cycles
Grade 1	Occasional bubbles in 10 cycles
Grade 2	2 - 4 bubbles in some cycles
Grade 3	Several bubbles in every cycle
Grade 4	Bubbles are heard continuously

Before we began we tried to find out what data was available. There were a number of studies, that were all over the place, as far as results are concerned. Graphing decompression sickness as a function of bubble grades showed a high degree of inconsistency from one study to another. DCS increased in a highly variable manner with an increase in bubble grade, but they all had one thing in common: The DCS rate was relatively flat with grades 0, 1 and 2. The studies shown in Figure 2 represents three to four thousand dives reported over several years from a number of places, and almost every one of them involved stage decompression dives, serious heavy duty dives, sometimes on mixed gases,

TABLE 3

MULTI-DAY, MULTI LEVEL DIVES TESTED IN PHASE 2

Day	Dive	Level 1	Level 2	Level 3	Level 4	Surface interval	Total bottom time
1	1	120/13	71/11	50/14	35/13	80	56
	2	80/16	50/13	40/25		180	58
	3	60/48	35/54			180	106
	4	40/90				689	91
2	1	95/22	65/05	50/13	35/26	72	70
	2	70/22	40/37			180	63
	3	55/59				180	63
	4	45/92				716	96
3		90/25	55/09	35/40		87	78
	2	60/38				92	42
	3	50/61				180	65
	4	40/90				802	94
4	1	110/16	70/08	50/13	40/15	66	57
	2	75/17	50/11	35/55		180	87
	3	60/49	35/41			180	94
	4	40/90				682	94
5	1	100/20	65/06	50/13	35/26	80	70
	2	70/24	40/49			180	77
	3	50/73				180	77
	4	45/92				680	96
6	1	85/27	50/17	35/26		95	74
	2	65/31				117	35
	3	55/53				60	57
	4	40/100				-	104

all kinds of things that we do not do in recreational diving. These studies were of limited value to a recreational diving investigation. As for a database of known outcome in recreational diving, with its very limited depth/time exposure matrix, it was virtually non-existent In all the dives that have been Doppler monitored and reported, that I have been able to find, and I have looked long and hard, there are probably a maximum of two dozen which fit within recreational no-stop limits. So when comparing our testing compare with databases of known outcome, please keep this in mind.

I made a composite report, just for my own edification. I pretended that all the data that was available represented a single study. I added all the DCS together, all the subjects together, all the different Doppler events together and came up with a body of data just as if there had been only one study, and the arrow in Figure 3 points to the dramatic increase in DCS that occurs as one goes past grade 2 bubbling. Analyses have shown that statistically grade 2 is not much different than grade 1 in DCS incidence.

Bubbling was not the primary determinant we were following in our study. The primary determinant was the presence or absence of decompression sickness, with Doppler as merely a mechanism which permits us to fine tune a bit.

It is well known with Doppler monitoring that one can have signs and symptoms of severe decompression sickness without detectable bubbles. It is also well known that it can sound like Niagara Falls without developing DCS. But as a general indicator it does give a bit of sensitivity which does not exist,when one simply uses the presence or absence of decompression sickness as the end point. It gives us a little bit of extra data, and if one accumulates enough dives monitored in this way it can be helpful.

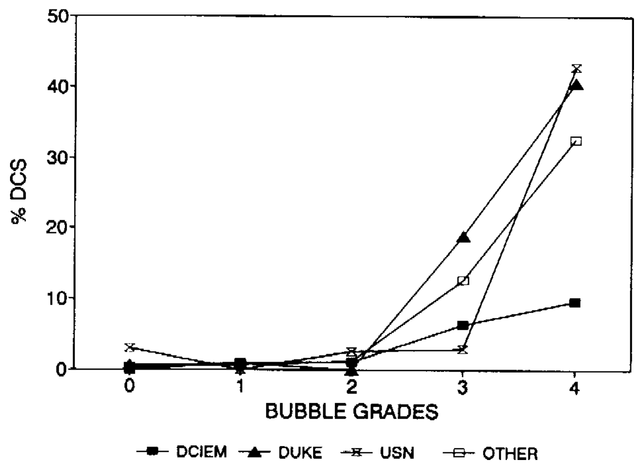

FIGURE 2 Graph of Doppler bubble grades and DCS from studies by the US Navy, the Defence and Civil Institute for Environmental Medicine (DCIEM), Duke University and others. Most of these dives were not the sort of dives done by recreational divers.

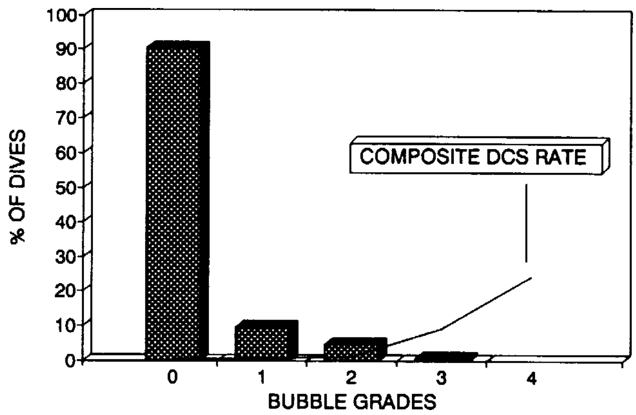

FIGURE 4 The bars show the bubble grades recorded in the IAPM multi-day studies. The composite DCS rate curve is from the combined studies shown in Figure 3. The curve rises at the point where the bubbles in the IAPM study virtually disappear.

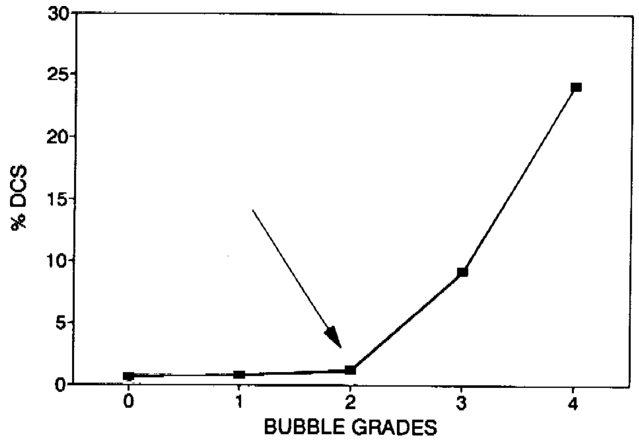

FIGURE 3 The studies of DCS graphed separately in Figure 2 have been grouped together to provide this graph. The arrow shows the bubble grade above which decompression sickness was more frequently recorded in these studies.

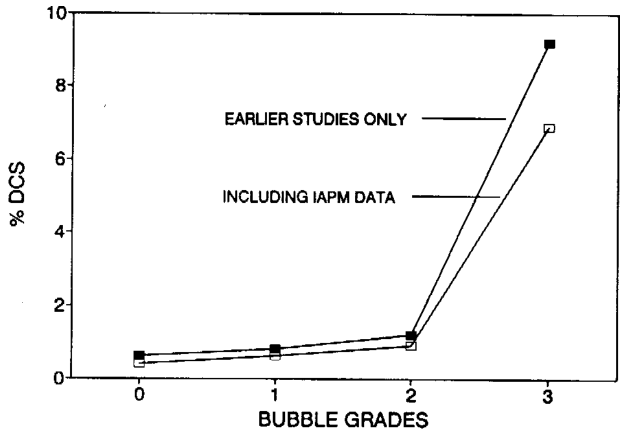

FIGURE 5 DCS incidence in earlier studies (top graph) is reduced by adding another 1,386 Doppler monitored dives (IAMP series) to the data base, but the shape of the curve is not changed.

Dr Powell monitored the subjects at rest, and then had them do deep knee bends and monitored them again. That would usually generate higher scores, but not in every case. The highest score that he was able to elicit was the one that was recorded.

There were only four subjects altogether who had grade 3 bubbles at any point in the dives, less than one percent.

I want to impress the point that there was a big change at grade 2. Figure 4 shows the bubble grades recorded at IAPM with our multi-day dives and the composite DCS rate curve from the combined studies. The curve begins to kick upwards, where it becomes an area of concern, at precisely the point where the bubbling in our study virtually disappears. I was happy with the outcome, but it was one that did not come as any surprise to us. We expected this, but it was necessary to demonstrate it.

We have had no cases of decompression sickness in the 1,386 dives, which have been When we add it in to the existing studies (Figure 5) the curve comes down. It does not change the character of the curve. Why did we do so much better than the other studies ? Some of them had shown up to 30 or 40 % decompression sickness. They were studying

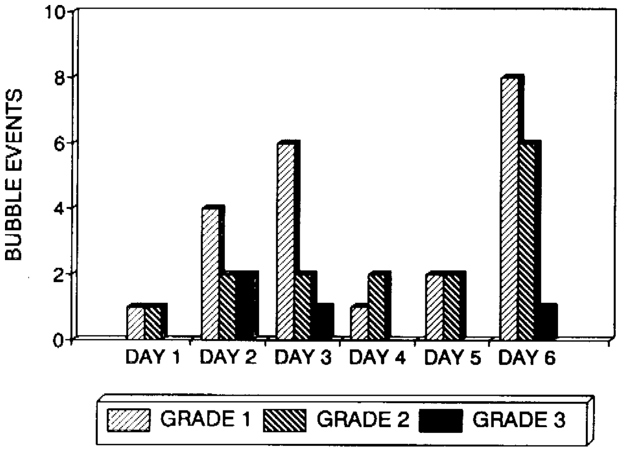

FIGURE 6 Number of bubblers and grades from day one to day six.

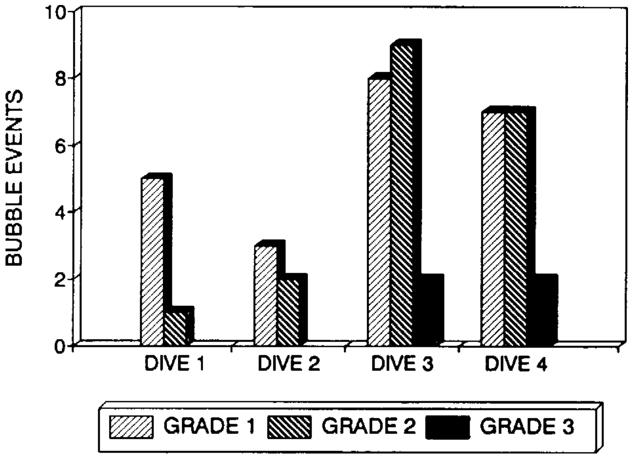

FIGURE 7 Total bubble numbers and grades, totalled for the six days, for each of the four daily dives.

staged decompression, severe exposures, mixed gases, etc. We were studying benign exposures, relatively trivial exposures, the kind of thing recreational divers can do every day. We made safety stops at 15 feet for 3 minutes every time, because the test design would take us to the no-stop limits, and had long surface intervals. In Phase 1 we did not do the stops. In Phase 2 we did routinely apply the stops, and when the rules which related to long surface intervals were relevant, they were also applied. The effects of these three things added together are what made the difference between this study and all those which preceded it.

What we were trying to determine was whether there is any trend if one went through six straight days of diving. For example could a dive, which is usually considered safe, become risky, just from sheer repetition, because one is doing it over and over again? That is what we wanted to find out.

I broke the results down by bubble grade. Figure 6 shows bubbles distribution from day one to day six. All the grade 1 follow an interesting pattern, they are approximately parallel to the number of multi-level dives, but since grade 1 is basically incidental bubbling, I do not think that means too much. It would appear from a look at grade 2 that there is a definite trend towards the end of the week, although very low, it appears to pick up towards the end. The vertical axis counts the number of events, actual occurrences, not percentages. There was some grade 2 bubbles, but they are only important due to their proximity to grade 3. Of the cases of grade 3 bubbling, three occurred early, and only one in the second part of the week. So I call that a random distribution of bubbles, and it would not appear from the available evidence to date that the feared trend was developing. But there is another way we can consider it.

Figure 7 shows each of the six days' dives, added together, and there does definitely seem to be a trend as one goes through the day, which was no great surprise. But to confuse the issue, it was not greatest at the end of the day, but appeared to peak at the end of the third dive and then fall off towards the fourth dive. Any statistician would laugh at conclusions drawn too strongly from this, as the numbers are so similar. But at any rate there was not a straight line increase across the board. It was a random pattern. So it does not look like a high risk situation.

Now (June 1990) in-water trials are in the planning stage. Every thing takes longer than it should, but it has been going for about a year trying to figure things out. Sometime toward the end of 1990 we will be doing in-water trials.

DAN in December 1989 recommended:

A maximum of four dives a day for six days and preferably no dive on the third or fourth day and

No more than three dives a day.

Why make that last recommendation ? Because we have already tested for three dives a day.

Will these recommendations be eased on the completion of the in-water trials? Assuming the in-water trials are as successful as everything to this point, will the recommendations be altered? Maybe, but it is not for me to decide. I suspect that they will not be changed. Table 5 shows how ideas, recommendations, concepts, and rules dribbled out on us, a piece at a time, as we learn more, as things evolve, and sometimes we forget how old concepts might be.

The idea of stopping at fifteen feet for three minutes is five years old in the PADI Divemaster instructional manual. Informally they recommended a safety stop a great deal earlier than that, but officially it has been in the book for over five years (Table 7). We have been hearing a lot about planning of dives ever since we heard that "Recreational

Dive Planner" would be the name of the instrument. Nowadays people are regularly talking about Dive Planning. Some people have always talked about it, but not many. One never used to hear about it as much as we do now. It is over two years since the multi-day limitations were introduced. Over two years ago the S.A.F.E.Diver campaign "Slowly Ascend From Every Dive" was introduced. In the middle of 1989 was the introduction of the idea, for the dinosaurs who just do not want to give up their beloved USN tables, which had been paid for, to at least mark them down to the limits which were tested in Seattle. Later in 1989 the 15 feet stop was extended to include all ascents to the surface.

Also in 1989, the limitation on deep repetitive diving were issued, once we found out there were crazy people doing things like making repetitive dives past 100 feet we said "Quit doing it, it is just not a safe practice."

TABLE 5

PADI'S EVOLVING PRACTICES

Mid 1985	Stop at 15 feet for 3 minutes
Jan 1988	Popularized term "Dive planning"
Mid 1988	Limitations on Multiday diving
Mid 1988	AFE Campaign (Slowly Ascend....)
Mid19 89	Reduced USN NDL's to RDP limits
Mid 1989	Extended 15/3 stop to ALL dives
Mid 1989	Limitation on deep repetitive dives

Sometime in the first quarter of 1990, there was a new rule that henceforth, if one goes past 130 feet in one's dive, that will be considered in the same category as exceeding the no-stop limit. It puts one in an emergency decompression status, and one should not dive for the next six hours, after one exonerates oneself with a 15 foot stop for 8 minutes. So we are getting quite bit stricter. With these established trends, it is highly likely that the limitations will remain.

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This is an edited transcript of a lecture given at the 1990 Annual Scientific Meeting of SPUMS.

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AN INTRODUCTION TO PALAU'S REEFS

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Palau is one of the richest coral reef areas in the world. Biologists define a location's richness in terms of its biological diversity or the number of species inhabiting a defined area. Within Palua's 370 km^2 it is estimated that there are over 1000 species of fish and 700 species of corals and anemones.[1-3] In contrast, the fish fauna of the entire state of Queensland is believed to number approximately 1600 species[4], 1500 of which occur within the 332,000 km^2 of the Great Barrier Reef Marine Park.[5] A further illustration of this richness is the collection by marine biologists of thirteen new species and one new genus of fish on a Palauan reef during a two hour period. While this may not seem like a large number to some people, one needs to consider that annually there are only 75 to 100 new species collected worldwide.[3]

The reasons for this high degree of diversity are believed to be twofold; first the archipelago has a long history of a steady, tropical climate and second is the presence of a wide variety of habitats within a relatively small area. The 340+ islands are volcanic in origin and capped by porous coral limestones. Every type of reef structure is represented here. To the north of the inhabited islands are small atolls and bank reef areas. A barrier reef encloses the lagoon while fringing reefs grow along the shore of many of the islands. Within the lagoon are many patch reefs, seagrass meadows, level sand and mud bottoms. These habitats are further subdivided into microhabitats due to the porous nature of the reef and limestone. The blue holes, caves, crevasses and smaller interstices provide great spatial heterogenity and enable more organisms to exist in a smaller area. Freshwater run-off adds to the diverse habitats by producing streams and extensive estuarine mangrove habitats. There are also a number of lakes which range from freshwater to marine conditions.

The unique nature of this reef system was recently acknowledged by CEDAM (an acronym for Conservation, Education, Diving, Archeology and Museums) International when that conservation organization placed Palau on its list of the seven underwater wonders of the world. The New York based CEDAM recognized Palau along with the Great Barrier Reef, northern Red Sea, the Belize barrier reef, Lake Baikal in the USSR, the Galapagos Islands and deep ocean vent communities. Among the criteria used in selecting the sites were scientific research value, environmental significance, unique marine organisms, natural beauty, geological significance and how representative the site was of a particular region.

The corals that construct these reefs are animals whose tissues are packed with symbiotic algae. These algae, called zooxanthellae, combine sunlight, and wastes (carbon