A NEW VPM ALGORITHM FOR REPETITIVE DIVES

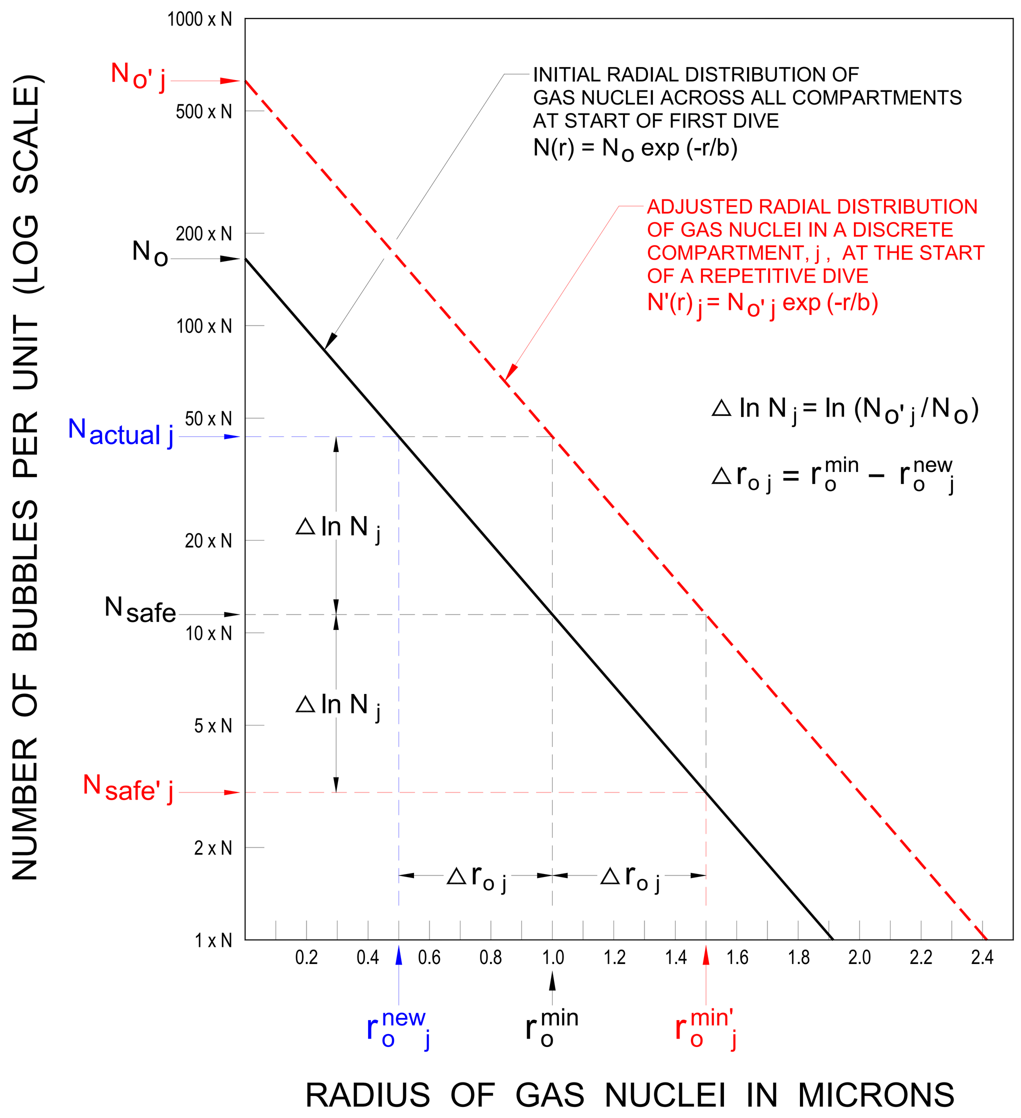
David E. Yount *
University of Hawaii
Honolulu, Hawaii

Eric B. Maiken
n&k Technology, Inc.
Santa Clara, California

Erik C. Baker
Affiliated Engineers SE, Inc.
Gainesville, Florida

* *this work is carried out in fond memory of David E. Yount who passed away on April 27th, 2000. David is represented here by his son Steffen Yount.*

The concept envisioned by David Yount for repetitive diving calculations:



What does this graph mean?

At the start of a first dive, if the diver has not been diving for a few weeks, the radial distribution of gas nuclei or "bubble seeds" in the body is assumed to be pristine. In other words, the radial distribution is the same in all tissue compartments and has its long-term equilibrium values.

During ascent or decompression on the first dive, the supersaturation gradients in each compartment may be relaxed (increased) by the VPM dynamic critical volume algorithm to allow N_{actual} versus N_{safe} number of bubbles to form. This causes a dispersion in the radial distribution of gas nuclei across the various tissue compartments.

To compensate on a repetitive dive, the new algorithm adjusts the minimum initial radius of gas nuclei in each compartment by an amount proportional to the dispersion that took place on the previous dive.

Its really a very simple concept and it makes sense!

Why is this new algorithm attractive?

- It extends directly from the Varying Permeability Model (VPM) on a fundamental level.
- It avoids the use of ad hoc factors.
- Although the algorithm is pretty green (we have only begun to explore many of its implications), the results so far look promising.

Calculation steps for the new algorithm:

1. Calculate the ascent profile for the first dive using the VPM dynamic critical volume algorithm (Yount & Hoffman, 1986). Assume pristine values for all VPM parameters including the minimum initial radius, r_o^{min}, of gas nuclei to be probed for bubble formation.
2. From the maximum supersaturation gradient, $P_{ss}^{new}{}_j$, allowed for each compartment on the first dive, calculate the associated value for the new initial radius, $r_o^{new}{}_j$, of gas nuclei probed for bubble formation in each compartment.
3. During the surface interval between dives, track the residual inert gas loading for each compartment in the usual way.
4. For the repetitive dive, an adjusted value for the minimum initial radius, $r_o^{min'}{}_j$, of gas nuclei to be probed for bubble formation will be used for each compartment. For short surface intervals, $r_o^{min'}{}_j = r_o^{min} + \wp r_{o\,j}$. For long surface intervals, the regeneration of the pristine radial distribution of gas nuclei may be considered by using the form, $r_o^{min'}{}_j = r_o^{min} + \wp r_{o\,j} \exp(-t_s / \Sigma_s)$ where t_s is the surface interval time and Σ_s is the surface regeneration time constant.
5. Calculate the ascent profile for the repetitive dive again using the VPM dynamic critical volume algorithm. This time use the adjusted minimum initial radius, $r_o^{min'}{}_j$, for each compartment and pristine values for all other VPM parameters.

A comparison and some sample profiles:

No-deco limits for 3 days of repetitive air diving - 120 fsw dives, twice a day, with 45 minute surface interval (RGBM profiles courtesy of Bruce R. Wienke):

Computer/Algorithm	Dive 1	Dive 2	Dive 3	Dive 4	Dive 5	Dive 6
Suunto Vyper RGBM	10	6	9	5	9	5
New VPM Algorithm	**9**	**8**	**8**	**8**	**8**	**8**
Decometer RGBM	12	9	10	9	9	9
Technical RGBM	13	11	11	10	10	9

Deep air forward and reverse profiles (depth in fsw / time in min):

Dive 1	Deco 1	Surface Interval	Dive 2	Deco 2
160/7	10/1	30	40/100	10/4
160/7	10/1	60	40/100	10/1
160/7	10/1	120	40/100	no deco
40/100	no deco	30	160/7	30/1, 20/1, 10/3
40/100	no deco	60	160/7	20/1, 10/2
40/100	no deco	120	160/7	20/1, 10/2

Trimix 16/33 dives to 250 fsw for 30 min. Deco mixes - air at 100 fsw, O_2 at 20 fsw:

Stop	Deco 1	Surface Interval	Deco 2
170	1	120	1
160	1		1
150	1		2
140	2		2
130	2		2
120	2		2
110	3		3
100	2		2
90	2		2
80	2		3
70	4		4
60	4		4
50	5		6
40	7		9
30	10		12
20	8		11
10	12		19

Program output showing how it works:

Sample air dive series
First dive to 120 fsw for 12 minutes (deco 10/2)
Surface interval 45 minutes
Repetitive dive to 120 fsw for 12 min. (deco 30/1, 20/2, 10/5)

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       DIVE #1 - FIRST DIVE TO 120 FSW FOR 12 MINUTES:

       ITERATION #   1

               Cpt  1  Cpt  2  Cpt  3  Cpt  4  Cpt  5  Cpt  6  Cpt  7  Cpt  8
1      Ro MIN 1.00000 1.00000 1.00000 1.00000 1.00000 1.00000 1.00000 1.00000
       PssMIN    18.5    18.8    18.9    19.0    19.1    19.1    19.1    19.2

               Cpt  9  Cpt 10  Cpt 11  Cpt 12  Cpt 13  Cpt 14  Cpt 15  Cpt 16
1      Ro MIN 1.00000 1.00000 1.00000 1.00000 1.00000 1.00000 1.00000 1.00000
       PssMIN    19.2    19.2    19.2    19.2    19.2    19.2    19.2    19.2

       ITERATION #   1   TDECO =    19.5 min

       ITERATION #   2

               Cpt  1  Cpt  2  Cpt  3  Cpt  4  Cpt  5  Cpt  6  Cpt  7  Cpt  8
       Ro NEW  .41834  .46320  .51947  .57943  .64368  .70466  .76284  .81500
       PssNEW    33.6    31.3    29.0    26.9    25.1    23.7    22.5    21.6

               Cpt  9  Cpt 10  Cpt 11  Cpt 12  Cpt 13  Cpt 14  Cpt 15  Cpt 16
       Ro NEW  .85896  .88943  .91082  .92840  .94274  .95448  .96389  .97140
       PssNEW    21.0    20.5    20.2    20.0    19.9    19.7    19.6    19.5

       ITERATION #   2   TDECO =     8.5 min

       ITERATION #   3

               Cpt  1  Cpt  2  Cpt  3  Cpt  4  Cpt  5  Cpt  6  Cpt  7  Cpt  8
       Ro NEW  .28136  .34230  .41975  .50174  .58757  .66624  .73830  .80025
       PssNEW    46.2    39.6    33.9    29.8    26.7    24.5    23.0    21.9

               Cpt  9  Cpt 10  Cpt 11  Cpt 12  Cpt 13  Cpt 14  Cpt 15  Cpt 16
       Ro NEW  .85050  .88429  .90750  .92627  .94138  .95363  .96336  .97106
       PssNEW    21.1    20.6    20.3    20.1    19.9    19.7    19.6    19.5

       ITERATION #   3   TDECO =     4.5 min

       ITERATION #   4

               Cpt  1  Cpt  2  Cpt  3  Cpt  4  Cpt  5  Cpt  6  Cpt  7  Cpt  8
2      Ro NEW  .21952  .28738  .37445  .46681  .56288  .64978  .72810  .79429
       PssNEW    57.1    45.7    37.0    31.4    27.5    25.0    23.2    22.0

               Cpt  9  Cpt 10  Cpt 11  Cpt 12  Cpt 13  Cpt 14  Cpt 15  Cpt 16
2      Ro NEW  .84716  .88229  .90622  .92547  .94088  .95331  .96316  .97094
       PssNEW    21.1    20.6    20.3    20.1    19.9    19.7    19.6    19.5

       ITERATION #   4   TDECO =     3.5 min

3      SURFACE INTERVAL: 45 MINUTES

       DIVE #2 - REPETITIVE DIVE TO 120 FSW FOR 12 MINUTES:

       ITERATION #   1

               Cpt  1  Cpt  2  Cpt  3  Cpt  4  Cpt  5  Cpt  6  Cpt  7  Cpt  8
4 5    Ro MIN 1.77874 1.71103 1.62415 1.53200 1.43615 1.34944 1.27129 1.20525
       PssMIN    13.8    14.3    14.8    15.3    15.8    16.3    16.8    17.3

               Cpt  9  Cpt 10  Cpt 11  Cpt 12  Cpt 13  Cpt 14  Cpt 15  Cpt 16
4 5    Ro MIN 1.15249 1.11745 1.09357 1.07437 1.05899 1.04658 1.03676 1.02900
       PssMIN    17.7    18.0    18.3    18.4    18.6    18.7    18.8    18.9

       ITERATION #   1   TDECO =    30.5 min

       ITERATION #   2

               Cpt  1  Cpt  2  Cpt  3  Cpt  4  Cpt  5  Cpt  6  Cpt  7  Cpt  8
       Ro NEW  .70791  .75654  .81045  .85962  .90304  .93583  .96004  .97638
       PssNEW    23.0    22.3    21.5    20.8    20.3    19.9    19.6    19.4

               Cpt  9  Cpt 10  Cpt 11  Cpt 12  Cpt 13  Cpt 14  Cpt 15  Cpt 16
       Ro NEW  .98657  .99184  .99472  .99660  .99782  .99861  .99911  .99943
       PssNEW    19.3    19.3    19.2    19.2    19.2    19.2    19.2    19.2

       ITERATION #   2   TDECO =    16.5 min

       ITERATION #   3

               Cpt  1  Cpt  2  Cpt  3  Cpt  4  Cpt  5  Cpt  6  Cpt  7  Cpt  8
       Ro NEW  .48172  .55353  .64168  .72899  .81071  .87455  .92232  .95455
       PssNEW    30.2    27.5    25.0    23.1    21.6    20.7    20.1    19.7

               Cpt  9  Cpt 10  Cpt 11  Cpt 12  Cpt 13  Cpt 14  Cpt 15  Cpt 16
       Ro NEW  .97446  .98465  .99016  .99372  .99601  .99748  .99841  .99900
       PssNEW    19.5    19.4    19.3    19.3    19.2    19.2    19.2    19.2

       ITERATION #   3   TDECO =    12.5 min

       ITERATION #   4

               Cpt  1  Cpt  2  Cpt  3  Cpt  4  Cpt  5  Cpt  6  Cpt  7  Cpt  8
       Ro NEW  .40688  .48480  .58337  .68348  .77878  .85376  .90986  .94754
       PssNEW    34.3    30.3    26.7    24.1    22.2    21.0    20.2    19.8

               Cpt  9  Cpt 10  Cpt 11  Cpt 12  Cpt 13  Cpt 14  Cpt 15  Cpt 16
       Ro NEW  .97067  .98244  .98877  .99286  .99547  .99715  .99821  .99887
       PssNEW    19.5    19.4    19.3    19.3    19.2    19.2    19.2    19.2

       ITERATION #   4   TDECO =    10.5 min

       ITERATION #   5

               Cpt  1  Cpt  2  Cpt  3  Cpt  4  Cpt  5  Cpt  6  Cpt  7  Cpt  8
5      Ro NEW  .36795  .44866  .55237  .65914  .76170  .84271  .90330  .94388
       PssNEW    37.2    32.1    27.7    24.6    22.5    21.2    20.3    19.8

               Cpt  9  Cpt 10  Cpt 11  Cpt 12  Cpt 13  Cpt 14  Cpt 15  Cpt 16
5      Ro NEW  .96871  .98131  .98807  .99242  .99520  .99698  .99810  .99880
       PssNEW    19.5    19.4    19.3    19.3    19.2    19.2    19.2    19.2

       ITERATION #   5   TDECO =     9.5 min
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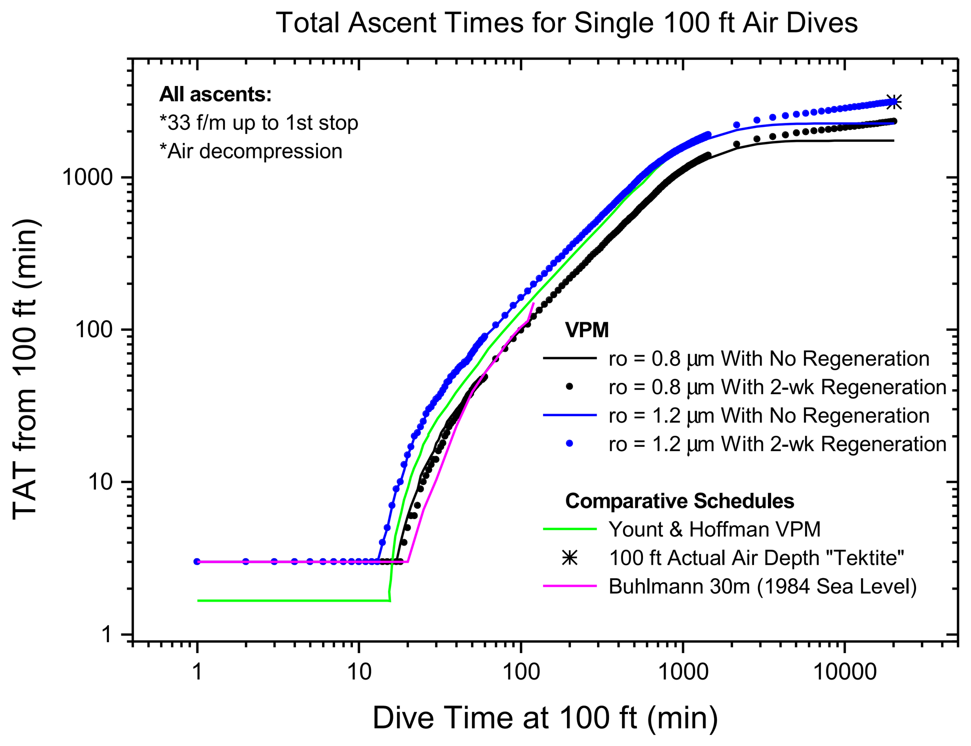
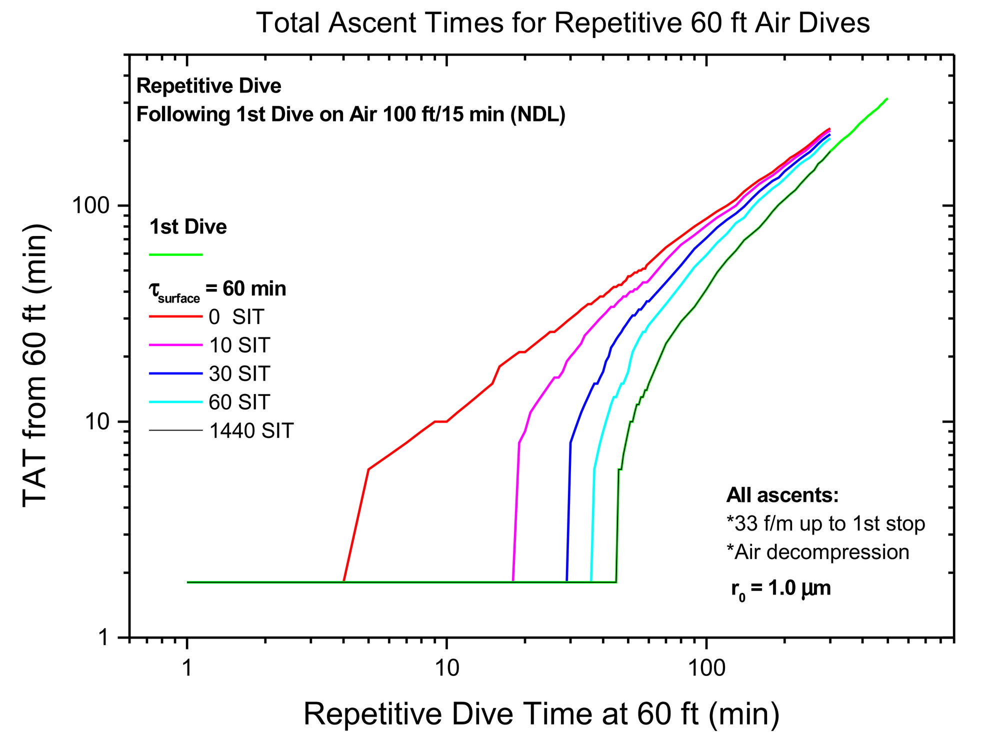
Exploring the implications of the new VPM algorithm for repetitive diving:

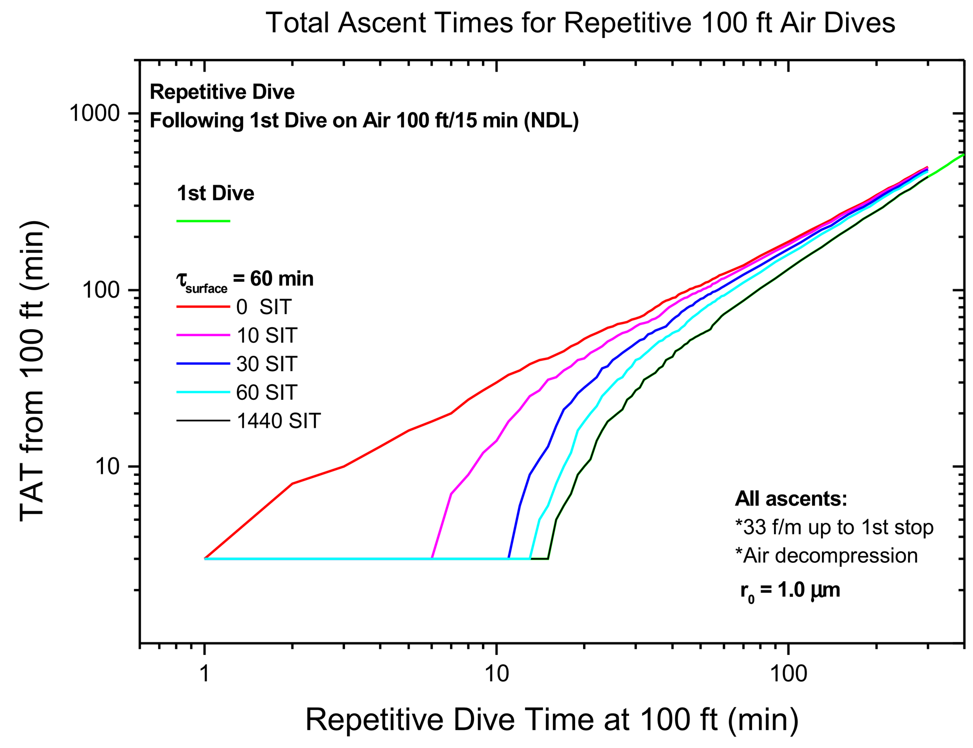
Total Ascent Times for Single 100 ft Air Dives



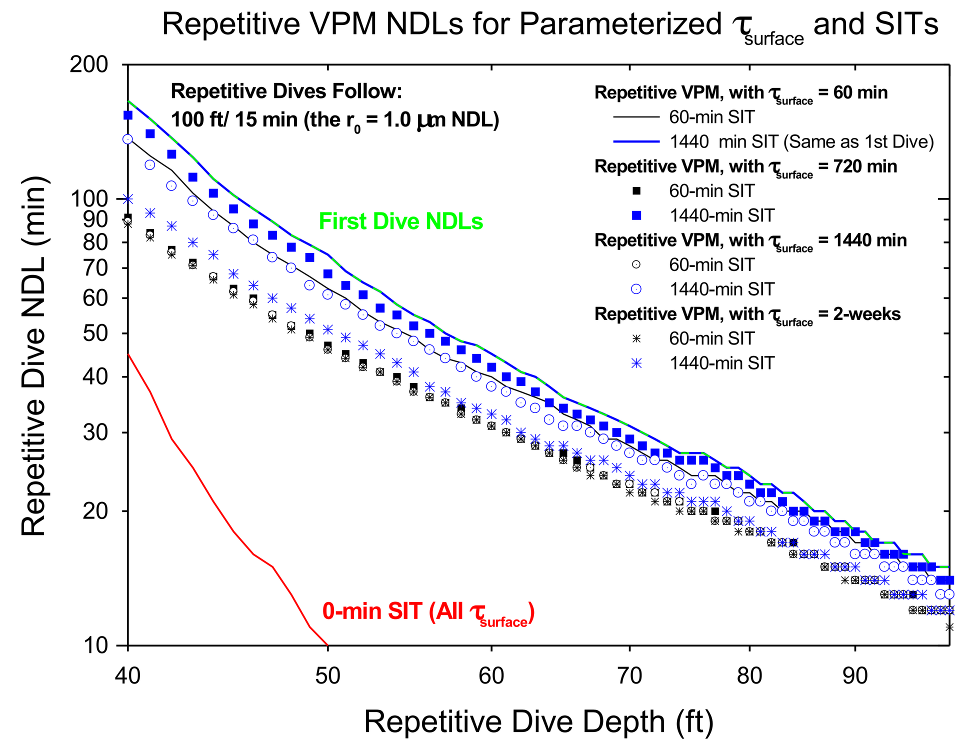
Total Ascent Times for Repetitive 60 ft Air Dives



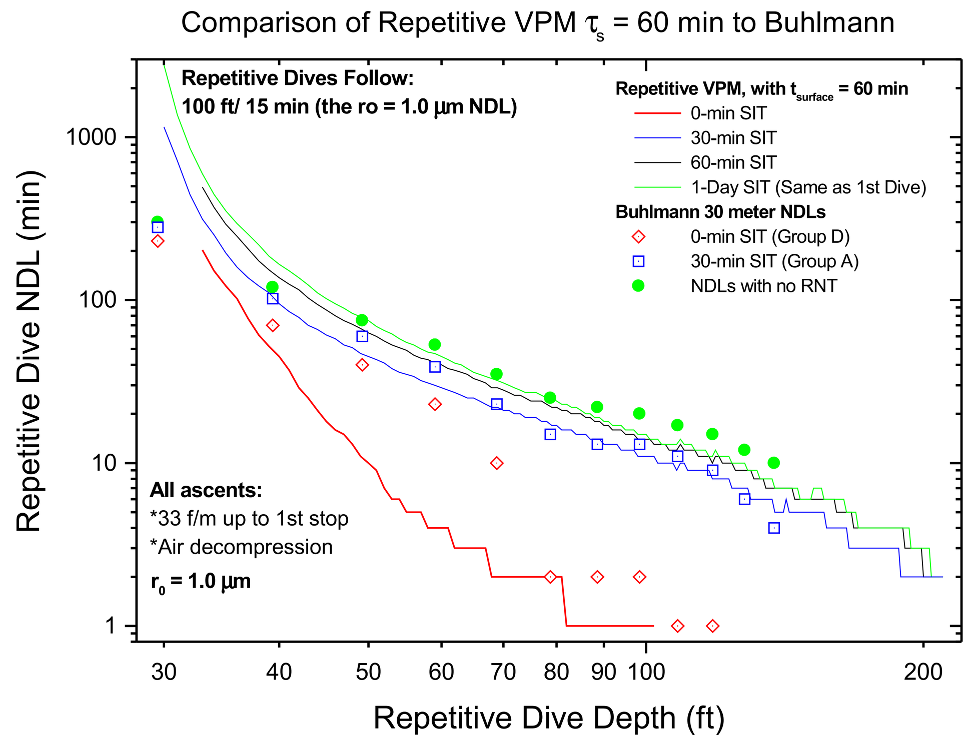
Total Ascent Times for Repetitive 100 ft Air Dives



Repetitive VPM NDLs for Parameterized $\tau_{surface}$ and SITs



Comparison of Repetitive VPM τ_s = 60 min to Buhlmann



Comparison of NDLs Resulting from Residual N_2 Only to $\tau_{surface}$ = 60 min Repetitive VPM Calculations