

A DEVELOPER'S VIEW OF NEW DECOMPRESSION PROCEDURES

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Introduction

This is a "position paper" from one who has over the last couple of decades been involved in or watched closely the development and introduction of a number of new decompression tables and procedures in a variety of environments. I can report both successful and some not-so-successful experiences. These have led me to a general concept of how, in my opinion, the "final" steps in the process of decompression procedure development might safely, effectively, and ethically be carried out. Let me first summarize the concept, then state my premises, lay out a working plan in more detail, and tell a story or two. The idea is simple and straightforward, but it may require some judgement at several points in order to be implemented.

New procedures are given appropriate "testing" under "laboratory conditions," and are then introduced into "provisional" operational use under controlled conditions. This calls for their being used by competent crews and divers under expert supervision, at sites where prompt and adequate treatment capability is readily available, and with careful and valid records keeping. Results are fed back, modifications made where necessary, and when sufficient experience in their use has been accumulated the provisional tables can be declared operational. However, decompression tables should never properly be regarded as "finished," but should be susceptible to revision whenever it makes sense.

Background

The first and foremost premise behind this approach is well known to all of this group but has to be mentioned, that successful new decompression procedures are based on decompression experience. Various mathematical, graphical, intuitive, and other processes are used to translate previous experience into new procedures. One might be tempted to say at this point that a set of new procedures--given the set of transition processes currently available--are no better than the experi-

ence on which they are based. That is not strictly true, because we learn from experience, and in any evolutionary design process whether it be the engine for a car or the recipe for a cake, we try to strengthen the weak points of the previous versions in the next edition. A second premise says that where proper capability to treat DCS is in place there should be no significantly greater risk *as a result of decompression sickness* to the diver in the field than to the one in the laboratory. Other field-related risks will certainly be greater there than in the lab, but these are not particularly related to the reliability of the decompression table. When recognized early and treated promptly, the DCS (decompression sickness) that might ensue from the unreliability of a decompression procedure poses little threat of lasting injury. The cases where "decompression sickness" has caused injury have virtually all been the result of delayed, improper, or inadequate treatment, or of some factor other than DCS (such as blowup and/or embolism).

Other factors have been brought out earlier in this meeting. Even an immense "laboratory" program may fail to establish a table's true reliability for its use under field conditions. Further, laboratory programs nowadays may be seriously constrained by ethical or insurance considerations, not to mention the costs. Because DCS occurs as a probabilistic or statistical event, the practicality of definitive laboratory testing, even with adjuncts such as bubble detection, will diminish as experience and hence reliability improve; it takes a lot more dives to establish that a DCS incidence is less than say 0.1% than to see an incidence when it is 10% or more.

While DCS may be inevitable, it should never be regarded as acceptable.

No practical diving procedures can be guaranteed to be totally free of DCS. The reliability of a set of decompression tables is a series of shades of gray, not areas of black and white.

Proposed plan for table validation

Here is a suggested "general" plan for validating a new set of decompression tables. It is neither complete nor definitive, but it covers the basic ideas; the main theme is to proceed with careful *small steps*. Figure 1 shows this diagrammatically.

Plan the validation

To begin with, the source of the new tables should be considered when planning the validation. If they closely resemble other tables whose reliability has been established, one would require few if any chamber tests before starting provisional field use. On the other hand, if the new procedures are based on novel concepts or fall in a category where there is little experience, a more extensive laboratory testing package or even a development program should be performed before considering serious field use. Validation would be performed on the product of the development program.

How many chamber tests?

This is an area where some judgement has to be applied. The choice of how many and what kind of tests to perform depends on how closely linked the new procedures are to valid experience, and also on how reliable and how relevant that experience was. And how well the new tables work.

It should be recognized that these chamber or laboratory validation tests are not intended to establish a "bends incidence" but rather to expose any catastrophic malfunctions in the development process. It is certainly unrealistic to expect that a series of chamber dives will prove that a set of tables will not result in DCS. They represent some small steps.

Before any great efforts are spent in validation it would be advisable to have procedures that are relatively new looked at by someone other than the table designers, preferably by someone experienced in and involved in the operational use for which the new tables are intended. This is not so much to try to predict the decompression reliability but to see if the patterns look reasonable, and to check that operational details such as gas switches are manageable and will be accepted by the divers.

Provisional use at sea

In general terms I would consider it all right to go directly to sea use under controlled conditions (discussed later) when the "new" tables in question are closely related to established experience and when the changes are designed to be in a conservative direction. This could be compared to the common practice of jumping to a deeper or longer table to add conservatism when the supervisor determines that it is needed. Small steps.

A half dozen or so validation dives might be needed for a less conventional modification such as speeding up decompression by increasing the level of oxygen breathed by the diver.

For a virtually new process such as diving with exotic gas mixtures or use of a constant PO_2 , we encounter the overlap of development and validation. If new decompression procedures are not firmly based on established experience then some laboratory trials or chamber dives are needed, and this should be called development rather than validation. Here judgement is needed to design a test plan appropriate to the degree of newness and uniqueness of the procedures.

For most *relatively established designs* I would accept a dozen or so clean chamber dives as adequate evidence that it is time to move to the stage of provisional use at sea.

If you are going to skip the "provisional" at-sea steps and want to proceed directly from the chamber to the stone tablets then hundreds of man-dives in the chamber may not be enough. By this I mean that it is unwise to present tables as "finished" based only on dry-chamber laboratory experience. When the laboratory has provisions for hard work in cold water using field equipment, the step to the sea is small.

But I am not advocating expensive "sea trials" for their own sake, unless the organization needs the exercise. A responsible diving outfit should have the capability to use provisional tables for an appropriate period *within the scope of normal operations*. The conditions for provisional use of new tables would vary considerably depending on the nature of the operation and the tables, but would involve a few principles. One, as we have noted, is to take small steps.

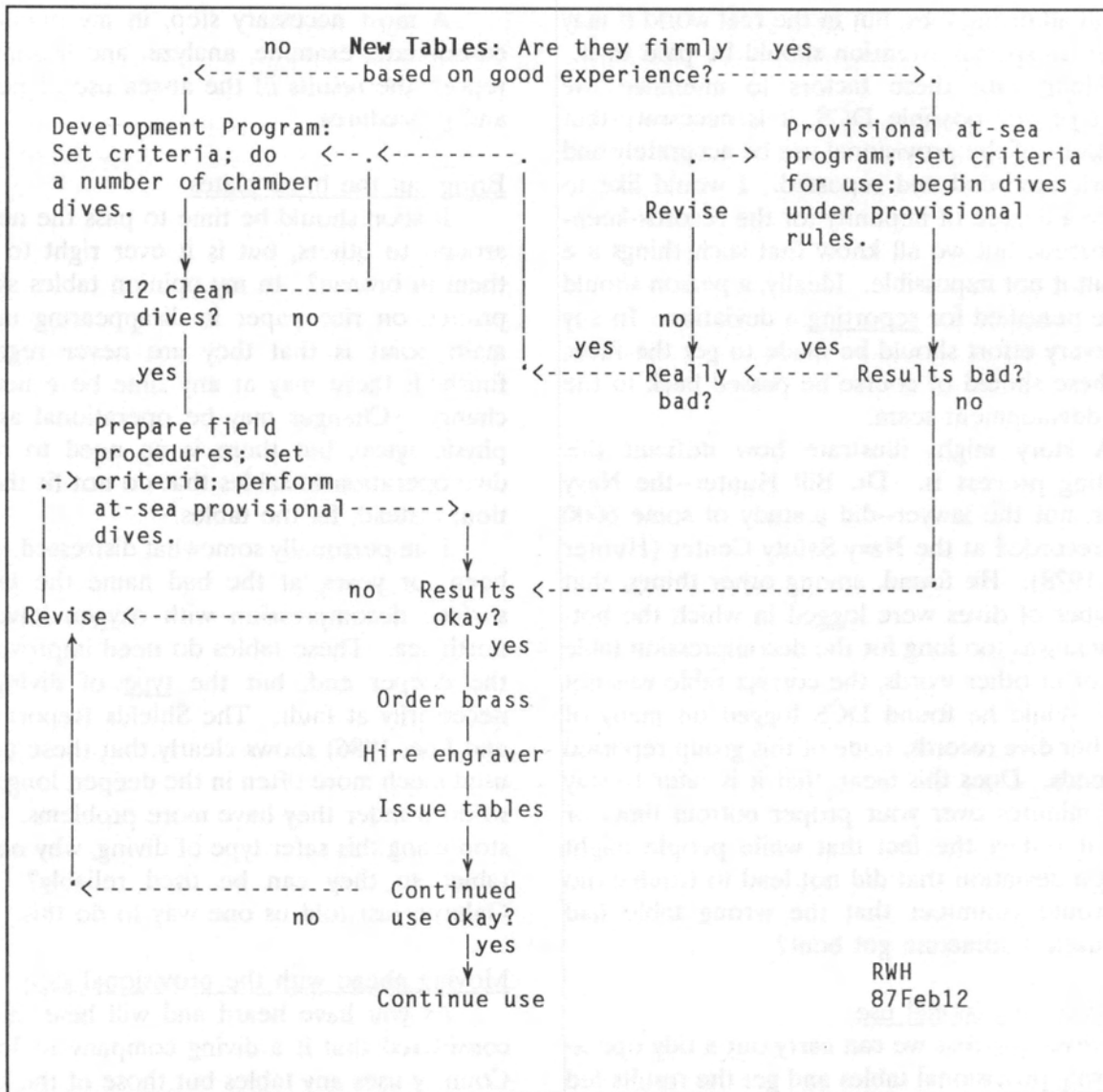


Figure 1. Steps in table validation.

Requirements for initial use of provisional tables

Provisional tables should be used at first by a competent crew, one that already knows the setting, the job, their equipment, the tables, and their operating procedures. The crew should know each other, and the supervisor should know his divers well. New tables should not be introduced for the first time under stressful conditions of weather, equipment, current, language, client pressure, and so on. Some have suggested that divers acknowledge with their "informed consent" that the tables are provisional; personally I believe this would be appropriate only in certain cases. Tables that represent sufficiently small steps away from proce-

dures acknowledged to be reliable by all concerned--including the divers of course--should be useable at sea without informed consent.

As important as the crew and the chamber, it is critical that *management* be involved and aware of the situation. The requirements offered here are tough enough when everyone is cooperating, and do not need the additional stress of obstructive or non-participating management.

The person in charge should be trained and have some experience in dealing with decompression sickness, and should have all the equipment, gases, drugs, communications, and know-how to handle a DCS event. In truth, this should be the

case on all diving jobs, but in the real world it may not be, so special attention should be paid to it.

Along with these factors to minimize the impact of any possible DCS, it is necessary that the results of the provisional use be accurately and honestly recorded and reported. I would like to suggest a degree of impunity for the records-keeping process, but we all know that such things are difficult if not impossible. Ideally, a person should not be punished for reporting a deviation. In any case every effort should be made to get the facts, and these should of course be passed back to the table development team.

A story might illustrate how difficult this reporting process is. Dr. Bill Hunter--the Navy doctor, not the lawyer--did a study of some 6000 dives recorded at the Navy Safety Center (Hunter et al, 1978). He found, among other things, that a number of dives were logged in which the bottom time was too long for the decompression table used; or in other words, the correct table was not used. While he found DCS logged on many of the other dive records, none of this group reported any bends. Does this mean that it is safer to stay a few minutes over your proper bottom time, or could it reflect the fact that while people might report a deviation that did not lead to trouble, no one would volunteer that the wrong table had been used if someone got bent?

Results of provisional use

Presuming that we can carry out a tidy operation using provisional tables and get the results fed back to the table team, one other principle needed is that if things do not go well enough, additional changes or revisions will be made. Any DCS should be investigated, and necessary corrective action taken. Often procedural or operational changes will suffice at this stage, but the tables should be changed when that is needed.

Judgement enters again in determining when enough provisional experience has been accumulated. I would expect that after only a few or a few dozen successful dives the provisional rules could be relaxed, with tougher jobs undertaken and the tables used by less experienced crews. The treatment capability should be standard; this might be an excuse to bring that aspect of an operation up to speed. If everything else is done well it will not be needed very much anyway.

A most necessary step, in my opinion, is to consolidate, examine, analyze, and if appropriate, report, the results of the at-sea use of new tables and procedures.

Bring out the brass plates

It soon should be time to pass the new tables around to others, but is it ever right to engrave them in bronze? In my opinion tables should be printed on rice paper in disappearing ink. The main point is that they are never regarded as finished; there may at any time be a need for a change. Changes may be operational as well as physiological, but there is no need to restrict a dive operation to tables that do not fit the operation; instead, fix the tables.

I am personally somewhat distressed, and have been for years, at the bad name the tables for surface decompression with oxygen have in the north sea. These tables do need improvement in the deeper end, but the type of diving is not necessarily at fault. The Shields Report (Shields and Lee, 1986) shows clearly that these tables are used much more often in the deeper, longer range, so no wonder they have more problems. But why stop using this safer type of diving, why not fix the tables so they can be used reliably? (Andre Galerne just told us one way to do this.)

Moving ahead with the provisional step

As you have heard and will hear more, it is considered that if a diving company in Jones Act Country uses any tables but those of the US Navy then lawsuits are guaranteed. We cannot do much about the legal climate that leads to this, but there ought to be some way to improve decompression tables. In preparing for this workshop I asked a diving company executive how to get new tables into use and his answer was, "Do it outside the USA."

If this workshop does not accomplish anything more, I would like to get the concept of *provisional use* acknowledged, accepted, approved, agreed upon, or somehow made useable.

Therein lies a story. Several years ago my colleagues and I prepared some state-of-the-art deep bell/bounce tables for a diving company. We sent them out labelled "provisional," with the comment that they should be so regarded until their operational people had shaken them down

with regard to operational details. To prepare the tables we had conservatively recomputed and revised the format of an older and well established set of tables that had been in use for several years. For a variety of reasons both operational and physiological there was a tough case of DCS. The plaintiff's attorney zeroed in on the fact that the contractor was using "experimental" tables. He even asked me if they had been tested on animals! The case settled out of court so I did not really find out how serious this would have been in front of a jury.

We are not primarily concerned here about the bizarre legal problems of commercial diving in the US, but our client NOAA and others of you here need the ability to get new tables. Sometimes this is for improved reliability, but more often it is to be able to use some new equipment or do a task that just was not thought of when USN was doing its table development. These things have to go through a provisional stage one way or the other. Lets make it legal and proper to do it on the job in small steps. To do this we need agreement by various agencies and a consensus of the experts in the field that this is the appropriate way to proceed.

Summary

At some point, either after some developmental chamber dives or by conservative modification of established procedures, it is necessary to begin using new decompression tables in the water. This should be done by taking careful small steps, using new procedures at sea under somewhat controlled conditions, always with the capability to treat DCS, and with good supervision, documentation, and feedback. This provisional step needs to be acknowledged by all as not only beneficial but necessary.

REFERENCES

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DISCUSSION AFTER DR. HAMILTON

DR. HAMILTON: I would like to end by asking a question of Jim? How do we go about doing this?

MR. SUTTERFIELD: Bill was talking about having an informed consent form signed. I think that an informed consent form is an excellent idea; however, make sure that you disclose everything. The thing that is much worse than having a form is having a form that is not complete, because if there are some risks that you do not disclose, you are automatically going to get nailed. So, just make sure that you do; there is nothing wrong with disclosing all the risks. If someone is serious about undertaking it and if it is the proper step where those tests should go forward, then I think you will get people to do that.

DR. ELLIOTT: It was good that you excluded conservative development of new tables from this discussion, the development of new tables. I think that is very important to distinguish.

We know very well from previous efforts that there are collaborative research projects where there was no single budget holder, neither the oil industry or the diving industry. Therefore, if the developed table is to be non-proprietary, who is going to pay for the development?

On your chart there was a sharp intake of breath when you said 12 dives and then you could do something. I think you will find that the discussion would focus on that. Please, could you answer the first question?

DR. HAMILTON: You mean who is going to pay for it? Jan Merta (Canadian Oil or Gas hands Administration) will pay for some of it. I really do not have the answer. Shell, maybe?

DR. ELLIOTT: No. There is no single budget holder in the oil industry.

DR. HAMILTON: That is right. And particularly now and in the next few years, we cannot expect to have a lot of money. Which is why I am asking for procedures that involve modest laboratory steps to eliminate the disasters, and then go carefully into the field. This is paid for by the client who needs the work. It costs a little more to do. The company has to absorb the records keeping task, the analysis, and a few other things. The only way that you are going to make sure that something that is new works is to go and use it.

As for issue of 12 clean dives, here is the step between a development program and a validation program. If you do a development program and have your criteria set up and everything and you can do a dozen dives that are good, then it is safe to use those provisional procedures in the field. But, the number 12 was put up there to spark the discussion.

DR. LAMBERTSEN: To keep a focus on what we are talking about, look at the word, "table." A table could better be called a "procedure." Then, it could be called a "set of procedures," because a table is one episode for one kind of dive and then that dive is over. That is a table for that dive. A set of tables is many of these.

When one talks about how much investigation--not numbers, we are saying how much investigation--is required to evaluate a diving procedure, one philosophy goes with one kind of diving as opposed to the many other kinds of diving. You may be dealing with many hundreds of diving tables for a given procedure. You must evaluate the whole procedure or you will not know whether or not that table fits inside of that whole procedure. Let us not start worrying about how many numbers one needs for something without seeing what it is we are talking about evaluating.

That includes the short and the long, the deep and the shallow, in terms of evaluation, because unless it all fits together, then it is not a rational set of procedures.

CAPT THALMANN: Two things. One, it appears Bill has drawn a safe flow chart that we use to develop tables already. So, what is new?

Being coldly objective, so this should not be taken personally, I mainly see the individual--from your standpoint--is spreading out the liability.

Let me give you an example. When you start out with a novel table like the Constant Partial Pressure Table, where there is no data base to start with, you need a large dive series to find out where you are before you can go out in the field. In another case, the U.S. Navy was faced with a unique diving operation that required long, shallow multilevel dives, for which the Diving Manual was absolutely unsuited. A procedure was put together, approved and put out into the Fleet without one man dive ever being done. Even though it was an absolutely unique procedure, it was totally based on accumulated experience. So, even within the confines of the U.S. Navy, some procedures are put forward without any testing, as long as the individuals agree that it is well within the realm of experience. You can make a judgment to decide whether or not that experience is valid. But the Navy is also willing to accept the liability for that decision. In other words, if things go wrong, they assume responsibility and have the mechanism for following up on it.

I think what your procedure is trying to do is maybe to take a smaller organization that may have a very large exposure and somehow get out a procedure which will spread the liability, because the logic to your procedure is very well founded. That is how it is done, except in the Navy, which has the ability to accept its own liability. A small diving company may not be able, in and of itself, to assume all of the liability, so then you hope that a consensus of experts will somehow absolve you of that. I wonder if our lawyer could say if that is really of any help?

Does the fact that a bunch of experts agree that it is a reasonable procedure in any way change the liability?

MR. SUTTERFIELD: Well, it certainly would knock out a claim for punitive damages, I would think, and I think it would mitigate the damages you have because you are acting totally responsibly and you have leaned on the best minds possible that you could find to do the right thing. It may very well walk you out of the courtroom free and clear.

As for risk, generally that is what the insurance industry does, it spreads the risk. So, in effect, they are spreading the risk; however, it is not spread as thin as it perhaps could be.

CHAIRMAN SCHREINER: At this point, I would like to make a belated introduction to you of the gentleman to whom this organization, this group around the table, owes its existence, having been convened in this manner. This is Mr. Elliott Finkle, who is the Director of the Undersea Research Program of the National Oceanic and Atmospheric Agency, NOAA.