PROFILE DATA BANKS

What Are Profile Data Banks?

Profile Data Banks are extended collections of dive profiles with conditions and outcomes. To validate tables, meters, and software within any computational model, profiles and outcomes are necessarily matched to model parameters with statistical (fit) rigor. Profile-outcome information is termed a Data Bank (DB) these days, and there are a couple of them worth discussing. Others will surely develop along similar lines. Their importance is growing rapidly in technical and recreational sectors not only for the information they house, but also for application to diving risk analysis and model tuning.

One well known DB is the DAN Project Dive Exploration (PDE) collection. The PDE collection focuses on recreational air and nitrox diving up to now, but is extending to technical, mixed gas, and decompression diving. Approximately 87,000 profiles reside on PDE computers with some 97 cases of DCS across the air and nitrox recreational diving. PDE came online in the 1995, under the guidance of Dick Vann and Petar Denoble. DAN Europe, under Alessandro Marroni, joined forces with DAN USA in the 2000s extending PDE. Their effort in Europe is termed Dive Safe Lab (DSL). DSL has approximately 50,000 profiles with 8 cases of DCS. For simplicity following, we group PDE and DSL together as one DB, as information is easily exchanged across their computers. In combo, PDE and DSL house some 137,000 profiles with 105 cases of DCS. The incidence rate is 0.0008 roughly. This is a massive and important collection.

Another more recent DB focused on technical, mixed gas, decompression diving is the Data Bank at Los Alamos National Laboratory (LANL DB). Therein some 2,900 profiles with 20 cases of DCS reside. The Authors are mainly responsible for bringing the LANL DB online in the early 2000s. Much of the LANL DB rests on data extracted from C&C Dive Team operations over the past 20 years or so. In LANL DB, the actual incidence rate is 0.0069, roughly 10 times greater than PDE. Such might be expected as LANL DB houses mixed gas, decompression profiles, a likely riskier diving activity with more unknowns.

In both cases, data collection is an ongoing effort, and profile information can be narrowed down to its simplest form, most of it coming from dive computer downloads tagging information across variable time intervals (3 – 5 secs) which is then processed into a more manageable format for future statistical analysis:

1. bottom mix/ppO2 , depth, and time;
2. ascent and descent rates;
3. stage and decompression mix/ppO2 , depths, and times;
4. surface intervals;
5. time to fly;
6. diver age, weight, sex, and health complications;
7. outcome rated 1 – 5 in order of bad to good;
8. environmental factors (temperature, current, visibility, equipment).

Different DBs will use variations on reported data, but the above covers most of the bases.

Why Are Profile Data Banks Important?

Staging is properly a single most concern in diving. Depths, exposure times, gas mixes and switches, ascent and descent rates, open circuit (OC) and rebreather (RB) systems, shallow or deep stops are a few of many choices facing divers. Within that set, there are an infinity of possibilities to safely bring a diver to the surface.

The question of diving data then becomes important. Many feel that the matching of models and data

requires data across a spectrum of diving activities, with the more the better, rather than just directed clinical but scattered tests. While manned tests of single profiles are certainly important, it is usually difficult to extrapolate results to all other cases because of the multiplicity of possible events for differing depths, gas mixtures, ascent rates, level stagings, and combinations of all. In other words, isolated tests are hard to kluge together, and, therefore, the widest possible spectrum of diving profileoutcomes is preferable. Besides, there is likely not enough money nor time to test all pertinent mixed gas, decompression profiles of interest across all diving sectors. In that same vein, the focus of Data Banks is operational diving, and not clinical tests.

Another concern is deep stop data across OC and RB diving. The shallow stop paradigm of Haldane has persisted for almost a century and most data taken over the years reflects shallow stop staging as the focus for testing and dive planning. While it can be shown that both deep stop and shallow stop diving can be effected within the same relative risk levels, deep stop diving is more efficient timewise (shorter) than shallow stop diving. To fill the gap in deep stop data, Data Banks need engage in collecting profile-outcomes for deep stop (bubble) models for correlation of bubble models with both deep stop and shallow stop data. Recall that bubble models generally require deeper decompression staging than dissolved (Haldane) gas models, and collapse to dissolve gas models in the limit of little, or no, bubble excitation and growth. The real task is deep stop decompression data correlations, as it has been shown that bubble models recover shallow stop staging as the failsafe option. But to be fair to Haldane, we need note that he tested deep stops 100 years ago, but for various and sundry reasons, they never made it into his early tables, nor later dissolved gas tables of others.

What's In Profile Data Banks?

Both DBs are storing important dive information as summarized. Specific profile entry points span recreational to technical, OC to RB, air to mixed gas, and shallow to deep diving. That's a lot of territory. PDE and DSL are focused on no decompression diving, while LANL DB is focused on mixed gas, OC and RB , deep decompression diving. Of course, overlaps exist.

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PDE plus DSL houses some 137,000 profiles with 105 cases of DCS. The underlying incidence rate is roughly p = 105/137, 000 = 0.0008, well below 1%. Both gather data on dives, conditions, and outcomes to assess DCS and risk factors. One interesting study contrasted risk in 3 dive groups, namely, warm water divers, cold water divers, and USN chamber (wet pod) divers. Outcomes are tabulated in Table 1. The main purpose of including USN chamber dives is one of calibration of model to data across all 3 cases. USN divers were also immersed and exercising too.

Table 1. Three Group Population Sample

Dive group	Dives	DCS hits	Incidence
warm water	51497	8	0.0002
cold water	6527	18	0.0028
USN chamber	2252	70	0.0311

The highest overall hit rate occurs in USN chamber divers, and lowest in warm water divers. But there is more info in this 3 class sample, as extensive statistical analysis shows.

While USN chamber dive risks are absolutely and relatively higher, a further breakdown of cold water versus (just) Scapa Flow risk shows that Scapa Flow risks are also inherently smaller by comparison to other cold water risks. Scapa Flow is located off the northern coast of Scotland in the Orkney Islands and is the historical cemetary for wrecks dating back to the Vikings. During WW1 and WW2, Scapa Flow was home to the Royal Navy. It is plausible to speculate that long, decompression dives put USN divers at higher risk than short, no decompression, warm water dives due to thermal stresses (temperature). And particularly, the lower risks for Scapa Flow divers are thought to result from extensive use of drysuits to offset heat loss as a thermal stress.

An important spinoff of the DSL collection is Doppler data collected off recreational air divers making 1/2 deep stops for 2-3 min after no decompression exposures. Bennett and Marroni clocked Doppler (bubble count) minima in divers performing 1/2 deep stops after exposures close to the old USN NDLs for various depths. Parallel analyses using profiles from the LANL DB exhibit risk minimization in the same time frames for the 1/2 deep stop within bubble models, but not supersaturation models. This is seen in Table 2. Supersaturation risk increases monotonically with deep stop time. Though relatively small, bubble risk reaches a minima somewhere in the 2-3 min 1/2 deep stop following dives to the old USN air NDLs. Such represents a useful symbiosis between DSL and LANL DBs.

Table 2. Doppler And Bubble Risk Minimization

Depth/time		**Bubble risk**				**Supersaturation risk**		
(fsw/min)	**(m/min)**							
		no stop	*1 min*	*2.5 min*	*4 min*	*1 min*	*2.5 min*	*4 min*
80/40	24,4/40	0.0210	0.0193	0.0190	0.0191	0.0212	0.0218	0.0226
90/30	27,4/30	0.0210	0.0187	0.0183	0.0184	0.0213	0.0220	0.0229
100/25	30,5/25	0.0210	0.0174	0.0171	0.0172	0.0215	0.0223	0.0234
110/20	33,5/20	0.0220	0.0165	0.0161	0.0162	0.0224	0.0232	0.0241
120/15	36,6/15	0.0200	0.0150	0.0146	0.0147	0.0210	0.0220	0.0238
130/10	39,6/10	0.0170	0 .0129	0.0125	0.0126	0.0178	0.0191	0.0213

In all cases, supersaturation risk tracks higher than bubble risk, but all are relatively small. This comes as no surprise as USN NDLs have been used safely and successfully with and without deep safety stops for many years. Having just said that, however, Doppler scores are certainly a modern concern for all divers, and most would likely prefer to dive regimens that minimize Doppler counts.

LANL Data Bank

Some 2,879 profiles now reside in the LANL DB. There are 20 cases of DCS in the data file. The underlying DCS incidence rate is, p = 20/2879 = 0.0069, below but near 1%. Stored profiles range from 150 fsw down to 840 fsw, with the majority above 350 fsw. All data enters through the Authors, that is, divers, profiles, and outcomes are filtered.

A summary breakdown of DCS hit (bends) data consists of the following:

1. OC deep nitrox reverse profiles – 5 hits (3 DCS I, 2 DCS II)
2. OC deep nitrox – 3 hits (2 DCS I, 1 DCS II)
3. OC deep trimix reverse profiles – 2 hits (1 DCS II, 1 DCS III)
4. OC deep trimix – 2 hits (1 DCS I, 1 DCS III)
5. OC deep heliox – 2 hits (2 DCS II)
6. RB deep nitrox – 2 hits (1 DCS I, 1 DCS II)
7. RB deep trimix – 2 hits (1 DCS I, 1 DCS III)
8. RB deep heliox – 2 hits (1 DCS I, 1 DCS II)

DCS I means limb bends, DCS II implies central nervous system (CNS) bends, and DCS III denotes inner ear bends (occurring mainly on helium mixtures). Both DCS II and DCS III are fairly serious afflictions, while DCS I is less traumatic. Deep nitrox means a range beyond 150 fsw, deep trimix means a range beyond 200 fsw, and deep heliox means a range beyond 250 fsw as a rough categorization. The abbreviation OC denotes open circuit, while RB denotes rebreather. Reverse profiles are any sequence of dives in which the present dive is deeper than the previous dive.

Nitrox means an oxygen enriched nitrogen mixture (including air), trimix denotes a breathing mixture of nitrogen, helium, oxygen, and heliox is a breathing mixture of helium and oxygen. None of the trimix nor heliox cases involved oxygen enriched mixtures on OC, and RB hits did not involve elevated oxygen partial pressures above 1.4 atm. Nitrogen-to-helium (heavy-to-light) gas switches occured in 4 cases, violating contemporary ICD (isobaric counterdiffusion) protocols. Isobaric counterdiffusion refers to two inert gases (usually nitrogen and helium) moving in opposite directions in tissues and blood.

When summed, total gas tensions (partial pressures) can lead to increased supersaturation and bubble formation probability.

None of the set exhibited full body nor CNS (central nervous system) oxygen toxicity (oxtox). The 20 cases come after the fact, that is diver distress with hyperbaric chamber treatment following distress. Profiles originate with seasoned divers as well as from broader field testing reported to us,coming from divers using wrist slate decompression tables with computer backups. Most profiles reach us directly as computer downloads, which we translate to a requisite format. Approximately 88% of LANL DB entries emanate from computer downloads.

The data is relatively coarse grained, making compact statistics difficult. The incidence rate across the whole set is small, on the order of 1% and smaller. Fine graining into depths is not meaningful yet, so we breakout data into gas categories (nitrox, heliox, trimix), as tabulated earlier. Table 3 indicates the breakdown.

Table 3. Profile Gas-DCS Summary

Mix	Total profiles	DCS hits	Incidence
OC nitrox	344	8	0.0232
RB nitrox	550	2	0.0017
all nitrox	894	10	0.0112
OC trimix	656	4	0.0061
RB trimix	754	2	0.0027
all trimix	1410	6	0.0042

OC heliox	116	2	0.0172
RB heliox	459	2	0.0044
all heliox	575	4	0.0070
total	**2879**	**20**	**0.0069**

The DCS hit rate with nitrox is higher, but not statistically meaningful across this (sparse) set. The last entry is all mixes, seen previously. In the above set, there are 35 marginals, that is, DCS was not diagnosed, but the diver surfaced feeling badly. In such cases, many do not weight the dive as a DCS hit.

It is also interesting to break mixed gas profiles into 100 fsw increments, though we do not do depth dependent statistics on these profiles. It is obvious that 500 fsw or so is the limit statistically to the data set. It is for that reason that we limit applications of the LANL algorithm to 540 fsw.

Table 4. Profile Gas-Depth Summary

	100 to 199 fsw (30 a 60 m)	**200 to 299 fsw (61 to 90 m)**	**300 to 399 fsw (90 to 120 m)**	**400 to 499 fsw (121 to 150 m)**	**500 to 599 fsw (151 to 180 m)**	**600+ fsw (181+ m)**	**total**
OC nitrox	268	76					344
RB nitrox	213	246	91				550
OC trimix	10	388	226	26	4	2	656
RB trimix	22	358	226	108			754
OC heliox		42	49	25			116
RB heliox	12	195	143	107	2		459
total	**525**	**1305**	**775**	**266**	**6**	**2**	**2879**

The corresponding DCS hit summary for Table 4 is given in Table 5.

Table 5. Profile Gas-Depth Summary

	100 to 199 fsw (30 a 60 to)	**200 to 299 fsw (61 to 90 m)**	**300 to 399 fsw (90 to 120 m)**	**400 to 499 fsw (121 to 150 m)**	**500 to 599 fsw (151 to 180 m)**	**600+ fsw (181+ m)**	**totale**
OC nitrox	5	3					8
RB nitrox		1	1				2
OC trimix		2		1		1	4
RB trimix			1	1			2
OC heliox			2				2
RB heliox			1	1			2

total	**5**	**6**	**5**	**3**		**1**	**20**

Profiles come from technical diving selectively, essentially mixed gas, extended range, decompression, and extreme diving. Profiles from the recreational community are not included, unless they involve extreme exposures on air or nitrox (many repetitve dives, deeper than 150 fsw, altitude exposures, etc). This low rate makes statistical analysis difficult, and we use a global approach to defining risk after we fit the model to the data using maximum likelihood. The maximum likelihood fit links directly to the binomial probability structure of DCS incidence in divers and aviators. Just a few comments here hopefully suffice to outline the complex mathematical process applied to model and data in what is termed maximum likelihood. The approach is used extensively across diving data.

How Do We Analyze Data In Profile Data Banks?

To analyze risk, a risk estimator must be used and fitted to the data. Two are very popular, that is, the supersaturation and bubble growth risk functions. These are explained in detail in Diving Physics With Bubble Mechanics And Decompression Theory In Depth for instance. They can be summarized in layman terms as follows:

1. supersaturation (ratio) risk estimator – uses the difference between total inert gas tension and ambient pressure divided by ambient pressure as a measure of risk;
2. bubble (ratio) risk estimator – uses the bubble growth rate divided by the initial volume of bubbles excited by compression-decompression as a measure of risk.

Mathematical expressions, and arbitrary parameters contained therein, are then fitted to the data in the process of maximum likelihood, that is, a probability function of all dive profiles and outcomes across the DB is matched in parameter and outcome space as best possible. Very high speed computers and sophisticated mathematical software are necessary in matching parameters to outcomes. Here at LANL, the world's largest and fastest supercomputers in parallel processing mode make short work of the fitting process.

In many studies, the supersaturation risk function does not correlate deep stop data well, while the bubble risk function fits both deep stop and shallow stop data. The bubble risk function we employ derives from the LANL bubble model (RGBM), of course, having enjoyed safe utility across many diving sectors in diverse application. But it is no stretch to note that many modern bubble models would suggest much the same, generically, compared to dissolved gas models.

What Have We Learned From Profile Data Banks?

This article could go on for pages and pages, but as additional food for thought, consider a number of related DB gleanings:

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Broadband analysis of PDE and SDL data shows some interesting features:

1. models do not always extrapolate outside their calibration (data) points;
2. probabilistic techniques coupled to real models are useful vehicles for diver risk estimation;
3. dive conditions (environmental stresses) may significantly affect risk;
4. the body mass index (BMI) often correlates with DCS risk, particulary for older and overweight divers;
5. human characteristics such as age, sex, and certification level affect the likelihood of diving morbidity and fatality;

6. leading causes of morbidity and mortality in diving are drowning, near drowning, barotrauma during ascension, and DCS;
7. only 2% of recreational divers use tables for dive planning, with the rest relying on dive computer;
8. nitrox diving is exploding in the recreational sector.

LANL Data Bank

LANL DB profile analysis of dissolved gas staging versus bubble staging and related metrics, suggests broadly:

1. deep stop data is intrinsically different from data collected in the past for diving validation, in that previous data is mainly based on shallow stop diver staging, a possible bias in dive planning;
2. deep stop data and shallow stop data yield the same risk estimates for nominal, shallow, and nonstop diving because bubble models and dissolved gas models converge in the limit of very small phase separation;
3. if shallow stop data is only employed in analyses, dissolved gas risk estimates will be usually higher than those computed with deep stop data;
4. pure O2 or EAN80 are standard OC switch gases in the 20 fsw zone;
5. deep stops are standard across mixed gas diving, and DCS spikes are nonexistent;
6. deep switches to nitrogen mixes off helium mixes are avoided by technical divers, instead oxygen fraction is increased by decrease in helium fraction;
7. deep stop dive computers serve mostly as backup or bailout, with tables and dive planning software the choice for deep stop diving;
8. DCS spikes across mixed gas, decompression, and deep stop diving are non existent using deep stop tables, meters, and software;
9. DCS incidence rates are higher for technical diving versus recreational diving, but still small;
10. RB usage is increasing across diving sectors;
11. wrist dive computers possess chip speeds that allow full resolution of even the most extensive bubble models;
12. technical diving data is most important for correlating models and data;
13. technical divers do not dive air, particularly deep air, with trimix and heliox the choices for deep excursions;
14. released deep stop tables, software, and meters enjoy extensive and safe utility among professional divers;
15. technical diving is growing in leaps and bounds, with corresponding data accessible off computers and bottom timers;

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