

Advanced Diving Seminar

USAF Oxygen Tables for Dry Diver Decompression

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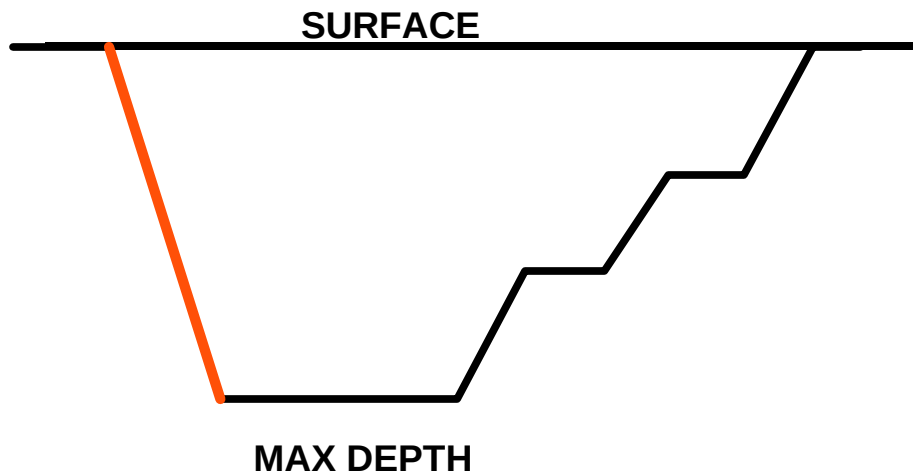
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Outline

- ◆ Terminology Review
- ◆ Decompression Table Theory
- ◆ Special Considerations with Oxygen
- ◆ Oxygen Table Derivation
- ◆ Standard Air Decompression Tables
- ◆ USAF Oxygen Decompression Tables
- ◆ Oxygen Table Usage

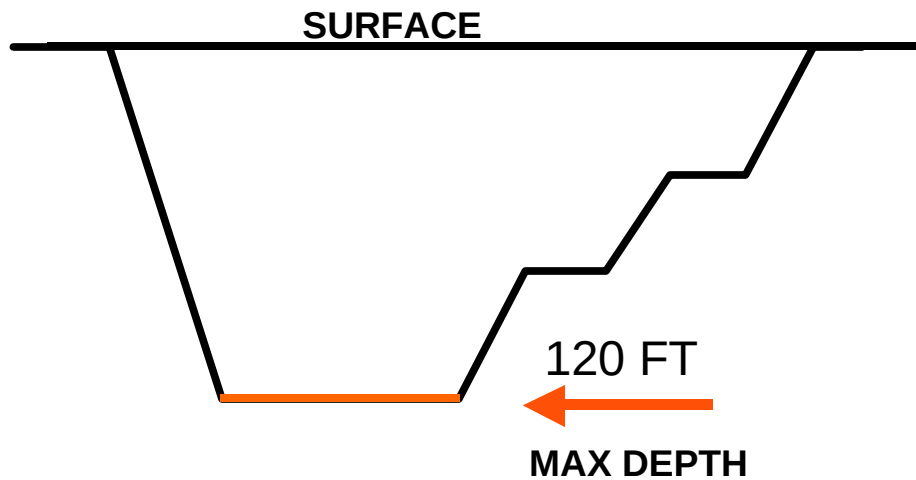
DESCENT TIME



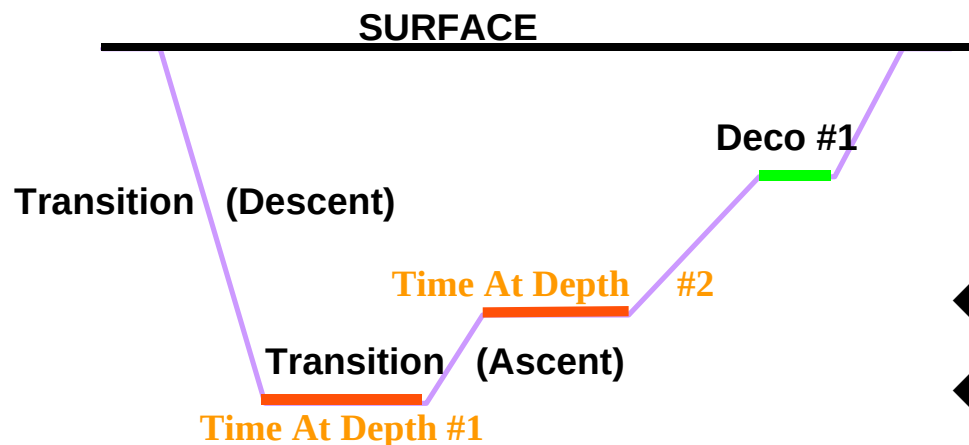
- ◆ The elapsed time required to attain maximum depth. Elapsed time from leaving surface pressure until maximum pressure is reached.

BOTTOM OR DEPTH

- ◆ The maximum depth attained during the dive, measured in feet of sea water.

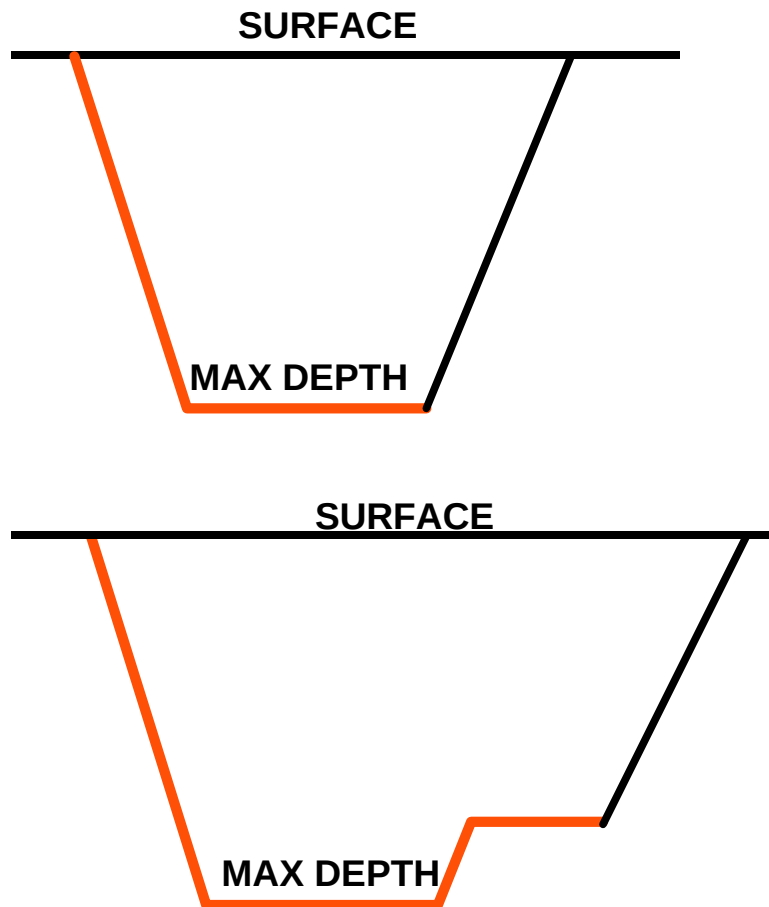


TIME AT DEPTH (Nobendem)



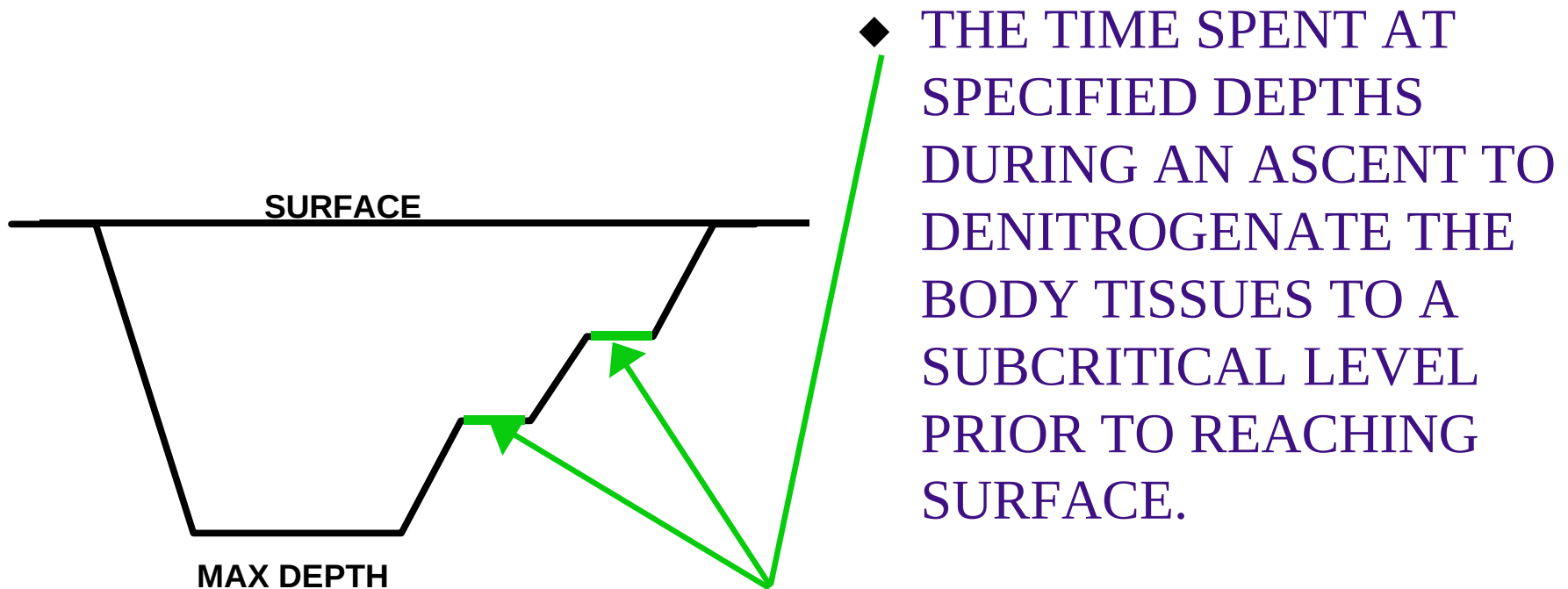
- ◆ The time spent at a depth, between reaching a given depth and the beginning of a depth change, prior to beginning decompression, measured in minutes.
- ◆ Abbreviated: TAD
- ◆ Used in Nobendem calculations where transition times are not included in bottom times

TOTAL BOTTOM TIME (TBT)

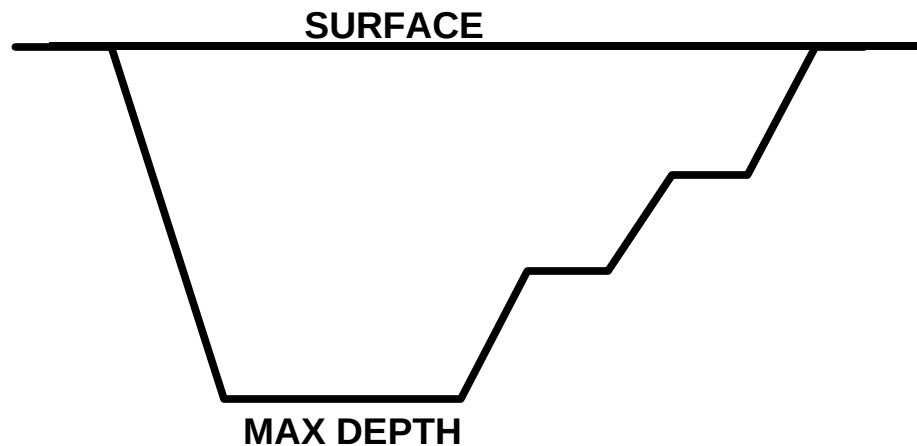


- ◆ THE ELAPSED TIME FROM LEAVING THE SURFACE UNTIL LEAVING MAXIMUM DEPTH. WHEN A DIVE TO MORE THAN ONE DEPTH IS SELECTED, THE T.B.T. SHOULD INCLUDE TIME FROM SURFACE TO LEAVING THE LAST DEPTH

DECOMPRESSION STOP

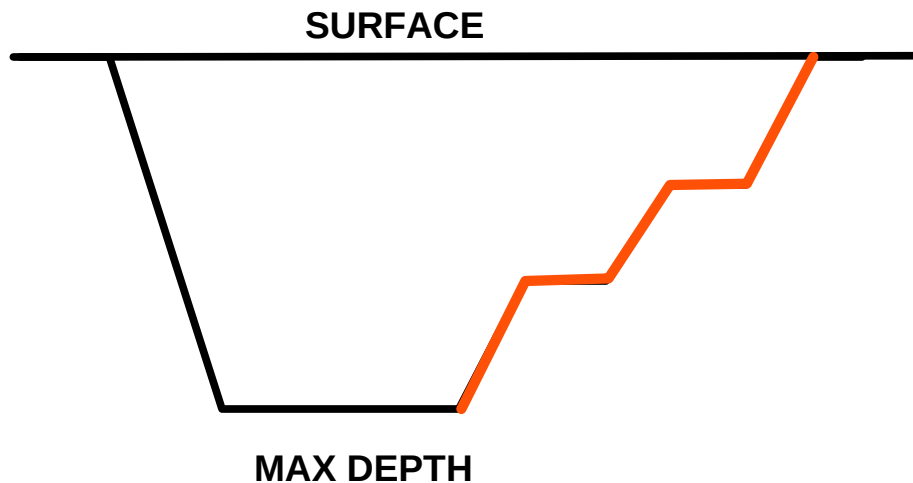


DECOMPRESSION SCHEDULE



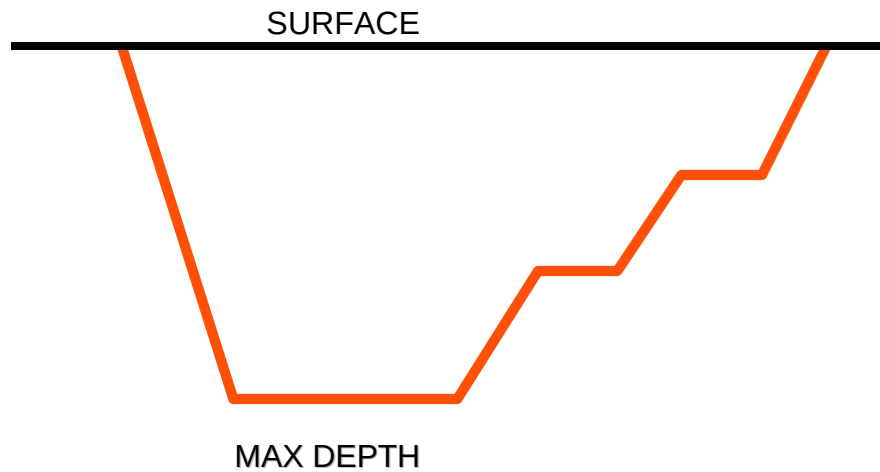
- ◆ SPECIFIC DECOMPRESSION PROCEDURE FOR A GIVEN COMBINATION OF DEPTH AND BOTTOM TIME AS LISTED IN A DECOMPRESSION TABLE; FEET/MINUTES

TOTAL DECOMPRESSION TIME (TDT)



- ◆ THE ELAPSED TIME FROM LEAVING MAXIMUM DEPTH UNTIL SURFACE IS REACHED. THE TOTAL TIME, INCLUDING DECOMPRESSION STOPS, REQUIRED TO ASCEND TO THE SURFACE

TOTAL TIME OF DIVE (TTD)



- ◆ THE ELAPSED TIME FROM LEAVING THE SURFACE TO REACHING SURFACE.

EQUALS THE
T.B.T. + T.D.T.

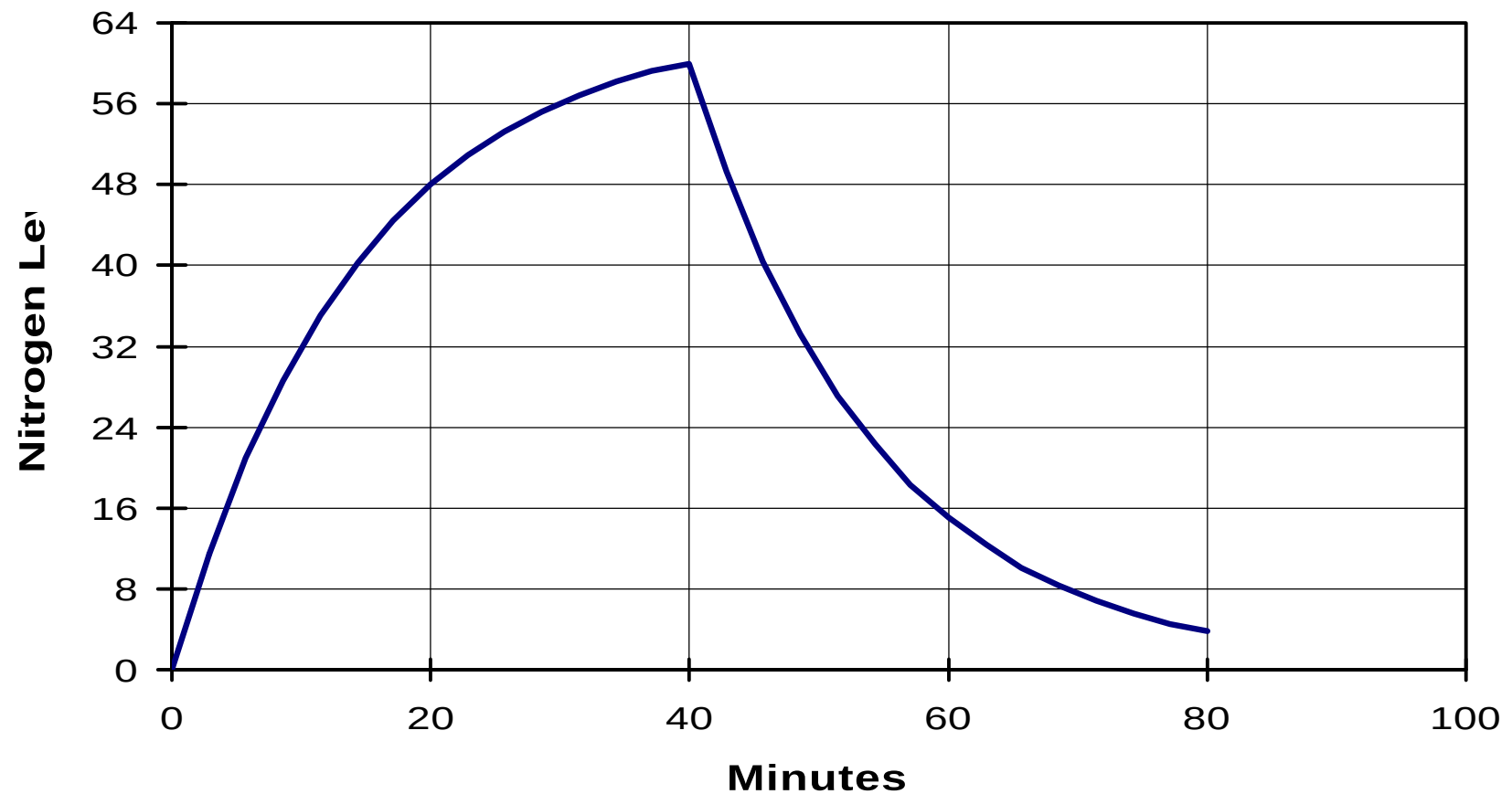
History of Deco Tables

- ◆ 1908 - Haldane's Air Decompression Tables
 - Tissue compartment theory with $t_{1/2}$ and M=2:1
 - Basis for all Navy Tables in use today
 - Assume: Surface of water at 1 ATA (760 mm Hg)
 - Breathing gas = Air (78% Nitrogen)
- ◆ Overly conservative for short/shallow dives
- ◆ Inadequate for deep/long dives

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 ($t_{1/2}$)
- ◆ Maximum permissible N2 for Depth

Exponential Model



Dry Diving Not = Wet Diving

◆ Physiological Differences: 1Gz vs Buoyancy

- Tissue bed perfusion
- Venous return

◆ USAF Diving Tables (1963)

- Dr. Bruce Bassett (Navy Table Modifications)
- Added 1 foot to bottom depth
- Added 5 min to bottom time
- All time at or shallower than 40 FSW on O₂ (added mid 70's)
- Decrease risk of DCS in Inside Observers
- Unscientific but obviously more conservative

Advantages of Oxygen

- ◆ Much more rapid elimination of tissue Nitrogen
 - Based on Differential Nitrogen Partial Pressure
 - Increases Nitrogen Diffusion Rate
 - Decreases Decompression time by 66 - 75%
- ◆ Longer bottom time for same tank volume
 - Less Deco Time => More Bottom Time
- ◆ Considerations:
 - Need second gas source
 - Must be O2 certified (High pressure O2 fire hazard)
 - Stainless Steel Will Burn Under High Pressure O2

Hazards of Oxygen

◆ CNS O₂ Toxicity

- Paul Bert Effect
- Generalized tonic clonic seizure
- Usually FATAL when occurs underwater!

◆ Pulmonary O₂ Toxicity

- Lorraine Smith Effect
- Produces “stiff, non-elastic” lung (decreased compliance)
- Unit Pulmonary Toxicity Dose (UPTD)

◆ Both Effects are Time and Pressure Dependent

- Nonlinear: Increased Depth ==> Much Faster Onset!

◆ Both Effects are Mitigated by Air Breaks

Oxygen Concepts

- ◆ O₂ breathing effectively STOPS the dive
 - Nitrogen removal from ALL tissue compartments
 - May have additional N₂ loading at deep AIR stops!
- ◆ Use Air Breaks to Prevent O₂ Toxicity
 - O₂ for 20 min max at 60 FSW
 - O₂ for 40 min max at 30 FSW
 - O₂ for 30 min max ascent from 60 - 30 FSW
- ◆ Aren't any guarantees with diving!
 - Controlled risk - IO in dry chamber - seizure NOT fatal!
 - Dive doc's responsibility to monitor - keep safe

Oxygen Tables Derivation

- ◆ Nobendem: 10 Tissue Compartment Model
- ◆ US Navy & NOAA 'M' Values
- ◆ Uses 100% O₂ as Decompression Gas
 - $P_{iN_2} = 0$
 - Rate of denitrogenation no longer depth related
- ◆ Safety Enhancement of 55 or 65
- ◆ Predefined sets of tables used for dive planning

-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	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)	65		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		1.3168	1.2150	1.1092	0.9988	0.9575	0.9538	0.9513	0.9444	0.9394	0.9369	Safety Slope
Initial Steady State FiO ₂	0.21		53.16	47.55	42.25	37.23	35.13	34.69	33.82	33.43	33.26	33.08	Safety Intercept
				Depth Gauge Must = 0 at Surface of Water!									
Linear Transition Time	2.00	2.0	33.45	29.65	27.80	26.92	26.49	26.35	26.28	26.17	26.14	26.12	PN ₂ (t)
Transition O ₂ Fraction	0.21												
Calculated Target PN ₂	73.47		241.67	208.18	174.86	141.57	128.48	126.59	123.65	121.37	120.02	119.09	Nxt Seg Ms
Initial PN ₂ Inspired	26.07		132.21	120.49	108.83	97.18	92.60	91.93	90.91	90.11	89.63	89.31	Safety Ms
Target - Initial	47.4		98.76	90.84	81.03	70.26	66.11	65.59	64.63	63.93	63.49	63.19	Buffer
Segment 1 Conditions													
Segment Depth (FSW)	60		73.46	72.79	67.76	57.01	45.53	40.15	37.08	31.94	30.07	29.10	PN ₂ (t)
Segment Time (Min)	60		172.82	148.02	123.75	99.91	90.35	88.77	86.04	84.35	83.42	82.71	Nxt Seg Ms
Inspired O ₂ Fraction	0.21		92.75	84.07	75.58	67.23	63.89	63.33	62.38	61.79	61.46	61.21	Safety Ms
Calculated PN ₂	73.47		19.29	11.29	7.81	10.22	18.35	23.18	25.30	29.85	31.39	32.11	Buffer
60.00													
Linear Transition Time	1.00	1.0											
Transition O ₂ Fraction	0.21		71.67	71.97	67.53	57.09	45.67	40.27	37.19	32.00	30.11	29.14	PN ₂ (t)
Calculated Target PN ₂	49.77		21.08	12.11	8.04	10.15	18.21	23.06	25.19	29.78	31.35	32.08	Buffer
Initial PN ₂ Inspired	73.47												
Target - Initial	-23.7												
Segment 2 Conditions													
Segment Depth (FSW)	30		54.32	62.65	63.01	55.14	44.89	39.81	36.86	31.86	30.03	29.07	PN ₂ (t)

Segment 2 Conditions													
Segment Depth (FSW)	30		54.32	62.65	63.01	55.14	44.89	39.81	36.86	31.86	30.03	29.07	PN ₂ (t)
Segment Time (Min)	2		149.89	127.98	106.72	86.03	77.64	76.17	73.50	72.01	71.23	70.58	Nxt Seg Ms
Inspired O ₂ Fraction	1		79.60	71.94	64.49	57.25	54.32	53.80	52.87	52.35	52.07	51.85	Safety Ms
Calculated PN ₂	0		25.29	9.29	1.48	2.11	9.43	13.99	16.00	20.48	22.05	22.77	Buffer
30.00													
Linear Transition Time	0.30	0.3											
Transition O ₂ Fraction	1		52.10	61.36	62.36	54.85	44.77	39.74	36.82	31.84	30.01	29.06	PN ₂ (t)
Calculated Target PN ₂	0		27.50	10.58	2.14	2.40	9.55	14.06	16.05	20.50	22.06	22.78	Buffer
Initial PN ₂ Inspired	0												
Target - Initial	0												
Segment 3 Conditions													
Segment Depth (FSW)	20		14.96	32.88	45.65	46.93	41.41	37.73	35.41	31.23	29.63	28.78	PN ₂ (t)
Segment Time (Min)	9		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	1		66.44	59.79	53.40	47.26	44.74	44.26	43.36	42.90	42.68	42.48	Safety Ms
Calculated PN ₂	0		51.47	26.91	7.75	0.33	3.33	6.54	7.95	11.68	13.05	13.70	Buffer
20.00													
Linear Transition Time	0.30	0.3											
Transition O ₂ Fraction	1		14.35	32.21	45.18	46.69	41.30	37.66	35.36	31.21	29.61	28.77	PN ₂ (t)
Calculated Target PN ₂	0		52.08	27.58	8.23	0.57	3.44	6.60	7.99	11.70	13.07	13.71	Buffer
Initial PN ₂ Inspired	0												
Target - Initial	0												
Segment 4 Conditions													
Segment Depth (FSW)	10		1.03	8.63	23.39	33.59	35.04	33.75	32.57	29.95	28.81	28.19	PN ₂ (t)
Segment Time (Min)	19		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	1		53.16	47.55	42.25	37.23	35.13	34.69	33.82	33.43	33.26	33.08	Safety Ms
Calculated PN ₂	0		52.13	38.92	18.86	3.64	0.09	0.94	1.25	3.48	4.45	4.90	Buffer
10.00													
Linear Transition Time	0.00	0.3											
Transition O ₂ Fraction	0.21		1.03	8.63	23.39	33.59	35.04	33.75	32.57	29.95	28.81	28.19	PN ₂ (t)
Calculated Target PN ₂	26.07		52.13	38.92	18.86	3.64	0.09	0.94	1.25	3.48	4.45	4.90	Buffer
Initial PN ₂ Inspired	33.97												
Target - Initial	-7.9												
Segment 5 Conditions													
Segment Depth (FSW)	0		1.03	8.63	23.39	33.59	35.04	33.75	32.57	29.95	28.81	28.19	PN ₂ (t)

Oxygen Table Derivation

- ◆ Bottom Time Stops when O2 Deco Begins
- ◆ O2 Breathing Blocks Depth-Related N2 Uptake
- ◆ Could Complete Entire Deco at Single Depth
- ◆ Ascent Sooner Minimizes O2 Toxicity
- ◆ Short Stays Combined In 165 FSW Tables
 - 50 & 30 FSW Stops Combined to Lengthen 60 & 40 FSW Stops
- ◆ RNT From 120 Min Tissue Group at Surfacing

Guidelines for Nobendem O2 Table Use

- ◆ Follow Standard USN Conventions
 - If Descent Time is LONGER than specified - ADD the excess to the actual Time at Depth
 - If Descent Time is LESS than specified - no changes
- ◆ NEVER exceed the 30 FPM rate to the first Deco stop
- ◆ Follow USN rules regarding delayed ascent time to the first deco stop (Diveman 3: 7-4.2 or DM 4: 9-6.2.1) to recalculate the required profile
- ◆ Calculate RNT in the standard fashion using the provided Repet Group Index Table 7-4
- ◆ Time at Depth STOPS when O2 Deco Starts! Match Total Dive Time to your Plan. You may breathe all the required O2 prior to ascent IF safe (depth vs O2 Tox!!)

Nobendem **Oxygen** Decompression Tables

For IO Use In Sea-Level Dry Chamber Dives

Descent Time to Bottom Depth = 1:30

SE = Safety Enhancement :: Ascent & Descent Rate = 30 FPM

D E P T H	Time At Depth	Time to 1st Stop	Deco Stops			Repet Group	Total Deco Time	Total Dive Time
			30	20	10			
4 5 F S W	10	1:30			0	A	1.5	13
	15	1:10			1	B	2.5	19
	20	1:10			2	B	3.5	25
	25	1:10			4	C	5.5	32
	30	1:10			6	C	7.5	39
	40	1:10			10	D	11.5	53
	50	:50		2	12	D	15.5	67
	60	:50		3	14	E	18.5	80
	70	:50		5	17	E	23.5	95
	80	:50		7	19	E	27.5	109
S E 6 5	90	:50		8	22	E	31.5	123
	100	:50		10	23	E	34.5	136
	110	:50		11	26	F	38.5	150
	120	:50		11	31	**	43.5	165
	130	:30	1	12	34	**	48.5	180
	140	:30	2	14	36	**	53.5	195
	150	:30	2	15	39	**	57.5	209
	160	:30	3	16	41	**	61.5	223

D E P T H	Time At Depth	Time to 1st Stop	D Stop		Repet Group	Total Deco Time	Total Dive Time
			20	10			
4 5 F S W	10	1:30		0	B	1.5	13
	15	1:30		0	B	1.5	18
	20	1:30		0	C	1.5	23
	25	1:10		1	C	2.5	29
	30	1:10		2	D	3.5	35
	40	1:10		6	D	7.5	49
	50	1:10		9	E	10.5	62
	60	1:10		12	E	13.5	75
	70	:50	1	13	F	15.5	87
	80	:50	2	16	F	19.5	101
S E 5 5	90	:50	4	18	F	23.5	115
	100	:50	5	20	G	26.5	128
	110	:50	6	22	G	29.5	141
	120	:50	7	24	G	32.5	154
	135	:50	8	27	G	36.5	173
	150	:50	10	32	G	43.5	195
	165	:50	13	35	G	49.5	216
	180	:50	15	38	G	54.5	236

** = Use Nobendem to Calculate Repetitive Dives - 120 min Tissue Group Method (USN) is Inadequate

Ascend to 1st Deco Stop on AIR. ALL Subsequent Deco Time on **OXYGEN** (consider O2 time & depth vs O2 Tox!)

TABLE 7-4
RESIDUAL NITROGEN TIMETABLE
FOR REPETITIVE AIR DIVES

NEW GROUP
DESIGNATION

USE EXACT DEPTH, **ROUND DEEPER** TO NEAREST DEPTH IF EXACT DEPTH NOT LISTED (if exact depth is 63 round deeper to 70)

40	241	213	187	161	138	116	101	87	73	61	49	37	25	17	7
50	160	142	124	111	99	87	76	68	56	47	38	29	21	13	6
60	117	107	97	88	79	70	61	52	44	36	30	24	17	11	5
70	96	87	80	72	64	57	50	43	37	31	26	20	15	9	4
80	80	73	68	61	54	48	43	38	32	28	23	18	13	8	4
90	70	64	58	53	47	43	38	33	28	24	20	16	11	7	3
100	62	57	52	48	43	38	34	30	26	22	18	14	10	7	3
110	55	51	47	42	38	34	31	27	24	20	16	13	10	6	3
120	50	46	43	39	35	32	28	25	21	18	15	12	9	6	3
130	44	40	38	35	31	28	25	22	19	16	13	11	8	6	3
140	40	38	36	32	29	26	23	20	18	15	12	10	7	5	2
150	38	35	32	30	27	24	22	19	17	14	12	9	7	5	2
160	36	33	31	28	26	23	20	18	16	13	11	9	6	4	2
170	34	31	29	26	24	22	19	17	15	13	10	8	6	4	2
180	31	29	27	25	22	20	18	16	14	12	10	8	6	4	2
190	30	28	26	24	21	19	17	15	13	11	10	8	6	4	2

Oxygen Deco Tables

- ◆ Two Scenarios (Use SE = 65 tables)
- ◆ 1: IO Already exposed - now needs Deco
- ◆ 2: Know total time in chamber - - Need to decide when Deco should start so clean at surface

Scenario 1

- ◆ Staff member locks in to assist patient
- ◆ 2:30 to 45 FSW
- ◆ There for 45 min on AIR
- ◆ What is Deco Profile?
- ◆ What is Repet Group?

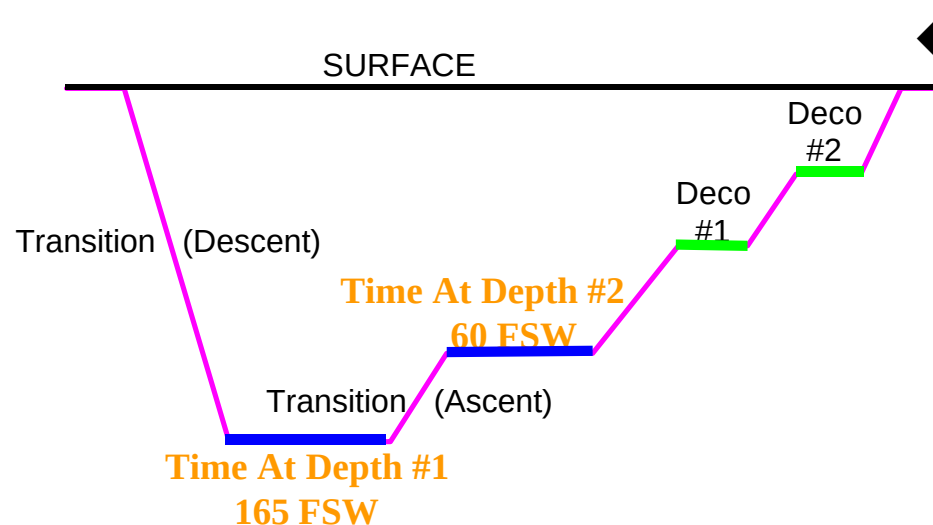
Scenario 2

- ◆ IO on regular wound care dive
- ◆ Will need to lock out at end of second O2 period
- ◆ Wants single O2 breathing period before ascent
- ◆ What is profile?
- ◆ What is Repet Group (approx)

Fire Suppression Test (FST)

- ◆ Boogie down to 165 (Actual ET = 7 min)
- ◆ 165 for 3 minutes (to get wet)
- ◆ Cruise up to 60 FSW (30 FPM ==> 3:30)
- ◆ 60 for 4 min (to get wet again)
- ◆ Use SE = 65
- ◆ What is Deco Profile & Repet Group?

TIME AT DEPTH (Nobendem)



**Fire Extinguisher Checks
take 3-4 Min at both
165 and 60 FSW**

- ◆ The time spent at a depth, between reaching a given depth and the beginning of a depth change, prior to beginning decompression, measured in minutes.
- ◆ Abbreviated: **TAD**
- ◆ Used in Nobendem calculations where transition times are not included in bottom times

Guidelines for Fire Test O2 Table Use

- ◆ Select the Table based on the 165 FSW Time At Depth (**TAD**) and the desired Safety Enhancement (**SE**)
 - SE=65 if 40 or older OR Hx undeserved DCS Hit
 - SE=55 if younger than 40 AND no Hx undeserved DCS
- ◆ If 165 or 60 Transition Time is LONGER than specified
 - ADD the excess to the 165 FSW Time at Depth
- ◆ If Transition Time is LESS than specified - no changes
- ◆ **NEVER** exceed the 30 FPM ascent rate!
- ◆ Ascend to 1st Deco Stop after 60 FSW test on AIR.
 - ALL Subsequent Deco Time on **OXGEN**
 - Ascent Delay on Air: Add Delay to Deco Time at Next Stop
 - Ascent Delay on **O2** Counts as Deco Time at Next Stop

Nobendem **Oxygen** Decompression Tables

Built-in Descent Time to 165 = 5:30 -- Ascent Time to 60 = 3:30

SE = Safety Enhancement :: Ascent & Descent Rate = 30 FPM

Fire Suppression Test - **TAD 165 = 3 Min**

S E	Time At 60	Time to 1st Stop	Deco Stops				Repet Group	Total Deco Time	Total Dive Time
			40	30	20	10			
6 5	3	1:00	4	0	7		C	13	28
	4	1:00	4	0	7		C	13	29
	5	1:00	4	0	8		C	14	31
	6	1:00	4	0	8		C	14	32

S E	Time At 60	Time to 1st Stop	Deco Stops				Repet Group	Total Deco Time	Total Dive Time
			40	30	20	10			
5 5	3	1:20			2	5	D	9	24
	4	1:20			2	5	D	9	25
	5	1:20			2	5	D	9	26
	6	1:20			2	6	D	10	28

Fire Suppression Test - **TAD 165 = 4 Min**

S E	Time At 60	Time to 1st Stop	Deco Stops				Repet Group	Total Deco Time	Total Dive Time
			40	30	20	10			
6 5	3	1:00	5	0	8		C	15	31
	4	1:00	5	0	8		C	15	32
	5	1:00	5	0	9		C	16	34
	6	1:00	5	0	10		C	17	36

S E	Time At 60	Time to 1st Stop	Deco Stops				Repet Group	Total Deco Time	Total Dive Time
			40	30	20	10			
5 5	3	1:00	3	0	5		D	10	26
	4	1:00	3	0	6		D	11	28
	5	1:00	3	0	6		D	11	29
	6	1:00	3	0	7		D	12	31

Fire Suppression Test - **TAD 165 = 5 Min**

S E	Time At 60	Time to 1st Stop	Deco Stops				Repet Group	Total Deco Time	Total Dive Time
			40	30	20	10			
6 5	3	:40	3	0	12	0	C	17	34
	4	:40	3	0	13	0	C	18	36
	5	1:00	6	0	10		D	18	37
	6	1:00	6	0	11		D	19	39

S E	Time At 60	Time to 1st Stop	Deco Stops				Repet Group	Total Deco Time	Total Dive Time
			40	30	20	10			
5 5	3	1:00	3	0	7		D	12	29
	4	1:00	3	0	8		D	13	31
	5	1:00	3	0	8		D	13	32
	6	1:00	3	0	9		D	14	34

QUESTIONS

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Scenario 1 - Solution

- ◆ 1:30 allowed for descent
 - $2:30 - 1:30 = 1$ min excess - add to bottom time = $45+1=46$
- ◆ 45 FSW for 50 min - read directly from table
- ◆ 50 second ascent to 20 FSW on air
- ◆ 2 min at 20 FSW on O2
- ◆ 20 second ascent to 10 FSW on O2
- ◆ 12 min at 10 FSW on O2
- ◆ 20 second ascent to surface on O2
- ◆ Repet Group = D

Scenario 2 - Solution

- ◆ 7 min descent
- ◆ Treatment time = $30+10+30 = 70$ min
- ◆ Ascent time = 2 min
- ◆ Total Dive Time = $7 + 70 + 2 = 79$
 - Descent time over 1:30 conservatively adds to bottom time
- ◆ Find TDT that is greater than 79 = 80 min
 - 45 for 60 min ==> TDT of 80 min
 - Requires total of 18:30 O2 Deco with Repet Group = E
- ◆ Start IO O2 11:30 after Pts begin #2 O2 Rx
 - Off at end of Pts #2 treatment and has 2 min to surface on air

FST - Solution

- ◆ Allowed 5:30 to get to 165 - took extra 1:30
- ◆ TAD 165 = 3:00 + 1:30 = 4:30 (rounds up to 5 min)
- ◆ TAD 60 = 4 min
- ◆ FST Table 165 for 5, 60 for 4 gives:
- ◆ 40 second ascent to 40 FSW on air
- ◆ 3 min at 40 FSW on O2
- ◆ 40 second ascent to 20 FSW on O2
- ◆ 13 min at 20 FSW on O2
- ◆ 40 second ascent to surface on O2
- ◆ Repet = C