RGBM - Reduced Gradient Bubble Model

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Dr. Bruce Wienke, Director of the Computation Testbed for Industry, Advanced Computing Laboratory at Los Alamos National Laboratory, and the creator of the **RGBM** (Reduced Gradient Bubble Model) has joined the Abysmal Diving team. Dr. Wienke will be assisting us in the implementation of his latest decompression model into **Abyss.**

This means that **Abyss** will be the first and only product in the world with a fully operational Bubble Mechanics model.

1. This will allow **Abyss** to more effectively handle Technical Repetitive decompression diving!!! (not a small issue in itself!!)
2. Dives in which the following dive is deeper than the first. (a real potential problem area).
3. This will also allow **Abyss** to run active tracking, in real time, of actual bubble growth based upon his published and proprietary unpublished research.

RGBM / ABYSS Implementation

The **Reduced Gradient Bubble Model (RGBM)** is a dual phase (dissolved and free gas) algorithm for diving calculations. Incorporating and coupling historical Haldanian dissolved gas transport with bubble excitation and growth, the **RGBM** extends the range of computational applicability of traditional methods. The **RGBM** is correlated with diving and exposure data on more complete physical principles. Much is new in the **RGBM** algorithm, and troublesome multidiving profiles with higher incidence of DCS are a target here. Some highlighted extensions for the **ABYSS** implementation of the Buhlmann basic algorithm include:

1. Standard Buhlmainiann no-stop time limits;
2. Restricted repetitive exposures, particularly beyond 30m / 100 ft, based on reduction in permissible bubble diffusion gradients within 2 hour time spans;
3. Restricted yo-yo and spike (multiple ascents and descents) dives based on excitation of new bubble seeds;
4. Restricted deeper-than-previous divers based on excitation of very small bubble seeds over 2 hour time spans:
5. Restricted multiday diving based on adaptation and regrowth of new bubble seeds;
6. Smooth coalescence of bounce and saturation limit points using 32 tissue compartments;
7. Consistent treatment of altitude diving, with proper zero point extrapolation of limiting tensions and permissible bubble gradients (through zero as pressure approaches zero);

8. Algorithm linked to diving data (tests), Doppler bubble, and laboratory micronuclei experiments;
9. Overall, parameters in **RGBM / ABYSS** are conservative, but flexible and easy to change or fit to new data.

What's in store for the future?

Quoting from Dr. Bruce Wienke..."The ultimate computational algorithm, coupling nucleation, dissolved gas uptake and elimination, bubble growth and collisional coalescence, and critical sites, would be very, very complicated, requiring super-computers such as CRAYS or their massively parallel cousins CMs for three dimensional modeling. Stochastic Monte Carlo methods and sampling techniques exist which could generate and stabilize nuclei from the thermodynamic functions, such as Gibbs or Helmholtz free energy, transport dissolved gas in flowing blood to appropriate sites, inflate, deflate, move, and collide bubbles and nuclei, and then tally statistics on tensions, bubble size and number, inflation and coalescence rate, free phase volume, and any other meaningful parameter, all in necessary geometrics."

Such types of simulations of similarly complicated problems last for 16-32 hours at the Los Alimos Laboratories, on lightning fast supercomputers with near Gigaflop speed (1billion floating point operations per second)

Technical Details on the **RGBM** (Reduced Gradient Bubble Model)

The **Reduced Gradient Bubble Model (RGBM)**, developed by DR Wienke, treats both dissolved and free phase transfer mechanisms, postulating the existence of gas seeds (micronuclei) with permeable skins of surface active molecules, small enough to remain in solution and strong enough to resist collapse. The model is based upon laboratory studies of bubble growth and nucleation, and grew from a similar model, the Varying Permeability Model (VPM), treating bubble seeds as gas micropockets contained by pressure permeable elastic skins.

Inert gas exchange is driven by the local gradient, the difference between the arterial blood tension and the instantaneous tissue tension. Compartments with 1, 2, 5, 10, 20, 40, 80, 120, 240, 480, and 720 halftimes, tau , are again employed. While, classical (Haldane) models limit exposures by requiring that the tissue tensions never exceed the critical tensions, fitted to the US Navy no-stop limits, for example. The reduced gradient bubble model, however, limits the supersaturation gradient, through the phase volume constraint. An exponential distribution of bubble seeds, falling off with increasing bubble size is assumed to be excited into growth by compression-decompression. A critical radius, r sub c , separates growing from contracting micronuclei for given ambient pressure, P sub c . At sea level, P sub c = 10m / 33 fsw , r sub c = .8 microns, and DELTA P = d. Deeper decompressions excite smaller, more stable, nuclei.

Within a phase volume constraint for exposures, a set of nonstop limits, t sub n , at depth, d, satisfy a modified law, d t sub n sup 1/2 = 122m / 400 fsw min sup 1/2 , with gradient, G, extracted for each compartment, tau , using the nonstop limits and excitation radius, at generalized depth, d = P - 10m / 33 fsw. Tables 2 and 3 summarize t sub n , G sub 0 , DELTA G , and delta , the depth at which the compartment begins to control exposures.

Table 2. Critical Phase Volume Time Limits.

depth - d		nonstop limit	depth -d		nonstop limit
(fsw)	(msw)	t sub n (min)	(fsw)	(msw)	t sub n (min)
30	9	250	130	40	9
40	12	130	140	43	8
50	15	73	150	46	7
60	18	52	160	47	6.5
70	21	39	170	50	5.8
80	24	27	180	53	5.3
90	27	22	190	56	4.6
100	30	18	200	59	4.1
110	33	15	210	62	3.7
120	36	12	220	65	3.1

Gas filled crevices can also facilitate nucleation by cavitation. The mechanism is responsible for bubble formation occurring on solid surfaces and container walls. In gel experiments, though, solid particles and ragged surfaces were seldom seen, suggesting other nucleation mechanisms. The existence of stable gas nuclei is paradoxical. Gas bubbles larger than 1 micron should float to the surface of a standing liquid or gel, while smaller ones should dissolve in a few seconds. In a liquid supersaturated with gas, only bubbles at the critical radius, r sub c , would be in equilibrium (and very unstable equilibrium at best). Bubbles larger than the critical radius should grow larger, and bubbles smaller than the critical radius should collapse. Yet, the Yount gel experiments confirm the existence of stable gas phases, so no matter what the mechanism, effective surface tension must be zero.

Table 3. Critical Phase Volume Gradients.

halftime	threshold depth		surface gradient		gradient change
tau (min)	delta (fsw)	delta (msw)	G sub 0 (fsw)	G sub 0 (msw)	DELTA G
2	190	58	151.0	46.1	0.518
5	135	41	95.0	29.0	0.515
10	95	29	67.0	20.5	0.511
20	65	20	49.0	15.0	0.506
40	40	12	36.0	11.0	0.468
80	30	10	27.0	8.2	0.417
120	28	8.5	24.0	7.3	0.379
240	16	4.9	23.0	7.0	0.329
480	12	3.7	22.0	6.7	0.312

Although the actual size distribution of gas nuclei in humans is unknown, these experiments in gels have been correlated with a decaying exponential (radial) distribution function. For a stabilized distribution accommodated by the body at fixed pressure, P sub c , the excess number of nuclei excited by compression-decompression must be removed from the body. The rate at which gas inflates in tissue depends upon both the excess bubble number, and the supersaturation gradient, G. The critical volume hypothesis requires that the integral of the product of the two must always remain less than some volume limit point, alpha V , with alpha a proportionality constant. A conservative set of bounce gradients, G bar , can be also be extracted for multiday and repetitive diving, provided they are multiplicatively reduced by a set of bubble factors, eta sup rep, eta sup reg , eta sup exc , all less than one, such that G bar = eta sup rep eta sup reg eta sup exc G.

These three bubble factors reduce the driving gradients to maintain the phases volume constraint. The first bubble factor reduces G to account for creation of new stabilized micronuclei over time scales of days. The second factor accounts for additional micronuclei excitation on deeper-than-previous dives. The third bubble factor accounts for bubble growth over repetitive exposures on time scales of hours. Clearly, the repetitive factors, eta sup rep , relax to one after about 2 hours, while the multiday factors, eta sup reg , continue to decrease with increasing repetitive activity, though at very slow rate. Increases in bubble elimination halftime and nuclei regeneration halftime will tend to decrease eta sup rep and increase eta sup reg . The repetitive fractions, eta sup rep , restrict back to back repetitive activity considerably for short surface intervals. The multiday fractions get small as multiday activities increase continuously beyond 2 weeks. Deeper-than-previous excursions incur the greatest reductions in permissible gradients (smallest eta sup exc) as the depth of the exposure exceeds previous maximum depth.