

Nobendem© and US Navy standard air decompression tables for inside chamber attendants working at altitude.

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INTRODUCTION

- Our multiplace chamber operates at an altitude of ≈ 4500 feet.
- The US Navy Standard Air tables are the gold standard in the US for computing decompression obligations and operations at altitude.
- The Nobendem© calculator was developed for use by Dr. Benton P. Zwart to compute decompression obligations for the US Air Force chambers.
- We will present a 4-year experience using Nobendem© for inside attendant decompression.

MATERIALS AND METHODS

- At altitudes >1000 feet the U.S. Navy tables are converted for inside attendant decompression safety.

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REVISION 6

U.S. Navy Diving Manual



Volume 1:	Diving Principles and Policies
Volume 2:	Air Diving Operations
Volume 3:	Mixed Gas Surface Supplied Diving Operations
Volume 4:	Closed-Circuit and Semiclosed Circuit Diving Operations
Volume 5:	Diving Medicine and Recompression Chamber Operations

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SUPERSEDES SS521-AG-PRO-010, REVISION 5, Dated 15 August 2005.

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MATERIALS AND METHODS

- Nobendem© use
- Enter a safety factor of 20-100%
- barometric pressure
- Actual time intervals
- Actual chamber pressure in feet of sea water (fsw)
- O2% breathed by the inside attendant

Profile A

CGP001 (CG 1988) Barotrauma Chart												
N ₂ Tissue Compartments												
	30	5	10	20	40	60	120	180	320	450	640	T1/2
Initial Tissue PN ₂	27.47	2.2960	2.0083	1.7050	1.3905	1.2726	1.2619	1.2548	1.2300	1.2208	1.2137	Isopleg
Safety Enhancement (20,100)	0	103.60	87.58	72.42	58.09	52.08	50.83	48.33	47.24	46.74	46.24	Intercept
Local Barometer (mmHg)	0.21	1.3168	1.2150	1.1092	0.9968	0.9575	0.9538	0.9513	0.9444	0.9394	0.9369	Safety Depth
Initial Dissolved State PFO ₂	0.21	63.16	47.65	42.26	37.23	35.13	34.19	33.82	33.43	33.26	33.08	Safety Reserve
Depth Gauge Must = 0 at Surface of Water!												
Linear Transition Time	0.00	0	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	PN ₂ (t)
Transition O ₂ Fraction	0.21	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	PN ₂ (t)
Calculated Target PN ₂	22.47	92.56	78.01	64.33	51.50	46.08	44.90	42.47	41.48	41.05	40.59	Not Seg Ms
Initial PN ₂ Inspired	22.47	46.97	41.87	37.08	32.59	30.69	30.28	29.43	29.08	28.93	28.77	Safety Ms
Target - Initial	0	24.50	19.40	14.61	10.12	8.22	7.81	6.96	6.62	6.46	6.30	Buffer
Segment 1 Conditions												
Segment Depth (FSW)	0	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	PN ₂ (t)
Segment Time (Min)	0	92.56	78.01	64.33	51.50	46.08	44.90	42.47	41.48	41.05	40.59	Not Seg Ms
Inspired O ₂ Fraction	0.21	46.97	41.87	37.08	32.59	30.69	30.28	29.43	29.08	28.93	28.77	Safety Ms
Calculated PN ₂	22.47	24.50	19.40	14.61	10.12	8.22	7.81	6.96	6.62	6.46	6.30	Buffer
Linear Transition Time												
Transition O ₂ Fraction	0.21	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	PN ₂ (t)
Calculated Target PN ₂	22.47	24.50	19.40	14.61	10.12	8.22	7.81	6.96	6.62	6.46	6.30	Buffer
Initial PN ₂ Inspired	22.47	46.97	41.87	37.08	32.59	30.69	30.28	29.43	29.08	28.93	28.77	Safety Ms
Target - Initial	0	24.50	19.40	14.61	10.12	8.22	7.81	6.96	6.62	6.46	6.30	Buffer
Segment 2 Conditions												
Segment Depth (FSW)	0	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	PN ₂ (t)
Segment Time (Min)	0	92.56	78.01	64.33	51.50	46.08	44.90	42.47	41.48	41.05	40.59	Not Seg Ms
Inspired O ₂ Fraction	0.21	46.97	41.87	37.08	32.59	30.69	30.28	29.43	29.08	28.93	28.77	Safety Ms
Calculated PN ₂	22.47	24.50	19.40	14.61	10.12	8.22	7.81	6.96	6.62	6.46	6.30	Buffer
Linear Transition Time												
Transition O ₂ Fraction	0.21	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	PN ₂ (t)
Calculated Target PN ₂	22.47	24.50	19.40	14.61	10.12	8.22	7.81	6.96	6.62	6.46	6.30	Buffer
Initial PN ₂ Inspired	22.47	46.97	41.87	37.08	32.59	30.69	30.28	29.43	29.08	28.93	28.77	Safety Ms
Target - Initial	0	24.50	19.40	14.61	10.12	8.22	7.81	6.96	6.62	6.46	6.30	Buffer
Segment 3 Conditions												
Segment Depth (FSW)	0	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	PN ₂ (t)
Segment Time (Min)	0	92.56	78.01	64.33	51.50	46.08	44.90	42.47	41.48	41.05	40.59	Not Seg Ms
Inspired O ₂ Fraction	0.21	46.97	41.87	37.08	32.59	30.69	30.28	29.43	29.08	28.93	28.77	Safety Ms
Calculated PN ₂	22.47	24.50	19.40	14.61	10.12	8.22	7.81	6.96	6.62	6.46	6.30	Buffer
Linear Transition Time												
Transition O ₂ Fraction	0.21	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	PN ₂ (t)
Calculated Target PN ₂	22.47	24.50	19.40	14.61	10.12	8.22	7.81	6.96	6.62	6.46	6.30	Buffer
Initial PN ₂ Inspired	22.47	46.97	41.87	37.08	32.59	30.69	30.28	29.43	29.08	28.93	28.77	Safety Ms
Target - Initial	0	24.50	19.40	14.61	10.12	8.22	7.81	6.96	6.62	6.46	6.30	Buffer
Segment 4 Conditions												
Segment Depth (FSW)	0	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	PN ₂ (t)
Segment Time (Min)	0	92.56	78.01	64.33	51.50	46.08	44.90	42.47	41.48	41.05	40.59	Not Seg Ms
Inspired O ₂ Fraction	0.21	46.97	41.87	37.08	32.59	30.69	30.28	29.43	29.08	28.93	28.77	Safety Ms
Calculated PN ₂	22.47	24.50	19.40	14.61	10.12	8.22	7.81	6.96	6.62	6.46	6.30	Buffer
Linear Transition Time												
Transition O ₂ Fraction	0.21	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	PN ₂ (t)
Calculated Target PN ₂	22.47	24.50	19.40	14.61	10.12	8.22	7.81	6.96	6.62	6.46	6.30	Buffer
Initial PN ₂ Inspired	22.47	46.97	41.87	37.08	32.59	30.69	30.28	29.43	29.08	28.93	28.77	Safety Ms
Target - Initial	0	24.50	19.40	14.61	10.12	8.22	7.81	6.96	6.62	6.46	6.30	Buffer
Segment 5 Conditions												
Segment Depth (FSW)	0	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	PN ₂ (t)
Segment Time (Min)	0	92.56	78.01	64.33	51.50	46.08	44.90	42.47	41.48	41.05	40.59	Not Seg Ms
Inspired O ₂ Fraction	0.21	46.97	41.87	37.08	32.59	30.69	30.28	29.43	29.08	28.93	28.77	Safety Ms
Calculated PN ₂	22.47	24.50	19.40	14.61	10.12	8.22	7.81	6.96	6.62	6.46	6.30	Buffer
Linear Transition Time												
Transition O ₂ Fraction	0.21	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	PN ₂ (t)
Calculated Target PN ₂	22.47	24.50	19.40	14.61	10.12	8.22	7.81	6.96	6.62	6.46	6.30	Buffer
Initial PN ₂ Inspired	22.47	46.97	41.87	37.08	32.59	30.69	30.28	29.43	29.08	28.93	28.77	Safety Ms
Target - Initial	0	24.50	19.40	14.61	10.12	8.22	7.81	6.96	6.62	6.46	6.30	Buffer
Segment 6 Conditions												
Segment Depth (FSW)	0	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	PN ₂ (t)
Segment Time (Min)	0	92.56	78.01	64.33	51.50	46.08	44.90	42.47	41.48	41.05	40.59	Not Seg Ms
Inspired O ₂ Fraction	0.21	46.97	41.87	37.08	32.59	30.69	30.28	29.43	29.08	28.93	28.77	Safety Ms
Calculated PN ₂	22.47	24.50	19.40	14.61	10.12	8.22	7.81	6.96	6.62	6.46	6.30	Buffer
Linear Transition Time												
Transition O ₂ Fraction	0.21	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	PN ₂ (t)
Calculated Target PN ₂	22.47	24.50	19.40	14.61	10.12	8.22	7.81	6.96	6.62	6.46	6.30	Buffer
Initial PN ₂ Inspired	22.47	46.97	41.87	37.08	32.59	30.69	30.28	29.43	29.08	28.93	28.77	Safety Ms
Target - Initial	0	24.50	19.40	14.61	10.12	8.22	7.81	6.96	6.62	6.46	6.30	Buffer
Final Depth (FSW)												
Final Air PN ₂	22.5											
Total Dive Time (Min)	0											
Residual PN ₂ (mm-mm)	0	0	0	0	0	0	0	0	0	0	0	0
Residual PN ₂ (mm-mm)	0	0	0	0	0	0	0	0	0	0	0	0
Torr Estimator: Air (0-20000) = 6500 Torr = 594.01 Equiv = -7.17 fsw												Report Group
												Notes

MATERIALS AND METHODS

-0.693147181		30	N ₂ Tissue Compartments										
Copyright (C) 1968 Benton P. Zwart			5	10	20	40	80	120	160	320	480	640	T1/2
Initial Tissue PN ₂	22.47		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)	655		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	0.00	0.0	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	22.47	PN ₂ (t)
Transition O ₂ Fraction	0.21												
Calculated Target PN ₂	22.47	92.58	78.01	64.33	51.50	46.08	44.90	42.47	41.48	41.05	40.59		Nxt Seg Ms
Initial PN ₂ Inspired	22.47	46.97	41.87	37.08	32.59	30.69	30.28	29.43	29.08	28.93	28.77		Safety Ms
Target - Initial	0	24.50	19.40	14.61	10.12	8.22	7.81	6.96	6.62	6.46	6.30		Buffer

Safety factor
65%

Murray UT, 4500 feet
barometric pressure 655
mmHg

Time interval

Oxygen breathing percent

Results / US Navy Air Tables

- USN standard air decompression tables at 4500 feet of altitude: Cross correction
($14.7 \text{ psig} / 12.7 \text{ psig} = 1.15$)
- 2 atm abs = 43.2 equivalent feet of sea water
($14.7 \text{ psig} + 2 \text{ psig} \times 1.15 \times 2.25$)
- 3 atm abs = 81.2 equivalent feet of sea water
($29.4 \text{ psig} + 2 \text{ psig} \times 1.15 \times 2.25$)

Results US Navy Air tables

- The inside attendant exposed to 2 atm abs, USN 45 fsw for 110 minutes exits the chamber as a USN repetitive group M.
- A USN repetitive group M must wait 8 hrs 1 min. SIT before ascent to 4000 feet from Murray, UT (USN table 9-6)

US Navy No Decompression Repetitive Table

Table 9-7. No-Decompression Limits and Repetitive Group Designators for No-Decompression Air Dives.

Depth (fsw)	No-Stop Limit	Repetitive Group Designation															
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Z
10	Unlimited	57	101	158	245	426	*										
15	Unlimited	36	60	88	121	163	217	297	449	*							
20	Unlimited	26	43	61	82	106	133	165	205	256	330	461	*				
25	595	20	33	47	62	78	97	117	140	166	198	236	285	344	469	595	
30	371	17	27	38	50	62	76	91	107	125	145	167	193	233	260	307	371
35	232	14	23	32	42	52	63	74	87	100	115	131	148	168	190	215	232
40	163	12	20	27	36	44	53	63	73	84	95	108	121	135	151	163	
45	125	11	17	24	31	39	46	55	63	73	83	94	107	114	125		
50	92	9	15	21	28	34	41	48	56	63	71	80	89	92			

“M”

45 fsw

114 minutes

Results US Navy Air tables

- Carbon monoxide protocol to 3 atm abs, USN 90 for 140 minutes requires surface decompression using oxygen which is impractical at our chamber.
- There is no USN group number after this exposure.

Table 9-9. Air Decompression Table (Continued).
(DESCENT RATE 75 FPM—ASCENT RATE 30 FPM)

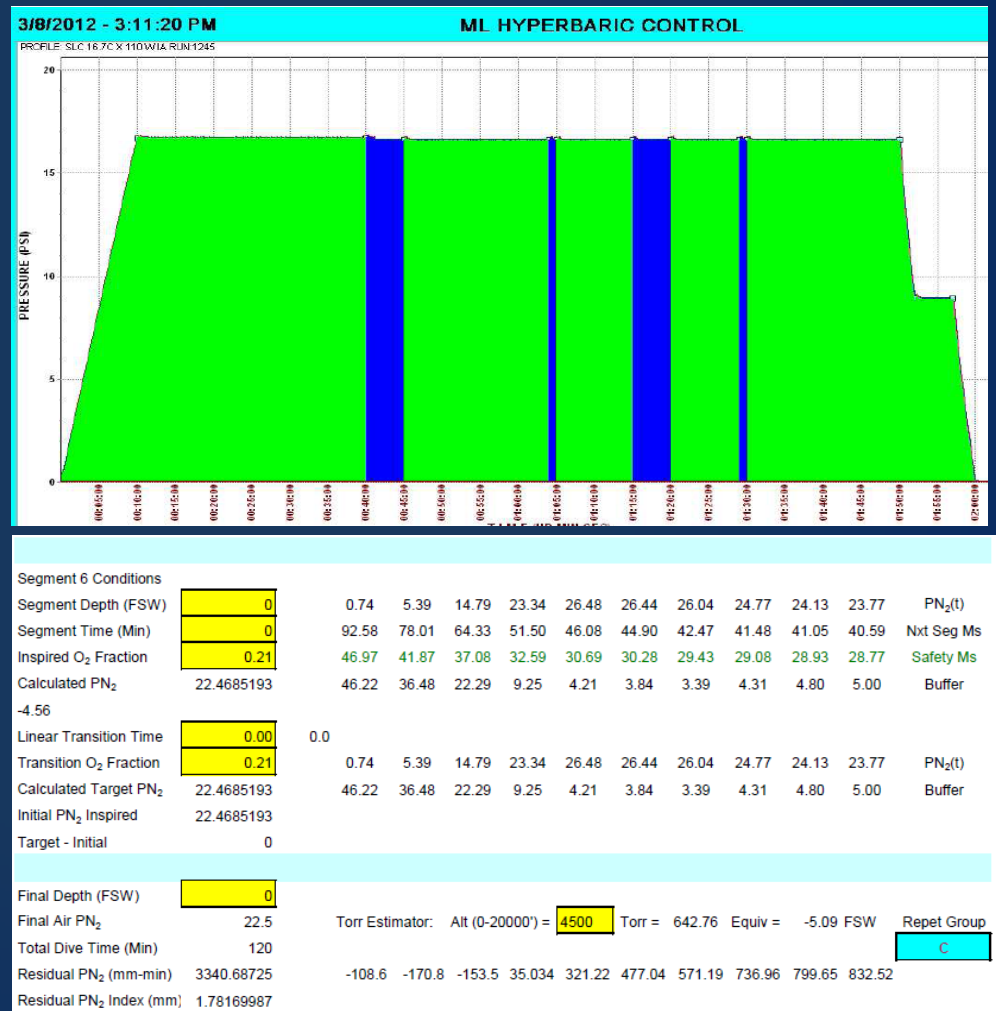
Bottom Time (min)	Time to First Stop (M:S)	Gas Mix	DECOMPRESSION STOPS (FSW) Stop times (min) include travel time, except first air and first O ₂ stop									Total Ascent Time (M:S)	Chamber O ₂ Periods	Repet Group
			100	90	80	70	60	50	40	30	20			
90 FSW														
Exceptional Exposure: In-Water Air/O ₂ Decompression ----- SurDO ₂ Required-----														
120	1:40	AIR								1	29	256	288:20	3.5
		AIR/O ₂								1	15	70	98:40	
130	1:40	AIR								5	28	291	326:20	3.5
		AIR/O ₂								5	15	78	110:40	
140	1:40	AIR								8	28	330	368:20	4
		AIR/O ₂								8	15	86	126:40	

140 minutes

Total time: 127 Air/O₂ + 140 O₂ > 4 hours !

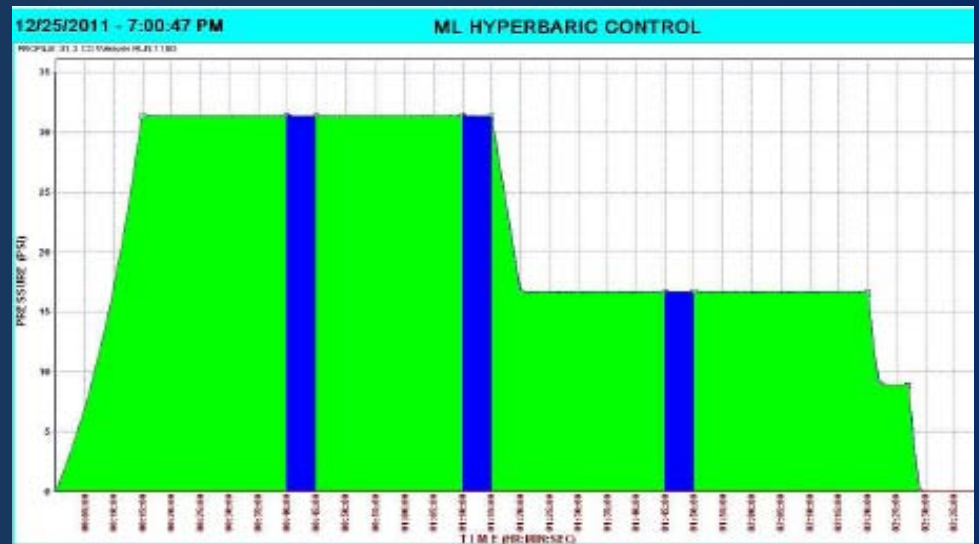
Results Nobendem© calculator allows the use of supplemental O₂

- 2 atm abs profile, the inside attendant breathes 100% O₂ for 40 minutes exiting as a USN group C.
- A USN group C allows an increase in altitude of 4000 feet from Murray, UT (USN table 9-6)



Results Nobendem© at 3 atm abs

- Inside attendant breathes 50% O₂ / 50% N₂ at 3 atm abs as much as possible
- 100% O₂ at 2 atm abs at intervals = 50 minutes
- Ending with a USN group C.



Segment 6 Conditions													
Segment Depth (FSW)	0	0.74	5.39	14.79	23.34	26.48	26.44	26.04	24.77	24.13	23.77	PN ₂ (t)	
Segment Time (Min)	0	92.58	78.01	64.33	51.50	46.08	44.90	42.47	41.48	41.05	40.59	Nxt Seg Ms	
Inspired O ₂ Fraction	0.21	46.97	41.87	37.08	32.59	30.69	30.28	29.43	29.08	28.93	28.77	Safety Ms	
Calculated PN ₂	22.4685193	46.22	36.48	22.29	9.25	4.21	3.84	3.39	4.31	4.80	5.00	Buffer	
-4.56													
Linear Transition Time	0.00	0.0											
Transition O ₂ Fraction	0.21	0.74	5.39	14.79	23.34	26.48	26.44	26.04	24.77	24.13	23.77	PN ₂ (t)	
Calculated Target PN ₂	22.4685193	46.22	36.48	22.29	9.25	4.21	3.84	3.39	4.31	4.80	5.00	Buffer	
Initial PN ₂ Inspired	22.4685193												
Target - Initial	0												
Final Depth (FSW)	0												
Final Air PN ₂	22.5	Torr Estimator: Alt (0-20000') = 4500		Torr = 642.76		Equiv = -5.09 FSW		Repet Group					
Total Dive Time (Min)	120												
Residual PN ₂ (mm-min)	3340.68725	-108.6	-170.8	-153.5	35.034	321.22	477.04	571.19	736.96	799.65	832.52	C	
Residual PN ₂ Index (mm)	1.78169987												

Results using Nobendem© and US Navy air tables

- 1007 exposures at 2 atm abs
- 7 exposures at 3 atm abs
- Inside attendant is allowed to strap the mask on and move about when the inspired O_2 is ≤ 1.5 atm abs
- Inside attendant Nobendem© repetitive group allows for 4,000 foot increase in altitude after pressure excursions

Conclusion

- The Nobendem© calculator may be used in conjunction with the USN tables. We have found the Nobendem© useful for planning the O₂ breathing interval for the inside attendant at chamber pressures up to 3 atm abs.
- Our use of Nobendem© is insufficient to discover low rates of decompression sickness.

DISCUSSION

