NOBENDEM

Advanced Decompression Tables

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Outline

- A Colorful History of Nitrogen Bubbles
- Haldanes Theory
- Decompression Table Theory
- “Tweaks”
- Nobendem Model
- Repet Dives - Some Insights
- Nobendem Calculator Examples

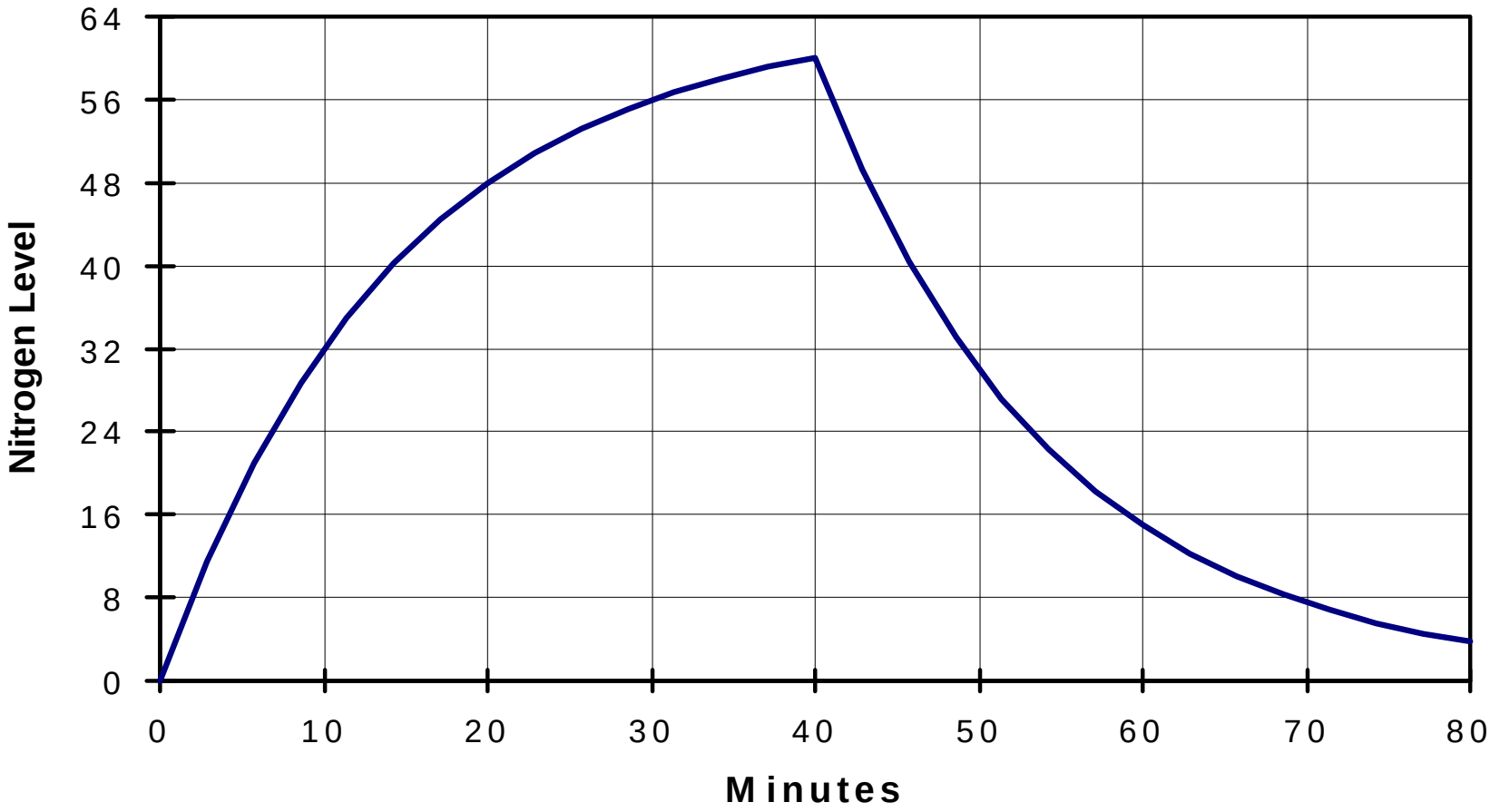
Blame Henry!

- Boyle saw Bubbles in “Pet Viper” (1670)
- 1840’s - Caisson Workers Illness
  - 1889 Moir’s Hudson River Recompression
    - Annual mortality decreases from 25% to 1.6%
- Bert Decides Bubbles are Nitrogen (1878)
- Henry’s Law of Solubilities
- Haldanes 2:1 Supersaturation Theory

Tissue Compartments

- Independent From Each Other
- Absorb and Release Nitrogen
- Exponential Model
  - $N(t) = N_0 + (N_f - N_0)*(1 - e^{-.693*t/k})$
- Characteristic = Half-Time ($t_{1/2}$)

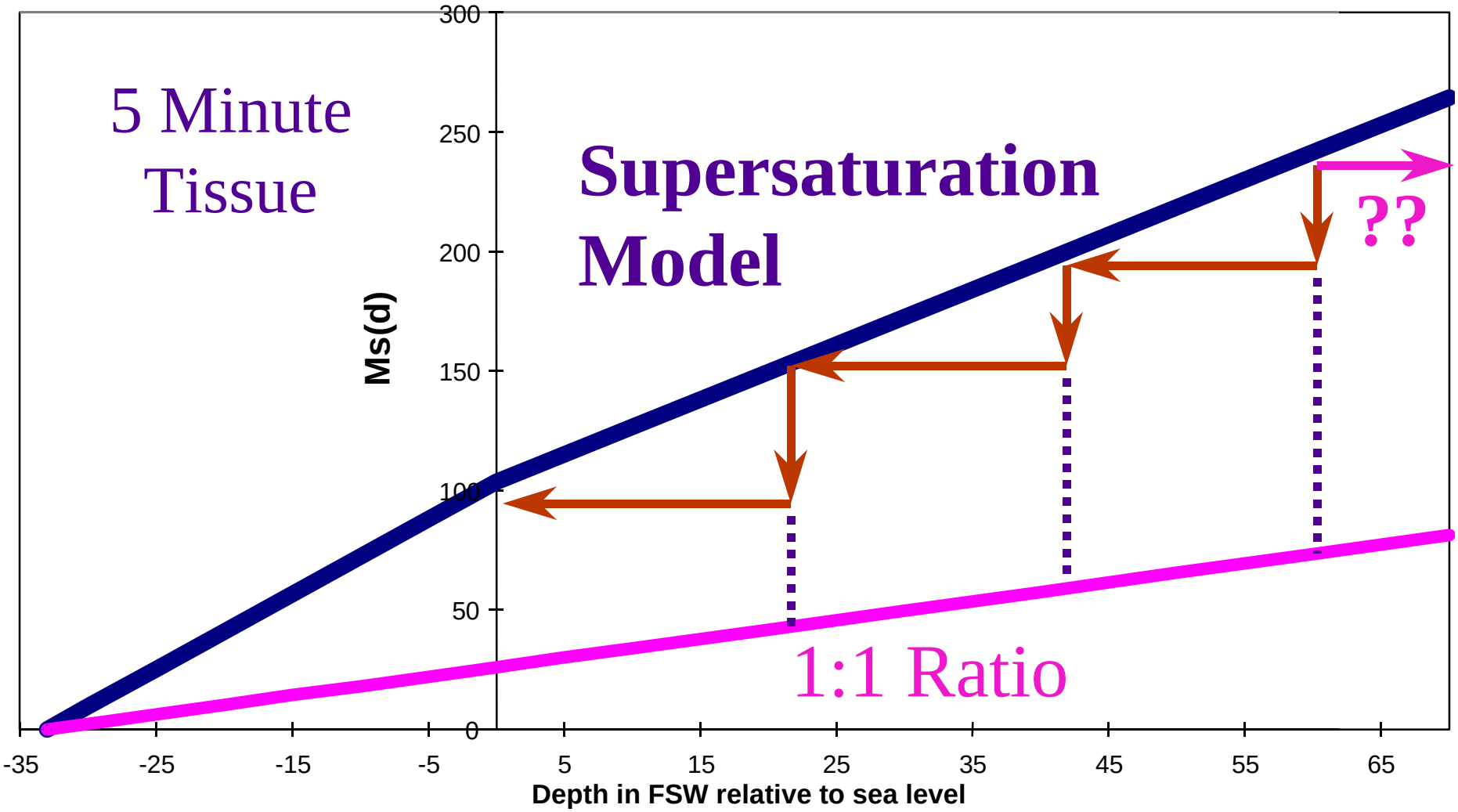
Exponential Model



The US Navy Model

- Diving At Sea Level
  - **Assumptions**
    - **Barometric Pressure = 760 Torr**
    - **Linear Supersaturation Model**
    - **Deepest Segment First**
    - **Staged Decompression**
    - **Ascent at 30 FPM**
  - **Methods**
    - **Only 6 Tissue Compartments**
      - **5, 10, 20, 40, 80, 120 Minutes**
    - **Look-up Tables**

Staged Decompression



TWEAKS

- Standard Table Mods making them “Safer”
  - Add 10 FSW to Max Depth
  - Add 5 Min to bottom time
  - Dive air tables on 28% O2 Nitrox
  - Round shallower on Repet group determination
  - Deco at or shallower than 40 FSW on 100% O2
- Unscientific, Uncalibrated
  - Usable in a pinch
  - Do afford increased margin of safety

The Nobendem Model

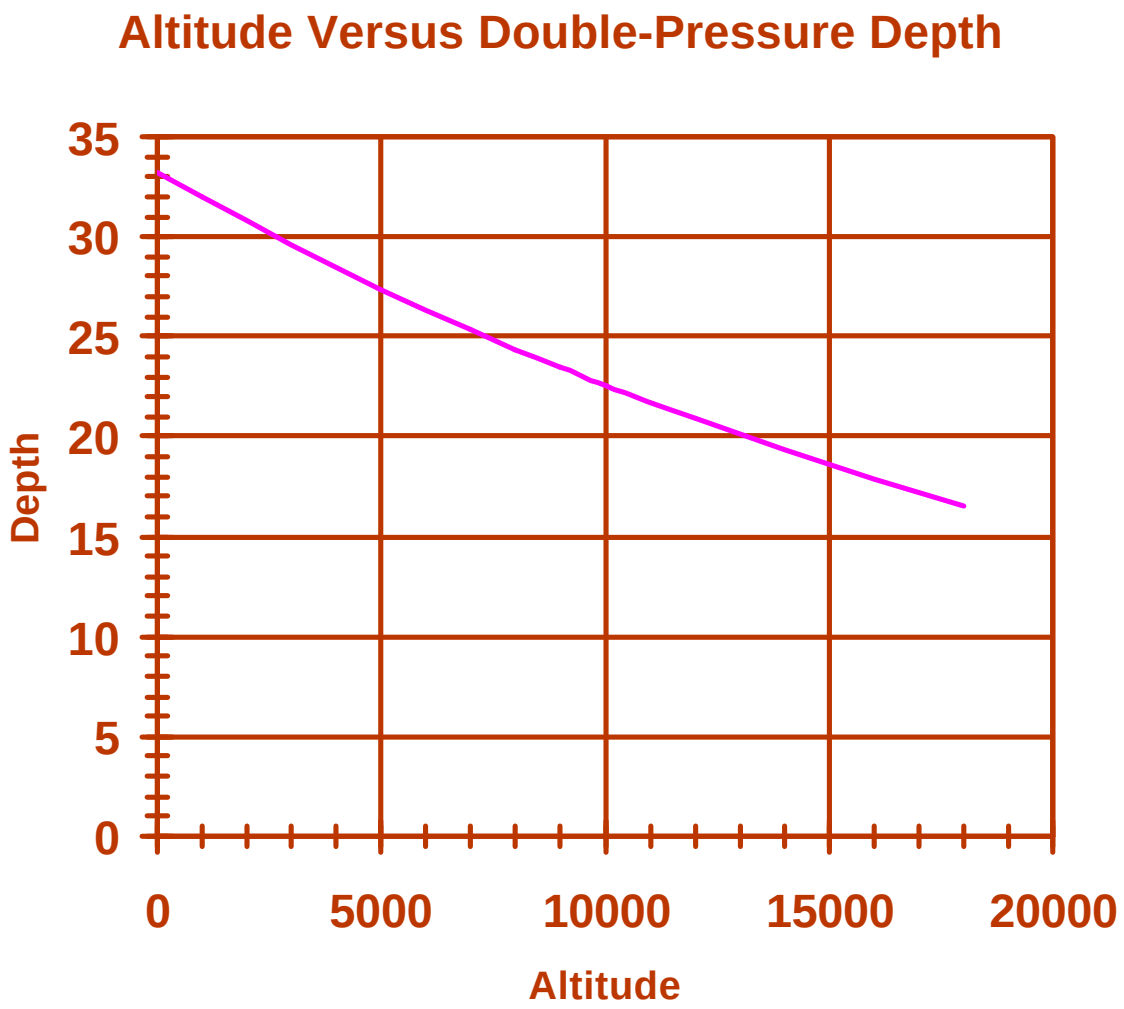
- Unrestricted Diving
  - **Assumptions**
    - **Barometric Pressure = Variable**
    - **Specify Your Nitrox Mix (21% Default = Air)**
    - **Non-Linear Supersaturation Model**
    - **Depth Profile As Desired**
    - **Staged Decompression (You Decide Where)**
    - **Ascent at Any Desired Rate (30 FPM Nominal)**
  - **Methods**
    - **10 Tissue Compartments**
      - **5, 10, 20, 40, 80, 120, 160, 320, 480, 640 Minutes**
    - **Real-Time Spreadsheet Calculator**

Tissue Compartment Ms(d)

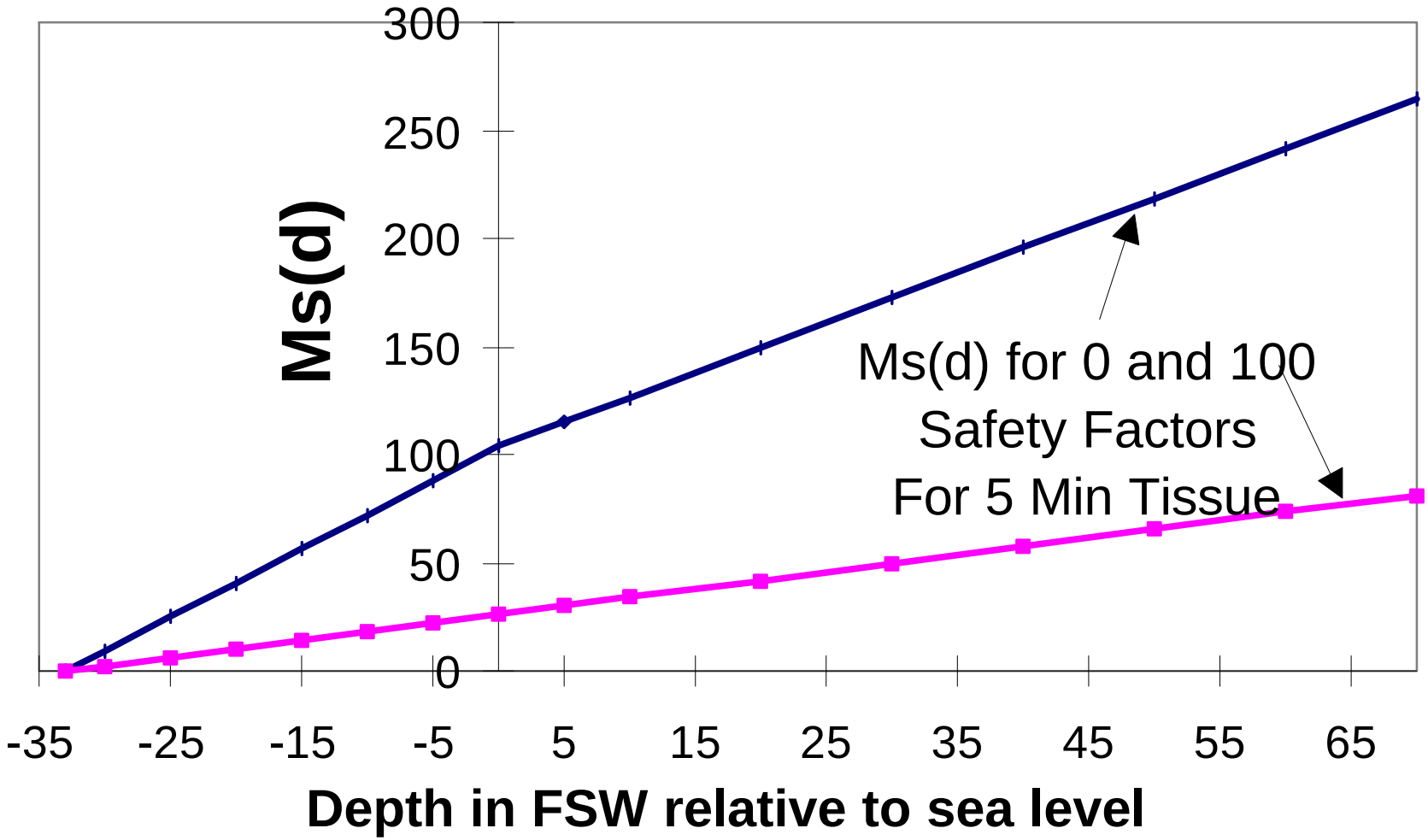
		Depth-specific Critical Values For Various Tissue Compartments									
	T1/2	**5**	**10**	**20**	**40**	**80**	**120**	**160**	**320**	**480**	**640**
Ms(d)											
Ms(0)		104.00	88.00	72.00	58.00	52.00	51.00	48.50	47.40	46.90	46.40
Ms(10)		126.00	107.00	90.00	72.00	65.00	64.00	61.43	60.12	59.48	58.90
Ms(20)		150.00	128.00	106.00	87.00	78.00	76.00	73.36	71.87	71.09	70.44
Ms(30)		174.00	148.00	124.00	99.00	90.00	88.00	85.29	83.61	82.69	81.99
Ms(40)		195.00	167.00	141.00	113.00	103.00	101.00	98.22	96.33	95.27	94.49
Ms(50)		220.00	189.00	158.00	128.00	115.00	114.00	111.15	109.06	107.85	106.99
Ms(60)		242.00	208.00	174.00	141.00	128.00	126.00	123.08	120.80	119.46	118.53
Ms(70)		263.00	228.00	192.00	156.00	142.00	140.00	137.00	134.50	133.00	132.00

Diving at Altitude
The BIG Problem!

The Double Pressure Dilemma



Nobendem
Safety Enhancement

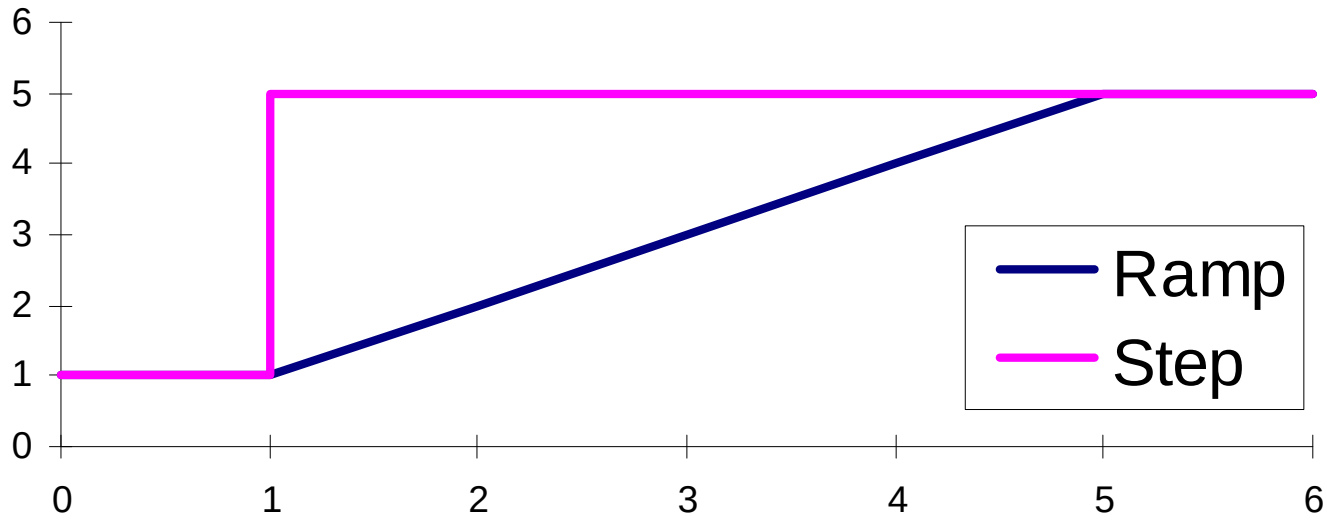


Transition Compensation

- Nitrogen Modeling During Ascent & Descent
- Must account for varying pN2 due to:
  - **Depth Change**
  - **Gas Mix Change**
- Linear Decomposition To Sum of 2 Exponentials
- Derate Component Due To Depth Change
  - **Assume Linear Transition**
  - **Compare to Tissue Compartment Half-Time**

Transition Model

Ramp and Step Functions



$$F(t-\tfrac{1}{2}, dt) = (0.5 + 0.5*dt/(t-\tfrac{1}{2} + dt))$$

The Nobendem Solution

-0.693147181	30					N_2 Tissue Compartments							
Copyright (C) 1998 Benton P. Zwart			5	10	20	40	80	120	160	320	480	640	T1/2
Initial Tissue PN_2	19.24		2.2990	2.0083	1.7060	1.3905	1.2726	1.2619	1.2548	1.2350	1.2208	1.2137	Slope
Safety Enhancement (0 - 100)	0		103.60	87.58	72.42	58.08	52.08	50.83	48.33	47.24	46.74	46.24	Intercept
Local Barometer (mmHg)	561		2.2990	2.0083	1.7060	1.3905	1.2726	1.2619	1.2548	1.2350	1.2208	1.2137	Safety Slope
Initial Steady State FiO2	0.21		103.60	87.58	72.42	58.08	52.08	50.83	48.33	47.24	46.74	46.24	Safety Intercept
					Depth Gauge Must = 0 at Surface of Water!								
Linear Transition Time	0.00	2.3	19.24	19.24	19.24	19.24	19.24	19.24	19.24	19.24	19.24	19.24	$PN_2(t)$
Transition O_2 Fraction	0.21												
Calculated Target PN_2	66.64		221.67	190.72	160.04	129.49	117.44	115.64	112.78	110.67	109.44	108.57	Nxt Seg Ms
Initial PN_2 Inspired	19.24		221.67	190.72	160.04	129.49	117.44	115.64	112.78	110.67	109.44	108.57	Safety Ms
Target - Initial	47.4		202.43	171.48	140.79	110.25	98.20	96.40	93.53	91.42	90.20	89.33	Buffer
Segment 1 Conditions													
Segment Depth (FSW)	60		66.36	63.00	53.50	41.68	32.24	28.37	26.26	22.89	21.71	21.11	$PN_2(t)$
Segment Time (Min)	37		76.47	64.65	53.46	42.87	38.44	37.52	35.68	34.87	34.50	34.13	Nxt Seg Ms
Inspired O_2 Fraction	0.21		76.47	64.65	53.46	42.87	38.44	37.52	35.68	34.87	34.50	34.13	Safety Ms
Calculated PN_2	66.64		10.11	1.65	(0.04)	1.19	6.20	9.16	9.41	11.98	12.79	13.03	Buffer
51.36													
Linear Transition Time	0.00	2.0											
Transition O_2 Fraction	0.21		66.36	63.00	53.50	41.68	32.24	28.37	26.26	22.89	21.71	21.11	$PN_2(t)$
Calculated Target PN_2	19.24		10.11	1.65	(0.04)	1.19	6.20	9.16	9.41	11.98	12.79	13.03	Buffer
Initial PN_2 Inspired	66.64												
Target - Initial	-47.4												
Segment 2 Conditions													
Segment Depth (FSW)	0		66.36	63.00	53.50	41.68	32.24	28.37	26.26	22.89	21.71	21.11	$PN_2(t)$

Comparison with USN Std Air Decompression Tables

		Comparison: Nobendem VS US Navy Dive Tables							
	Depth	Time	Ascent	Deco 40	Deco 30	Deco 20	Deco 10	Tot Deco	RNT 40
Navy	40	270	1.3				15	16.3	101
Nobendem							15	16.3	105
Nobendem Safety = 10							33	34.3	97
Navy	100	50	3.3			2	24	29.3	73
Nobendem							26	29.3	78
Nobendem Safety = 10						8	28	39.3	77
Navy	100	240	3.3	14	42	84	142	285.3	**
Nobendem				17	43	101	199	363.3	68
Nobendem Safety = 10				31	53	122	263	445.3	52
Navy	160	15	5.3			1	4	10.3	49
Nobendem							4	9.3	47
Nobendem Safety = 10							8	13.3	47
Navy	160	60	5.3	9	19	33	69	135.3	101
Nobendem				10	19	33	73	140.3	108
Nobendem Safety = 10				17	20	45	105	192.3	89

Navy Table DCS Risks

- 2.5% “No Deco”
- 5% Deco Dive
- 7.5% Repet Deco Dive
- Too Scary For Me! Fudge Factors:
  - Use Next Deeper Depth
  - Use Next Longer Time
  - Descent Time Counts as Bottom Time
  - Shallower Depth Counts As If Still At Deepest Depth
  - Ascent Slower Than 5 Minutes Counts as Bottom Time

Nobendem Safety Compensation

Dive to 75 FSW for 43 minutes, then to 83 FSWfor 15 minutes, then surface.

		Comparison: Nobendem Safety Models						
	Depth	Time	Depth	Time	Ascent	Deco 20	Deco 10	Tot Deco
Straight Nobendem	75	43	83	15	2.7		15	17.7
Navy Rules	80	50	90	20	2.7	2	26	30.7
Nobendem w/ Safety = 20	75	43	83	15	2.7	3	31	36.7

Recommendation: Always Dive Nobendem with SE=20!

Repet Dives

- USN Tables
  - Look only at 120 min tissue
  - Assign Repet Group Based on N2 Level at End Of Dive
  - Exponential N2 Decay Over Surface Interval
    - Fudge! Decays With $T_{1/2}$ = 160 min!!
  - Look at Next Dive Bottom Depth
    - ?Time At Depth To Reach N2 Level in 120 Min Tissue
    - Apply That RNT as Pre-charge to All Tissue Groups
  - Add RNT to Next Dive's Planned Bottom Time

Repet Dives

- Nobendem
  - Match USN Mechanism
    - Calculate RNT and Apply to Tissues of 120 Min or Less
  - For Tissue Compartments > 120 Min
    - **Take the Greater Of:**
      - **The RNT Calculated Load**
      - **The 4/3 Exponential Decay for the Tissue Compartment**
  - Equivalent to Navy Tables for Short - Intermediate Dives
  - More Conservative for Longer Dives
    - Don’t get “**’ed Out”

Using Nobendem

- Determine your Dive Type
  - Single; Multiple (Repet); Long (more than 6 segments)
- Select the Appropriate Spreadsheet Page
- Select “Tools”, “Macros”, “Run Macro”
  - Reset (Short / Long) for (6 / 12) segment spreadsheet
- Modify the Safety Enhancement as required
  - 20 for wet dives recommended
  - 55 - 65 for “dry” dives (chamber)
    - 55 if < 40 .AND. no undeserved DCS
    - 65 if > 39 .OR. any undeserved DCS

Using Nobendem

- Enter the barometric pressure at waters surface
  - Use Pressure Calculator if unknown
  - If above sea level, requires 2.2 days for equilibration
- Enter equilibrium breathing gas mix FiO_2
  - Air = 0.21
- Enter the descent time in Min.Tenths
- Enter the descent breathing gas FiO_2
  - If diving Nitrox, then run the “Change Oxy” Macro!
- Enter the depth of the first segment of the dive
  - FSW beneath the surface (FFW/FSW handled automatically)

Using Nobendem

- Enter Time Spent at Segment 1 Depth (Min)
- Enter the Segment 1 breathing gas FiO_2
- Enter the Travel Time to the Segment 2 depth
- Enter the Breathing Gas Mix for the Transition
- Repeat steps for other pre-deco dive depths
- After LAST depth/time segment SKIP transition
- Enter shallowest Depth with **NO RED** in Buffer
  - Next Segment depth controls permissible N_2 comparison

Using Nobendem

- Go back to previous seg, enter ascent time & gas
  - 30 FPM max ascent rate (value suggested)
  - May be able to decrease Deco depth if long ascent!
- Go to NEXT seg - Enter desired next stop depth
- Return to first stop - enter Time to clear **RED**
  - Try various time periods till segment buffer values zero out
  - This is the amount of time needed at the deco stop
- Enter segment transition time gas mix
- Repeat process until you reach the surface!

Example Dive

- Plan a Deco Schedule for 80 FSW X 52 Min
  - Safety Enhancement = 20
  - Air dive
  - 3 minute descent (pretty slow!)
  - 52 min bottom time
  - Optimize first stop!
  - Second stop 1/2 way to the surface

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Copyright (C) 1998 Benton P. Zwart			5	10	20	40	80	120	160	320	480	640	T1/2
Initial Tissue PN_2	26.07		2.2990	2.0083	1.7060	1.3905	1.2726	1.2619	1.2548	1.2350	1.2208	1.2137	Slope
Safety Enhancement (20-100)	20		103.60	87.58	72.42	58.08	52.08	50.83	48.33	47.24	46.74	46.24	Intercept
Local Barometer (mmHg)	760		1.9968	1.7642	1.5224	1.2700	1.1757	1.1671	1.1614	1.1456	1.1342	1.1285	Safety Slope
Initial Steady State FiO2	0.21		88.08	75.26	63.14	51.66	46.86	45.86	43.86	42.99	42.59	42.19	Safety Intercept
					Depth Gauge Must = 0 at Surface of Water!								
Linear Transition Time	3.00	2.7	40.85	33.37	29.60	27.78	26.91	26.63	26.49	26.28	26.21	26.17	$PN_2(t)$
Transition O_2 Fraction	0.21												
Calculated Target PN_2	89.27		287.61	248.31	208.95	169.36	153.92	151.81	148.74	146.06	144.42	143.36	Nxt Seg Ms
Initial PN_2 Inspired	26.07		247.89	216.46	184.97	153.29	140.94	139.26	136.79	134.65	133.35	132.49	Safety Ms
Target - Initial	63.2		207.04	183.08	155.37	125.51	114.03	112.63	110.31	108.38	107.14	106.32	Buffer
Segment 1 Conditions													
Segment Depth (FSW)	80		89.23	87.75	79.43	64.30	49.53	42.88	39.15	32.99	30.77	29.63	$PN_2(t)$
Segment Time (Min)	52		126.90	107.90	89.66	72.12	64.92	63.55	60.96	59.66	59.02	58.45	Nxt Seg Ms
Inspired O_2 Fraction	0.21		108.30	93.10	78.51	64.47	58.71	57.62	55.54	54.51	53.99	53.53	Safety Ms
Calculated PN_2	89.27		19.06	5.35	(0.92)	0.18	9.18	14.74	16.39	21.52	23.22	23.90	Buffer
80.00													
Linear Transition Time	2.30	2.3											
Transition O_2 Fraction	0.21		79.32	83.14	77.85	64.14	49.75	43.12	39.37	33.13	30.87	29.71	$PN_2(t)$
Calculated Target PN_2	33.97		28.98	9.96	0.66	0.34	8.96	14.50	16.17	21.38	23.12	23.83	Buffer
Initial PN_2 Inspired	89.27												
Target - Initial	-55.3												

Segment 2 Conditions													
Segment Depth (FSW)	10		41.45	53.94	61.93	58.05	48.07	42.46	39.07	33.15	30.93	29.77	PN_2(t)
Segment Time (Min)	13		115.33	97.80	81.09	65.14	58.53	57.22	54.66	53.47	52.90	52.36	Nxt Seg Ms
Inspired O_2 Fraction	0.21		98.25	84.23	70.86	58.10	52.81	51.76	49.72	48.76	48.31	47.88	Safety Ms
Calculated PN_2	33.97		56.80	30.29	8.93	0.05	4.74	9.30	10.65	15.61	17.38	18.11	Buffer
10.00													
Linear Transition Time	0.20	0.2											
Transition O_2 Fraction	0.21		41.19	53.64	61.72	57.96	48.04	42.45	39.07	33.15	30.93	29.77	PN_2(t)
Calculated Target PN_2	30.02		57.06	30.60	9.13	0.14	4.77	9.32	10.65	15.61	17.38	18.11	Buffer
Initial PN_2 Inspired	33.97												
Target - Initial	-3.95												
Segment 3 Conditions													
Segment Depth (FSW)	5		31.42	38.37	48.87	51.57	45.85	41.41	38.50	33.05	30.91	29.77	PN_2(t)
Segment Time (Min)	15		103.60	87.58	72.42	58.08	52.08	50.83	48.33	47.24	46.74	46.24	Nxt Seg Ms
Inspired O_2 Fraction	0.21		88.08	75.26	63.14	51.66	46.86	45.86	43.86	42.99	42.59	42.19	Safety Ms
Calculated PN_2	30.02		56.66	36.89	14.26	0.10	1.02	4.45	5.37	9.94	11.68	12.42	Buffer
5.00													
Linear Transition Time	0.00	0.2											
Transition O_2 Fraction	0.21		31.42	38.37	48.87	51.57	45.85	41.41	38.50	33.05	30.91	29.77	PN_2(t)
Calculated Target PN_2	26.07		56.66	36.89	14.26	0.10	1.02	4.45	5.37	9.94	11.68	12.42	Buffer
Initial PN_2 Inspired	30.02												
Target - Initial	-3.95												
Segment 4 Conditions													
Segment Depth (FSW)	0		31.42	38.37	48.87	51.57	45.85	41.41	38.50	33.05	30.91	29.77	PN_2(t)

Results Comparison

- Navy => 80 for 60 needs 17 min @ 10 FSW
- Nobendem SE(20) => 28 min Deco Stops
- Nobendem SE(0) => 13 min @ 10 FSW
- Nobendem SE(0) 80 for 60 => 18 min @ 10 FSW
- Nobendem SE(20), 1 stop => 31 min @ 10 FSW

EXTRA CREDIT!!

WHY is the Nobendem SE(20) 2-stop 3 min shorter than the SE(20) 1-stop?

References

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- Boni M, Schibli R, Nussberger P, Buhlmann A. Diving at diminished atmospheric pressure. Undersea Biomedical Research, Vol 3(3), 1976, 189-204.

QUESTIONS??

MORE EXAMPLES

- General Example #1
- PhD Entrance Exam
- TT-5 Profile Comparisons
- Ascent Rate from 165 FSW
- Your Worst Deco Nightmare
- Repets, with a twist!
- Sprinkler Check at 165

Download All at http://www.brooks.af.mil/web/hyper/