



NAUI Tri-Mix Instructor Guide

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Photos by Denise Morrissette

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WARNING

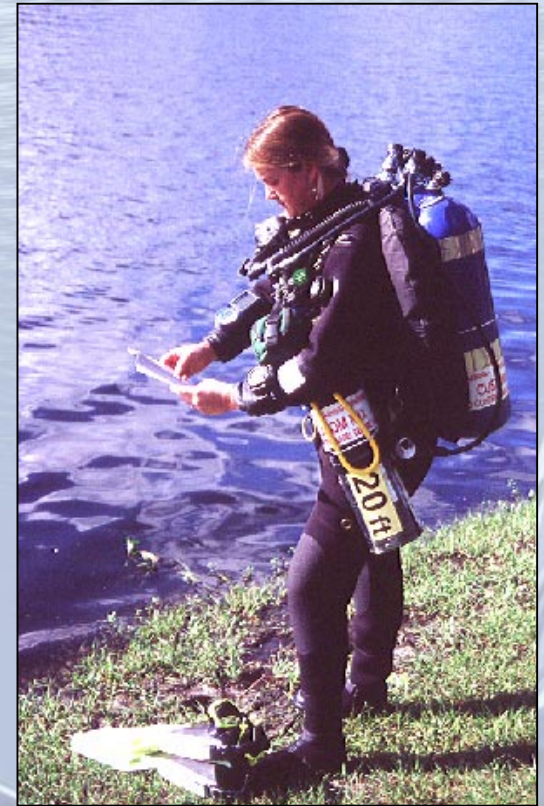
This presentation is a training supplement which should only be implemented by a NAUI certified Mixed Gas Scuba Instructor. This material does not contain all there is to know about scuba diving and breathing gas mixtures containing helium (e. g. trimix, heliair, helitrox, and heliox) or nitrogen or oxygen. Mixed gas diving is an inherently dangerous activity and will always carry risk of personal injury or death even if all currently known safety guidelines, limits and training standards are followed. In fact, at the time of this publication there are no validated trimix decompression tables. Use or implementation of any information contained herein is the sole responsibility of the individual. Do not proceed if you do not understand this warning and accept the inherent risks of mixed gas diving.

Your signature below indicates you understand and accept that there are known and unknown hazards of mixed gas diving and you still wish to participate in this training and hereby agree to indemnify and hold harmless the authors, The National Association of Underwater Instructors, Inc. (NAUI), and your instructor for property damage, personal injury or death regardless of its cause.

Student Signature _____ Date _____

PREREQUISITES

- ✓ **Minimum age 21 years old**
- ✓ **Medical clearance & physically fit**
- ✓ **Decompression Techniques & Technical EANx Diver certification**
- ✓ **Minimum of 250 logged dives**
- ✓ **Minimum of 75 dives deeper than 130 ft. & 10 staged deco EANx dives**
- ✓ **Self sufficient & solo capabilities**



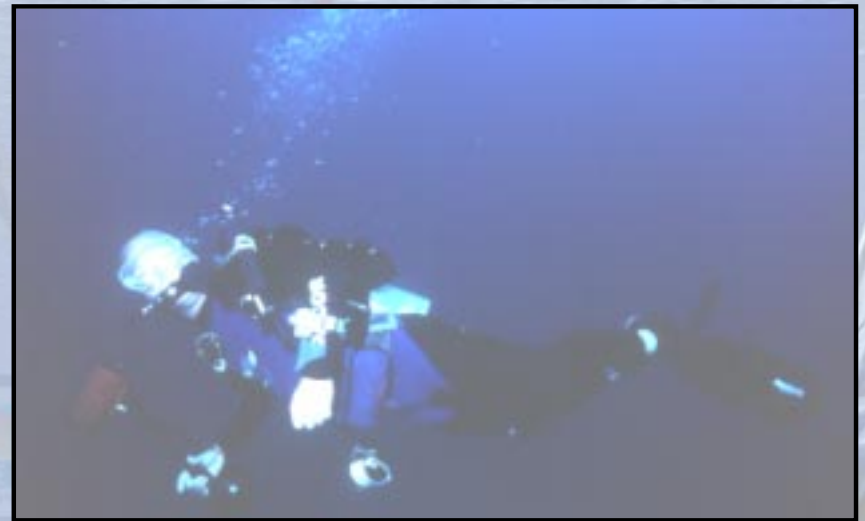
MINIMUM DIVE REQUIREMENTS

Level I Trimix

- ✓ Total of 6 dives
- ✓ 2 decompression dives
- ✓ 190 ft. < 2 dives < 225 ft.

Level II Trimix

- ✓ Level I plus 2 extra dives
- ✓ 225 ft. < 2 dives < 300 ft.



SECTIONS

Do not proceed if you have not read and signed a copy of Slide 2.

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SECTION 1 TOPICS

- ✓ **Mixed Gases**
- ✓ **Gas Properties**
- ✓ **Specific Heat Capacity**
- ✓ **Thermal Conductivity**
- ✓ **Thermal Conductivity Related to Air**
- ✓ **Dropping Core Temperature**
- ✓ **Suit Insulation Values**
- ✓ **Dry Suit Inflation Gas**
- ✓ **Ideal Versus Real Gas Behavior**
- ✓ **Determining Best Trimix**
- ✓ **Partial Pressure Blending Trimix**
- ✓ **Usable Cascade Volume**
- ✓ **Helium is an Asphyxiant**

MIXED GASES

One or more inert gases combined with O₂ to reduce decompression and/or eliminate narcosis and toxicity.

Heliox - (Helium and Oxygen)

Heliair - (Helium and Air, where Oxygen < 21%)

Helitrox - (Helium and Nitrox, where Oxygen > 21%)

Trimix - (Helium, Nitrogen, Oxygen)

Hydreliox - (Hydrogen and Helium, balance O₂ < 4%)

Hydrox - (Hydrogen, balance Oxygen < 4%)

Neox - (Neon and Oxygen)

GAS PROPERTIES

GAS	MOLECULAR WEIGHT (g/m)	WATER / OIL SOLUBILITY	NARCOTIC POTENCY
Hydrogen: H₂	2.016	0.0170 / 0.050	1.83
Helium: He	4.003	0.0086 / 0.015	4.26
Neon: Ne	20.180	0.0097 / 0.019	3.58
Nitrogen: N₂	28.020	0.0130 / 0.061	1.00
Argon: Ar	39.440	0.0260 / 0.140	0.43
Oxygen: O₂	32.000	0.0950 / 0.012	
CO₂	44.010		
CO	28.010		
Air*	28.810		

SPECIFIC HEAT CAPACITY

C_p Btu/lbm · °F @ 70 °F

Gas	C_p
O ₂	0.22
N ₂	0.25
He	1.24
H ₂	3.43
Ar	0.12
CO ₂	0.20
Air	0.24

THERMAL CONDUCTIVITY

cal/sec · cm · °C × 10⁻⁵

Oxygen	6.6
Helium	36.9
Nitrogen	6.4
Argon	4.4
Air	6.42

THERMAL CONDUCTIVITY RELATED TO % OF AIR CONDUCTIVITY

EAN	H₂	He	Ar	CO₂
100%	704%	586%	68.2%	62.4%

DROPPING CORE TEMPERATURE

98 °F (37 °C) Cold sensations, skin vasoconstriction, increased muscle tension, increased O₂ consumption

97 °F (36 °C) Uncontrollable shivering, sporadic gross shivering, hyperventilation, higher O₂ consumption

95 °F (35 °C) Clinical hypothermia, mental confusion, irrational thought, decreased will to struggle

93 °F (34 °C) Memory loss, and speech, sensory and motor impairment

SUIT INSULATION VALUES

Suit	1 ata	4 ata
0.25 in. (6 mm) neoprene wet suit	0.77	0.25
0.25 in. (6 mm) neoprene dry suit & nylon pile	2.33	0.60
0.4 in. (10 mm) rubber dry suit & 0.3 (8 mm) urethane foam underwear	2.10	0.87
0.4 in. (10 mm) rubber dry & 0.3 (8 mm) thinsulate	2.40	1.20

DRY SUIT INFLATION GAS

- ✓ Nitrogen and Argon are “*suitable*” inert gases
- ✓ Ideally inflation gas should sustain life
- ✓ 10% O₂ is normoxic from 20-495 ft. (6-150 m)
- ✓ Purge ambient air from suit after attired
- ✓ Fill suit from auxiliary argon supply at surface
- ✓ Install a pressure relief valve on first-stage LP port as a precaution against a HP seat failure
- ✓ Backup LP inflator hose

IDEAL VERSUS REAL GAS BEHAVIOR

- * A gas is said to behave as an ideal gas if its molecules do not exert any force, attractive or repulsive, on one another and the volumes of molecules are negligibly small compared to distance between them.
- * For pressures up to 50 ata (1617 fsw) O₂, He, and H₂ are within 5% of ideal behavior.

DETERMINING BEST TRIMIX

1. $P \text{ ata} = (\text{MOD} \div 33 \text{ fsw/ata}) + 1 \text{ ata}$
2. $\text{Max PO}_2 < 1.44 \text{ ata}$
3. $\text{FN}_2 = [(\text{END} + 33 \text{ fsw}) \div (\text{MOD} + 33 \text{ fsw})] \times 0.79$
4. $\text{FO}_2 = \text{PO}_2 \div P \text{ ata}$
5. $\text{FHe} = 1.0 \text{ ata} - (\text{FO}_2 + \text{FN}_2)$

PARTIAL PRESSURE BLENDING TRIMIX

- ✓ Lay cylinders down during filling and cooling
- ✓ Wait for the gas temperature to stabilize and verify the pressure before adding another gas
- ✓ Analyze O₂ content after combining He and O₂
- ✓ A 1% error in O₂ at the heliox stage may cause a 4% or 5% error in the final N₂% and He%
- ✓ Analyze O₂ content at the final target pressure

USABLE CASCADE VOLUME

1. **Rated Cylinder Pressure per Cubic Foot:**

rated cylinder psi \div rated cylinder ft³ = psi/ft³

2. **Usable Supply Pressure:**

supply psi - needed scuba psi = usable supply psi

3. **Available Supply Volume:**

usable supply psi \div supply psi/ft³ = available supply ft³

4. **Required Scuba Volume:**

(scuba ft³ \div scuba psi) \times required psi = required scuba ft³

5. **Number of Cascade Fills:**

available supply ft³ \div required scuba ft³ = number of fills

HELIUM IS AN ASPHYXIAN

! Do not leave pure helium in a scuba cylinder, but if you do — label it

HELIUM - DO NOT BREATHE!

! Decant helium in a well-ventilated area.

SECTION 1 EXAMINED



- ✓ **Mixed Gases**
- ✓ **Gas Properties**
- ✓ **Specific Heat Capacity**
- ✓ **Thermal Properties**
- ✓ **Dropping Core Temperature**
- ✓ **Suit Insulation Values**
- ✓ **Dry Suit Inflation Gas**
- ✓ **Ideal Versus Real Gas Behavior**
- ✓ **Determining Best Trimix**
- ✓ **Partial Pressure Blending**
- ✓ **Usable Cascade Volume**

SECTION 2 TOPICS

- ✓ Helium Versus Nitrogen
- ✓ Saturation/Desaturation
- ✓ Halftime Comparisons
- ✓ Equivalent/Effective Depth Formulas
- ✓ Dissolved Gas Models
- ✓ Free Gas Phase Models
- ✓ Schedule Comparisons
- ✓ Gas Selection
- ✓ Normoxic Ranges
- ✓ Common O₂/N₂ Deco Mixes
- ✓ Gas Switching Problems
- ✓ Oxygen Window
- ✓ Total Deco Times for Various Deco Gases
- ✓ Additional Considerations

HELIUM VERSUS NITROGEN

- **Faster tissues control deep deco stops while slower tissues control shallow stops**
- **Pressure ratios can exceed the typical limiting ratio for compartments with faster halftimes**
- **Lower solubility in oil may yield shorter halftimes for fatty tissue**
- **More rapid diffusion rate calls for deeper deco stops and a slower ascent rate to minimize bubble formation**

SATURATION AND DESATURATION SPEED

- α Saturation and desaturation speed of an inert gas is inversely proportional to the square root of its atomic mass (molecular weight).**
- α Helium saturates/desaturates about 2.65 times faster than nitrogen, resulting in shorter halftimes for the same critical tensions.**

HALFTIME COMPARISONS

SATURATION HALFTIMES (mins)

N₂	5	10	23	37	79	114	238	351	795
He	2	4	9	14	30	43	90	133	300

DESATURATION HALFTIMES (mins)

N₂	8	15	34	56	119	171	357	527	1193
He	3	6	13	21	45	65	135	199	450

EQUIVALENT / EFFECTIVE DEPTH FORMULAS

EQUIVALENT AIR DEPTH

for air or nitrox at sea level and altitude*

$$\text{EAD} = [(\text{FN}_2 \div 0.79) \times (d + 33 \text{ fsw})] - 33 \text{ fsw}$$

$$*\text{EAD} = [(\text{FN}_2 \div 0.79) \times (d + P_h)] - P_h$$

EFFECTIVE DEPTH

for any inert gas and elevation

$$\text{ED} = [(f_k \div f_{ks}) \times (d + P_h)] - P_h$$

DISSOLVED GAS MODELS

Haldane/Workman

USN

Bühlmann

ZH-L

Hamilton

DCAP

- **Limits tissue saturation**
- **Maximizes elimination gradient**

FREE GAS PHASE MODELS

VPM by Yount & Hoffman

Varying Permeability Model

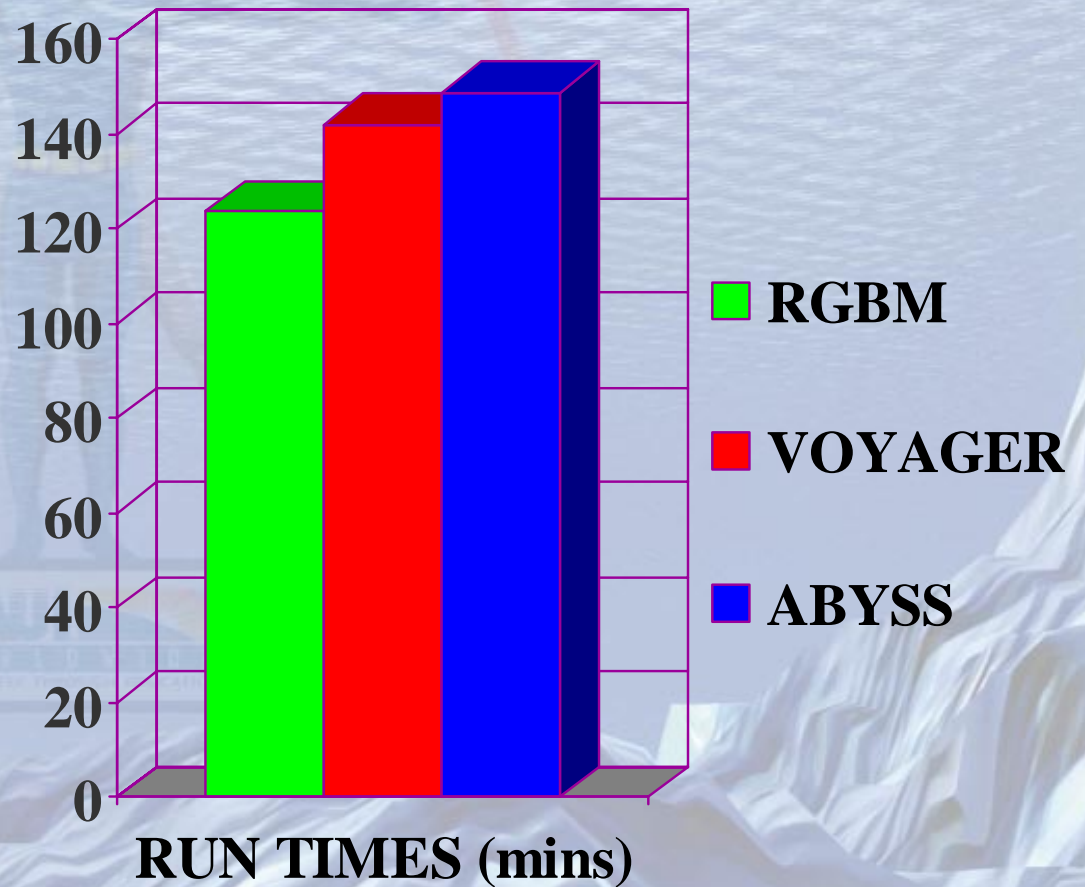
RGBM by Bruce Wienke

Reduced Gradient Bubble Model

- **Phase separation or bubbles trigger simple DCS**
 - **DCS prevention \approx bubble prevention**
- **Gradual pressure reduction minimizes bubble formation**

SCHEDULE COMPARISON

- **250 fsw for 28 min using TX 16/33/51**
- **Air switch at 100 fsw on ascent**
- **O₂ switch at 20 fsw on ascent**



TX16/24 @ 170 FSW FOR 25 MIN

VOYAGER (ZH-L)

fsw	mix	mins
10	O ₂	12
20	O ₂	7
30	air	9
40	air	4
50	air	2
60	air	1
100	air	0
170	16/24	25

Deco Time = 35 minutes

RGBM

fsw	mix	mins
10	O ₂	6
20	O ₂	4
30	air	5
40	air	3
50	air	3
60	air	1
70	air	1
80	air	1
90	air	0
100	air	1
170	16/24	25

Deco Time = 25 minutes

TX16/24 @ 52 MSW FOR 25 MIN

VOYAGER (ZH-L)

msw	mix	mins
3	O ₂	12
6	O ₂	7
9	air	9
12	air	4
15	air	2
18	air	1
30	air	0
52	16/24	25

Deco Time = 35 minutes

RGBM

msw	mix	mins
3	O ₂	6
6	O ₂	4
9	air	5
12	air	3
15	air	3
18	air	1
21	air	1
24	air	1
27	air	0
30	air	1
52	16/24	25

Deco Time = 25 minutes

RGBM & ZH-L COMPARISONS

RGBM & ZHL stop time comparisons, 30 fpm descent & ascent, TX down and up, air up from 100 fsw, O2 up from 20 fsw										
Total Deco	47	78	50	83	98	72	59	157	115	93
O2 10	10	16	11	17	31	23	19	48	35	28
O2 20	6	10	6	11	19	14	11	28	20	16
AIR 30	8	12	9	13	17	14	12	28	22	18
AIR 40	5	9	5	9	11	9	7	18	14	12
AIR 50	4	6	3	7	8	5	4	12	9	7
AIR 60	3	5	3	5	5	3	3	8	6	5
AIR 70	2	3	3	3	3	3	2	5	4	3
AIR 80	1	2	1	2	2	1	1	4	3	2
AIR 90	1	2	1	2	2			3	2	2
AIR 100	1	2	1	2				2		
TX 16/33 110	2	2	2	3				1		
TX 16/33 120	1	2	1	2						
TX 16/33 130	1	2	1	2						
TX 16/33 140	0	2	1	2						
TX 16/33 150	1	1	1	1						
TX 16/33 160	1	1	1	1						
TX 16/33 170		1		0						
TX 16/33 180				1						
TX 16/33 190										
TX 16/33 250	8.33 min	8.33 min	8.33 min	8.33 min	8.33 min	8.33 min	8.33 min	8.33 min	8.33 min	8.33 min
TX 16/33 250	20 min	30 min	20 min	30 min	20 min	20 min	20 min	30 min	30 min	30 min
generated on:	RGBM	RGBM	RGBM	RGBM safer	A150	A120	A100	A150	A120	A100
corresponds to:	A100	A100	A120	A120	ZHL	ZHL	ZHL std	ZHL safer	ZHL	ZHL std

GAS SELECTION

- » **Bottom Mix, Back Gas**
- » **Bailout Mix**
- » **Travel Mix, Transition Gas**
- » **Deco Gas/Mix, Hot Gas/Mix**
- » **Surface Supplied/Staged Gas**
- » **Suit Inflation/Insulation Gas**
- » **Medical O₂, Treatment Gas**

NORMOXIC RANGES

$$0.16 \text{ ata} \leq \text{PO}_2 \leq 1.44 \text{ ata}$$

- **Heliair 16/24/60** - Normoxic 0 - 264 fsw
END 136 fsw at 190 fsw & 163 fsw at 225 fsw
- **Heliair 14/33/53** - Normoxic 5 - 306 fsw
END 117 fsw at 190 fsw & 140 fsw at 225 fsw
- **Trimix 16/40/44** - Normoxic 0 - 264 fsw
END 91 fsw at 190 fsw & 111 fsw at 225 fsw
- **Trimix 14/50/36** - Normoxic 5 - 306 fsw
END 69 fsw at 190 fsw & 85 fsw at 225 fsw

NORMOXIC RANGES

$$0.16 \text{ ata} \leq \text{PO}_2 \leq 1.44 \text{ ata}$$

- **Heliar 16/24/60** - Normoxic 0 - 80 msw
END 41 msw at 58 msw & 50 msw at 69 msw
- **Heliar 14/33/53** - Normoxic 1.5 - 93 msw
END 36 msw at 58 msw & 43 msw at 69 msw
- **Trimix 16/40/44** - Normoxic 0 - 80 msw
END 28 msw at 58 msw & 34 msw at 69 msw
- **Trimix 14/50/36** - Normoxic 1.5 - 93 msw
END 21 msw at 58 msw & 26 msw at 69 msw

COMMON O₂/N₂ DECO MIXTURES

DECO MIX	MOD	STOP DEPTH
OXYGEN	≤ 20 fsw	20 fsw
EAN80	≤ 33 fsw	30 fsw
EAN70	≤ 42 fsw	40 fsw
EAN50	≤ 72 fsw	70 fsw
EAN36	≤ 113 fsw	110 fsw
EAN32	≤ 132 fsw	130 fsw
AIR	≤ 218 fsw	210 fsw

COMMON O₂/N₂ DECO MIXTURES

DECO MIX	MOD	STOP DEPTH
OXYGEN	≤ 6 msw	6 msw
EAN80	≤ 10 msw	9 msw
EAN70	≤ 13 msw	12 msw
EAN50	≤ 22 msw	21 msw
EAN36	≤ 34 msw	34 msw
EAN32	≤ 40 msw	40 msw
AIR	≤ 66 msw	64 msw

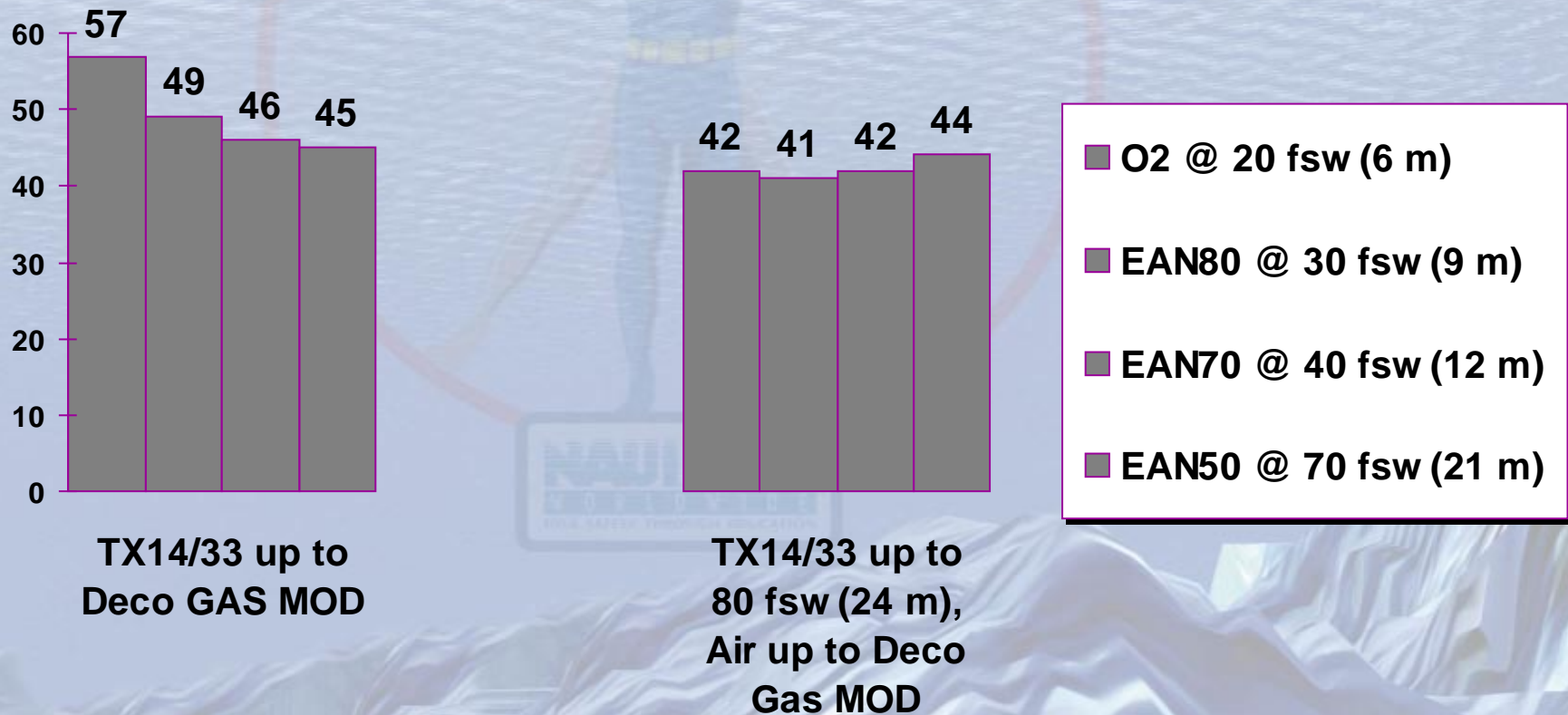
GAS SWITCHING PROBLEMS

- ✓ **Omitted Decompression (Gas Loss)**
- ✓ **Hyperoxic Seizure (Off Oxygen Effect)**
- ✓ **Hypoxic Blackout (Extraction Effect)**
- ✓ **Squeeze (Middle Ear Oxygen Absorption)**
- ✓ **DCS and VGE (Isobaric Counter Diffusion)**
- ✓ **Narcosis and HPNS**

OXYGEN WINDOW

	Dry Air	Alveolar Air	Arterial Blood	Venous Blood	Tissue
33 fsw Pressure →	O ₂ : 6.6	H ₂ O: 2.0	H ₂ O: 2.0	H ₂ O: 2.0	H ₂ O: 2.0
		CO ₂ : 1.8	CO ₂ : 1.8	CO ₂ : 1.8	CO ₂ : 2.1
		O ₂ : 4.5	O ₂ : 3.8	O ₂ : 1.6	O ₂ : 0.5
	N ₂ : 26.4	N ₂ : 24.7	N ₂ : 24.7	N ₂ : 24.7	N ₂ : 24.7

TOTAL DECO TIMES FOR VARIOUS DECO GASES



WHY USE AIR OR AN AIR ALTERNATIVE?

- ✍ **Performs as a deep decompression gas**
- ✍ **Abort gas during descent or at training depth**
- ✍ **Life saving bailout option if back gas is lost**
- ✍ **Less expensive**
- ✍ **Air avoids blending and potential analysis error**

ADDITIONAL CONSIDERATIONS

- ! Depending on the depth, a switch to air can cause the sudden onset of nitrogen narcosis**
- ! The physiological transition may be smoother using TX 17/26 or a similar Heliair alternative**

WHY USE OXYGEN?

- ✓ **No inert gas uptake**
- ✓ **Fastest inert gas washout - highest gradient**
- ✓ **The 10 ft. (3 m) stop can be made at 20 ft. (6 m) to benefit from increased hydrostatic pressure**
- ✓ **Available as a treatment gas upon surfacing**
- ✓ **No mixing and avoids potential analysis error**

ADDITIONAL CONSIDERATIONS

- ✓ **5 minute normoxic breaks every 20 minutes**
- ✓ **Vasoconstrictor, free radicals and reduced breathing stimulus compared to nitrox**
- ✓ **Volume requirement is difficult to meet without use of an O₂ compatible HP booster**

SECTION 2 COMPARED



Photo by Andy Ogburn

- ✓ **Helium Versus Nitrogen**
- ✓ **Saturation/Desaturation Speed**
- ✓ **Halftime Comparisons**
- ✓ **Equivalent/Effective Depth Formulas**
- ✓ **Decompression Models**
- ✓ **Schedule Comparisons**
- ✓ **Gas Selection**
- ✓ **Common O₂/N₂ Deco Mixtures**
- ✓ **Gas Switching Problems**
- ✓ **Deco-Gas Comparisons**

SECTION 3 TOPICS

- ✓ **Human Response to PO_2**
- ✓ **Average RMV and VO_2 Rates**
- ✓ **Metabolic O_2 Consumption**
- ✓ **Personal Limitations**
- ✓ **Environmental Considerations**
- ✓ **Physiological Problems**

HUMAN RESPONSE TO PO₂

PO₂ ata

RESPONSE

0.21 - 0.18	Normal, no noticeable effects
0.17 - 0.12	accelerated breathing, incoordination
0.12 - 0.10	Tires easily, emotional, insensitive to pain, abnormal fatigue
0.10 - 0.06	Lethargy, apathy, confusion, collapse, unconsciousness, nausea, vomiting
0.06 or less	Gasping, convulsions, respiratory arrest

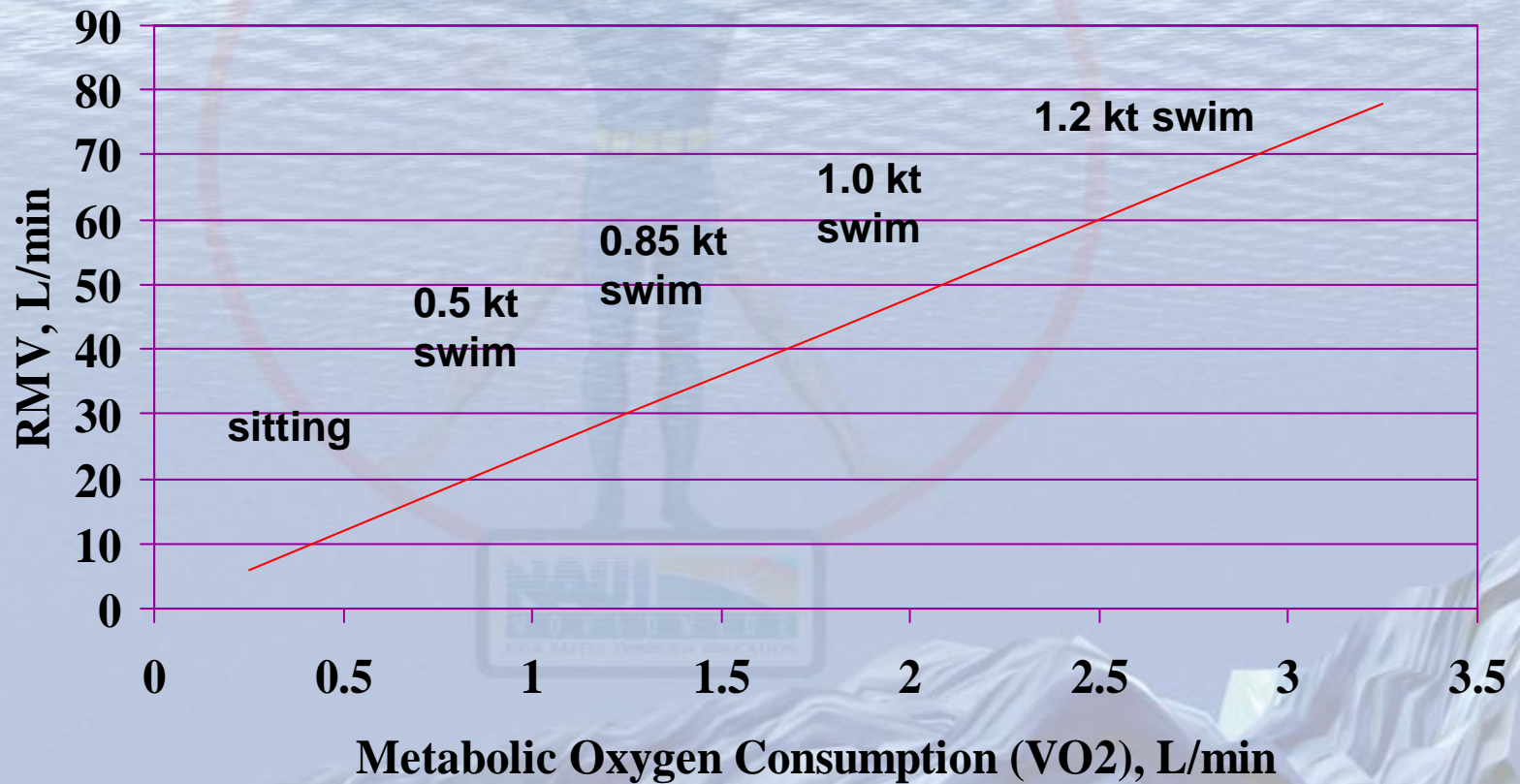
AVERAGE RMV AND VO₂ RATES

	RMV	VO₂
Slow Swim	0.6 ft³/min	0.8 L/min
Average Swim	1.0 ft³/min	1.5 L/min
Fast Swim	1.4 ft³/min	1.8 L/min
Max Swim	2.5-3.5 ft³/min	3-4 L/min

AVERAGE RMV AND VO₂ RATES

	RMV	VO₂
Slow Swim	18 L/min	0.8 L/min
Average Swim	28 L/min	1.5 L/min
Fast Swim	40 L/min	1.8 L/min
Max Swim	70-100 L/min	3-4 L/min

METABOLIC O₂ CONSUMPTION



PERSONAL LIMITATIONS

- **Equivalent Narcotic Depth (END)**
- **Oxygen Depth Limits (MOD)**
- **Oxygen Time Limits (NOAA, USN)**
- **Intellectual Capability**
- **Psychological Stability**
- **Physical Ability**

ENVIRONMENTAL CONSIDERATIONS

- ✓ **Location**
- ✓ **Depth**
- ✓ **Visibility**
- ✓ **Current**
- ✓ **Temperature**
- ✓ **Exposure Time**
- ✓ **Time of Day**
- ✓ **Marine Life**
- ✓ **Weather**
- ✓ **Sea State**
- ✓ **Tides**
- ✓ **Sunlight**

PHYSIOLOGICAL PROBLEMS

- ✓ **Narcosis**
- ✓ **Toxicity**
- ✓ **Dehydration**
- ✓ **DCS**
- ✓ **HPNS**
- ✓ **Hypoxia**
- ✓ **Hyperoxia**
- ✓ **Hypercapnia**

PHYSIOLOGICAL PROBLEMS

- ✓ **Hypothermia**
- ✓ **Hyperthermia**
- ✓ **Hypoglycemia**
- ✓ **Squeeze**
- ✓ **Reverse Block**
- ✓ **Vertigo**
- ✓ **Blackout**
- ✓ **Drowning**

SECTION 3 IDENTIFIED

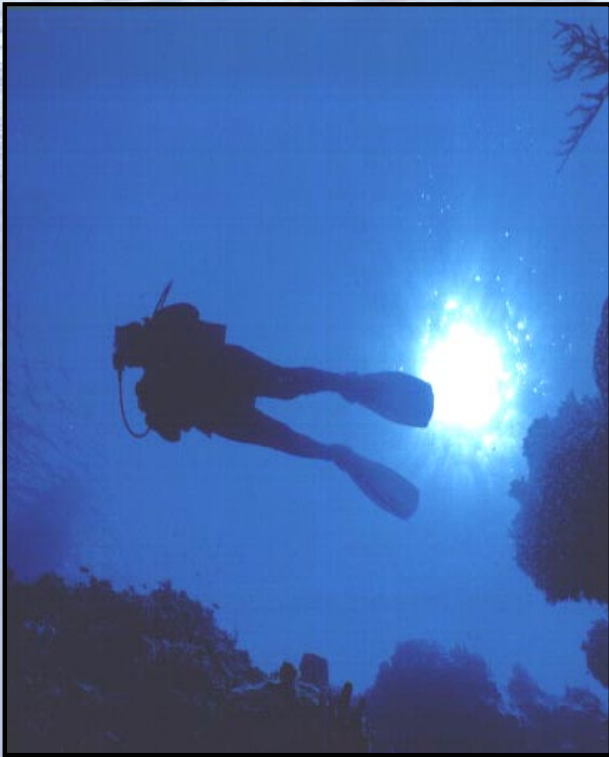


Photo by Jan Neal

- ✓ **Human Response to PO_2**
- ✓ **Average RMV and VO_2 Rates**
- ✓ **Metabolic O_2 Consumption**
- ✓ **Personal Limitations**
- ✓ **Environmental Considerations**
- ✓ **Physiological Problems**

SECTION 4 TOPICS

- ✓ **Time Terminology**
- ✓ **Descent / Ascent Rates**
- ✓ **Dive Planning**
- ✓ **Imperial Calculations**
- ✓ **Trimix Diver Plan**
- ✓ **Trimix Team Plan**
- ✓ **Metric Calculations**
- ✓ **Gas Utilization Charts**
- ✓ **Contingency Plans**
- ✓ **ABCs**
- ✓ **Air No-Stop Limits**
- ✓ **RGBM Trimix NDLs**
- ✓ **Helitrox NDLs**
- ✓ **ASCEND Safely**

TIME TERMINOLOGY

- 🕒 **Descent Time**
- 🕒 **Ascent Time**
- 🕒 **Stop Time**
- 🕒 **Deco Time**
- 🕒 **Run Time**
- 🕒 **Total Time**
- 🕒 **Surface Interval Time**

DESCENT / ASCENT RATES

- ❖ **Too fast or too slow a descent rate**
- ❖ **Too fast or too slow an ascent rate**
- ❖ **Ascent rate between stops**
- ❖ **Delays in the descent or ascent**

DIVE PLANNING

- ◆ **Trimix Diver Plan**
- ◆ **Equivalent Narcotic Depth**
- ◆ **CNS and Pulmonary O₂ Exposures**
- ◆ **Deco schedule and contingency plan**
- ◆ **Gas requirements and gas management rules**
- ◆ **Label MOD for each mix with depth units**
- ◆ **Establish objectives**
- ◆ **Trimix Team Plan**
- ◆ **Communications (diver-diver, diver-surface)**

IMPERIAL CALCULATIONS

- * **END (NED) = $[(FN_2 \div 0.79) \times (\text{Depth} + 33 \text{ fsw})] - 33 \text{ fsw}$**
- * **AED = $[(FO_2 + FN_2) \times (\text{Depth} + 33 \text{ fsw})] - 33 \text{ fsw}$**
- * **$FN_2 = [(\text{END} + 33 \text{ fsw}) \div (\text{Depth} + 33 \text{ fsw})] \times 0.79$**
- * **$P_g = F_g \times P \text{ ata}$ and **MOD = $PO_2 \div FO_2$****
- * **%CNS Exposure = $(\text{exp. time} \div \text{time limit}) \times 100\%$**
- * **OTU Totals = $(\text{exp. min.s} \times \text{OTU per min})$**
- * **SCR pressure = $(\text{pressure} \div \text{minutes}) \div P \text{ ata}$**
- * **SCR volume = $(\text{rated vol.} \div \text{rated psi}) \times \text{SCR psi}$**
- * **Cylinder Time = $(\text{cyl. vol.} \div \text{SCR vol.}) \div P \text{ ata}$**
- * **Thirds Turn Pressure = $\text{cyl. psi} - (\text{rounded cyl. psi} \div 3)$**
- * **Thirds Supply Capacity = $(\text{planned use} \div 2) \times 3$**

TRIMIX DIVER PLAN

DIVER _____ DATE _____

SITE _____ TYPE OF DIVE _____

RESTING SCR _____ WORKING SCR _____ RMV _____ B. GAS TURN PSI _____ RULE _____

MAX. DEPTH _____ SCHED. DEPTH _____ BOTTOM TIME _____ TOTAL RUN TIME _____

B. MIX O2% _____ He % _____ N2% _____ CF _____ PSI _____ D MIN _____ D MAX _____

DECO MIX 1 O2% _____ He % _____ N2% _____ CF _____ PSI _____ D SWITCH _____ MOD _____

DECO MIX 2 O2% _____ He % _____ N2% _____ CF _____ PSI _____ D SWITCH _____ MOD _____

FSW	ATA	FO2	PO2	STOP TIME	%CNS	OTU	CF GAS	RUN TIME
10	1.3							
20	1.6							
30	1.9							
40	2.2							
50	2.5							
60	2.8							
70	3.1							
80	3.4							
90	3.7							
100	4.0							
110	4.3							
120	4.6							
130	4.9							
140	5.2							
150	5.5							
160	5.8							
170	6.1							
180	6.4							
190	6.7							
200	7.0							
TOTALS								

GEAR CK SCHEDULE CK BUDDY GEAR CK BUDDY SCHEDULE CK

DIVER SIGNATURE _____

BUDDY VERIFICATION _____

TRIMIX DIVER PLAN

DIVER Jane D. DATE dd/mm/yy

SITE Atlantic Ocean

TYPE OF DIVE Wall Dive

REST SCR 0.3 cf/m

WORK SCR 0.7 cf/m

AVG. RMV 0.6 cf/m

TURN PSI 1800 RULE thirds

MAX. DEPTH 240 fsw

SCHED. DEPTH 240 fsw

BOTTOM TIME 20 mins

TOTAL RUN TIME 103 mins

B. MIX O2% 14

He% 33 N2% 53

CF 200

PSI 2400 D MIN 5 fsw D MAX 306 fsw

DECO MIX 1 O2% 17

He% 26 N2% 57

CF 50

PSI 3000 D SWITCH 100 fsw MOD 247 fsw

DECO MIX 2 O2% 80

He% 0 N2% 20

CF 40

PSI 3000 D SWITCH 30 fsw MOD 30 fsw

DESCENT				ASCENT						
FSW	ATA	FO2	PO2	FO2	PO2	STOP TIME	CNS %	OTU	CF GAS	DECO RUN
10	1.3	0.17	-	0.80	1.04	24	8.0	24.00	9.36	88
20	1.6	0.14	-	0.80	1.28	13	7.2	19.24	6.24	63
30	1.9	0.14	-	0.80	1.52	8	6.7	14.24	4.56	49
40	2.2	0.14	-	0.17	-	13	-	-	8.58	40
50	2.5	0.14	-	0.17	-	8	-	-	6.00	26
60	2.8	0.14	-	0.17	-	5	-	-	4.20	17
70	3.1	0.14	-	0.17	-	2	-	-	1.86	11
80	3.4	0.14	-	0.17	0.58	2	0.28	00.54	1.81	8
90	3.7	0.14	-	0.17	0.63	2	0.28	00.54	2.22	5
100	4.0	0.14	0.56	0.17	0.68	2	0.35	00.94	2.40	2
110	4.3	0.14	0.60	0.17	0.73					
120	4.6	0.14	0.64	0.14	0.64					
130	4.9	0.14	0.69	0.14	0.69					
140	5.2	0.14	0.73	0.14	0.73					
150	5.5	0.14	0.77	0.14	0.77					
160	5.8	0.14	0.81	0.14	0.81					
170	6.1	0.14	0.85	0.14	0.85	4.2	1.18	3.49	15.37	
180	6.4	0.14	0.90	0.14	0.90					
240	8.3	0.14	1.16	0.14	1.16	20	9.6	26.40	116.20	
TOTALS						103.2	33.59	89.39	178.80	

GEAR CK

SCHEDULE CK

BUDDY GEAR CK

BUDDY SCHEDULE CK

DIVER SIGNATURE Jane Diver

BUDDY VERIFICATION Joe Instructor

TRIMIX TEAM PLAN

DATE _____

SITE _____

TYPE OF DIVE _____

ENTRY POINT _____

EXIT POINT _____

GEAR SCH

DIVER 1 _____ ROLL _____ B. GAS CF _____ TIME IN _____ OUT _____

DIVER 2 _____ ROLL _____ B. GAS CF _____ TIME IN _____ OUT _____

B. MIX:	O2% _____	He% _____	N2% _____	D MIN _____	D MAX _____
DECO MIX 1:	O2% _____	He% _____	N2% _____	D SWITCH _____	MOD _____
DECO MIX 2:	O2% _____	He% _____	N2% _____	D SWITCH _____	MOD _____

PLANNED MAX DEPTH _____ **FSW**
PLANNED BOT TIME _____ **MINS**

SCHEDULE DEPTH _____ **FSW**
TOTAL RUN TIME _____ **MINS**

10 FSW _____ MINS	90 FSW _____ MINS	170 FSW _____ MINS	NOTES
20 FSW _____ MINS	100 FSW _____ MINS	180 FSW _____ MINS	
30 FSW _____ MINS	110 FSW _____ MINS	190 FSW _____ MINS	
40 FSW _____ MINS	120 FSW _____ MINS	200 FSW _____ MINS	
50 FSW _____ MINS	130 FSW _____ MINS	_____ FSW _____ MINS	
60 FSW _____ MINS	140 FSW _____ MINS	_____ FSW _____ MINS	
70 FSW _____ MINS	150 FSW _____ MINS		
80 FSW _____ MINS	160 FSW _____ MINS		

COLOR/TYPE LIFT BAG

EMERGENCY SIGNAL

EMERGENCY CONTACT _____
DAN 1- (919) 684-4326

TRIMIX TEAM PLAN

DATE Today

TIME 10:00 AM

SITE Atlantic Ocean

TYPE OF DIVE Trimix Training Dive 2

ENTRY PT Mooring Buoy off Bow

EXIT PT Drift Deco with Lift Bag

GEAR TBL

DIVER 1 John I.

ROLL Instructor

B. GAS CF 240

TIME IN 10:00 am

OUT 10:58 am

DIVER 2 Jane D.

ROLL Student

B. GAS CF 240

TIME IN 10:00 am

OUT 10:58 am

B. MIX: O2 % 16 He % 24

N2 % 60

D MIN sea level

D MAX 297 fsw

DECO MIX 1: O2 % 21 He % 0

N2 % 79

D SWITCH 100 fsw

MOD 218 fsw

DECO MIX 2: O2 % 100 He % 0

N2 % 0

D SWITCH 20 fsw

MOD 20 fsw

PLANNED MAX DEPTH 170 FSW

SCHEDULE DEPTH 170 FSW

PLANNED BOT TIME 25 MINS

TOTAL RUN TIME 56 MINS

10 FSW 6 MINS

90 FSW 0 MINS

170 FSW 25 MINS

20 FSW 4 MINS

100 FSW 1 MINS

180 FSW MINS

30 FSW 5 MINS

110 FSW MINS

190 FSW MINS

40 FSW 3 MINS

120 FSW MINS

200 FSW MINS

50 FSW 3 MINS

130 FSW MINS

FSW MINS

60 FSW 1 MINS

140 FSW MINS

FSW MINS

70 FSW 1 MINS

150 FSW MINS

80 FSW 1 MINS

160 FSW MINS

NOTES:

RGBM Schedule

30 fpm descent/ascent

Deploy lift bag at 10:25 am

COLOR/TYPE LIFT BAG

50 lb yellow lift bag

EMERGENCY SIGNAL

4 ft red inflatable tube

EMERGENCY CONTACT Spouse's Name & Telephone No.

DAN HOTLINE 1-919-684-4326

METRIC CALCULATIONS

* **END (NED) = $[(FN_2 \div 0.79) \times (\text{Depth} + 10 \text{ msw})] - 10 \text{ msw}$**

* **AED = $[(FO_2 + FN_2) \times (\text{Depth} + 10 \text{ msw})] - 10 \text{ msw}$**

* **$FN_2 = [(\text{END} + 10 \text{ msw}) \div (\text{Depth} + 10 \text{ msw})] \times 0.79$**

* **$P_g = F_g \times \text{bar}$ and $\text{MOD} = PO_2 \div FO_2$**

* **%CNS Exposure = $(\text{exp. time} \div \text{time limit}) \times 100\%$**

* **OTU Totals = $(\text{exp. min.s} \times \text{OTU per min})$**

* **SCR pressure = $(\text{pressure} \div \text{minutes}) \div \text{bar}$**

* **SCR volume = $(\text{cyl. vol.} \div \text{cyl. pres.}) \times \text{SCR pres.}$**

* **Cylinder Time = $(\text{cyl. vol.} \div \text{SCR vol.}) \div \text{bar}$**

* **Thirds Pressure = $\text{cyl. pres.} - (\text{rounded cyl. pres.} \div 3)$**

* **Thirds Supply Capacity = $(\text{planned use} \div 2) \times 3$**

TRIMIX DIVER PLAN

DIVER _____ DATE _____

SITE _____ TYPE OF DIVE _____
 RESTING SCR _____ WORKING SCR _____ RMV _____ B. GAS TURN BAR _____ RULE _____
 MAX. DEPTH _____ SCHED. DEPTH _____ BOTTOM TIME _____ TOTAL RUN TIME _____
 B. MIX O2% _____ He % _____ N2% _____ L _____ BAR _____ D MIN _____ D MAX _____
 DECO MIX 1 O2% _____ He % _____ N2% _____ L _____ BAR _____ D SWITCH _____ MOD _____
 DECO MIX 2 O2% _____ He % _____ N2% _____ L _____ BAR _____ D SWITCH _____ MOD _____

MSW	BAR	FO2	PO2	STOP TIME	%CNS	OTU	L GAS	RUN TIME
3	1.3							
6	1.6							
9	1.9							
12	2.2							
15	2.5							
18	2.8							
21	3.1							
24	3.4							
27	3.7							
30	4.0							
33	4.3							
36	4.6							
39	4.9							
42	5.2							
45	5.5							
48	5.8							
51	6.1							
54	6.4							
57	6.7							
60	7.0							
TOTALS								

GEAR CK χ SCHEDULE CK χ BUDDY GEAR CK χ BUDDY SCHEDULE CK χ

DIVER SIGNATURE _____ BUDDY VERIFICATION _____

TRIMIX TEAM PLAN

DATE _____

SITE _____

TYPE OF DIVE _____

ENTRY POINT _____ EXIT POINT _____ GEAR \checkmark SCH \checkmark

DIVER 1 _____ ROLL _____ B. GAS L _____ TIME IN _____ OUT _____ χ χ

DIVER 2 _____ ROLL _____ B. GAS L _____ TIME IN _____ OUT _____ χ χ

B. MIX: O2% _____ He% _____ N2% _____ D MIN _____ D MAX _____
DECO MIX 1: O2% _____ He% _____ N2% _____ D SWITCH _____ MOD _____
DECO MIX 2: O2% _____ He% _____ N2% _____ D SWITCH _____ MOD _____

PLANNED MAX DEPTH _____ MSW
PLANNED BOT TIME _____ MINS

SCHEDULE DEPTH _____ MSW
TOTAL RUN TIME _____ MINS

3 MSW _____ MINS _____	27 MSW _____ MINS _____
6 MSW _____ MINS _____	30 MSW _____ MINS _____
9 MSW _____ MINS _____	33 MSW _____ MINS _____
12 MSW _____ MINS _____	36 MSW _____ MINS _____
15 MSW _____ MINS _____	39 MSW _____ MINS _____
18 MSW _____ MINS _____	42 MSW _____ MINS _____
21 MSW _____ MINS _____	45 MSW _____ MINS _____
24 MSW _____ MINS _____	48 MSW _____ MINS _____

51 MSW _____ MINS _____
54 MSW _____ MINS _____
57 MSW _____ MINS _____
60 MSW _____ MINS _____
MSW _____ MINS _____
MSW _____ MINS _____

NOTES

COLOR/TYPE LIFT BAG

EMERGENCY SIGNAL

EMERGENCY CONTACT _____
DAN 1-919-684-4326

SINGLE CYLINDERS GAS VOLUME UTILIZATION CHART

CYL PSIG	CYLINDER PRESSURES (PSIG)															
	4/5 CYL PSIG				3/4 CYL PSIG				2/3 CYL PSIG				1/2 CYL PSIG			
	3700	3400	3300	3200	3100	3000	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000
3600	3300	3200	3100	3000	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800
3500	3200	3100	3000	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700
3400	3100	3000	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600
3300	3000	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500
3200	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400
3100	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300
3000	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200
2900	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100
2800	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000
2700	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900
2600	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	
2500	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900		
2400	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	800		
2300	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	800			
2200	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	800				
2100	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	800	700				
2000	1700	1600	1500	1400	1300	1200	1100	1000	900	800	700					
1900	1600	1500	1400	1300	1200	1100	1000	900	800	700						
1800	1500	1400	1300	1200	1100	1000	900	800	700	600						
1700	1400	1300	1200	1100	1000	900	800	700	600							
1600	1300	1200	1100	1000	900	800	700	600								
1500	1200	1100	1000	900	800	700	600	500								
1400	1100	1000	900	800	700	600	500									
Rated ft ³	SINGLES GAS VOLUME (FT ³) USED (SEV)															
ST 131	15	20	25	30	35	40	45	50	55	60	65	69	74	79	84	89
ST 125	14	19	24	28	33	38	43	47	52	57	62	66	71	76	80	85
HP 120	10	14	17	21	24	27	31	34	38	41	45	48	51	55	58	62
HP 100	9	11	14	17	20	23	26	29	31	34	37	40	43	46	49	51
ST 104	12	16	20	24	28	32	35	39	43	47	51	55	59	63	67	71
ST 98	11	15	19	22	26	30	33	37	41	45	48	52	56	59	63	67
ST 95	11	14	18	22	25	29	32	36	40	43	47	50	54	58	61	65
AL 80	8	10	13	15	18	21	23	26	28	31	33	36	39	41	44	46
Single cylinder volumes.		Red values are nearest 1/3 rated capacity.										Copyright 1998, Underwater Dynamics, Inc.				

DOUBLE CYLINDERS GAS VOLUME UTILIZATION CHART

CYL PSIG	CYLINDER PRESSURE (PSIG)															
	4/5 CYL PSIG				3/4 CYL PSIG				2/3 CYL PSIG				1/2 CYL PSIG			
	3700	3400	3300	3200	3100	3000	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000
3600	3300	3200	3100	3000	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800
3500	3200	3100	3000	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700
3400	3100	3000	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600
3300	3000	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500
3200	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400
3100	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300
3000	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200
2900	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100
2800	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000
2700	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900
2600	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	
2500	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900		
2400	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	800		
2300	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	800			
2200	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	800				
2100	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	800	700				
2000	1700	1600	1500	1400	1300	1200	1100	1000	900	800	700					
1900	1600	1500	1400	1300	1200	1100	1000	900	800	700						
1800	1500	1400	1300	1200	1100	1000	900	800	700	600						
1700	1400	1300	1200	1100	1000	900	800	700	600							
1600	1300	1200	1100	1000	900	800	700	600								
1500	1200	1100	1000	900	800	700	600	500								
1400	1100	1000	900	800	700	600	500									
Rated ft ³	DOUBLES GAS VOLUME (FT ³) USED (SEV)															
ST 131	30	40	50	60	69	79	89	99	109	119	129	139	149	159	169	179
ST 125	28	38	47	57	66	76	85	95	104	114	123	133	142	152	161	170
HP 120	21	27	34	41	48	55	62	69	75	82	89	96	103	110	117	123
HP 100	17	23	29	34	40	46	51	57	63	69	74	80	86	91	97	103
ST 104	24	32	39	47	55	63	71	79	87	95	102	110	118	126	134	142
ST 98	22	30	37	45	52	59	67	74	82	89	97	104	111	119	126	134
ST 95	22	29	36	43	50	58	65	72	79	86	94	101	108	115	122	130
AL 80	15	21	26	31	36	41	46	51	56	62	67	72	77	82	87	92
Twin cylinder volumes.			Red values are nearest 1/3 rated capacity.										Copyright 1998, Underwater Dynamics, Inc.			

GAS VOLUME UTILIZATION CHART															
CYL (BAR)	CYLINDER PRESSURES (BAR)														
	3/4 CYL PRESSURE				2/3 CYL PRESSURE				1/2 CYL PRESSURE						
300	290	280	270	260	250	240	230	220	210	200	190	180	170	160	150
290	280	270	260	250	240	230	220	210	200	190	180	170	160	150	140
280	270	260	250	240	230	220	210	200	190	180	170	160	150	140	130
270	260	250	240	230	220	210	200	190	180	170	160	150	140	130	120
260	250	240	230	220	210	200	190	180	170	160	150	140	130	120	110
250	240	230	220	210	200	190	180	170	160	150	140	130	120	110	100
240	230	220	210	200	190	180	170	160	150	140	130	120	110	100	90
230	220	210	200	190	180	170	160	150	140	130	120	110	100	90	80
220	210	200	190	180	170	160	150	140	130	120	110	100	90	80	70
210	200	190	180	170	160	150	140	130	120	110	100	90	80	70	60
200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50
190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40
180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30
170	160	150	140	130	120	110	100	90	80	70	60	50	40	30	20
160	150	140	130	120	110	100	90	80	70	60	50	40	30	20	10
150	140	130	120	110	100	90	80	70	60	50	40	30	20	10	
140	130	120	110	100	90	80	70	60	50	40	30	20	10		
130	120	110	100	90	80	70	60	50	40	30	20	10			
120	110	100	90	80	70	60	50	40	30	20	10				
110	100	90	80	70	60	50	40	30	20	10					
100	90	80	70	60	50	40	30	20	10						
90	80	70	60	50	40	30	20	10							
80	70	60	50	40	30	20	10								
70	60	50	40	30	20	10									
60	50	40	30	20	10										
50	40	30	20	10											
Rated VOL	GAS VOLUME (LITERS) USED														
	SURFACE EQUIVALENCY VOLUMES (SEV)														
5400	180	360	540	720	900	1080	1260	1440	1620	1800	1980	2160	2340	2520	2700
4500	150	300	450	600	750	900	1050	1200	1350	1500	1650	1800	1950	2100	2250
3600	120	240	360	480	600	720	840	960	1080	1200	1320	1440	1560	1680	1800
3000	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500
2700	90	180	270	360	450	540	630	720	810	900	990	1080	1170	1260	1350
2400	80	160	240	320	400	480	560	640	720	800	880	960	1040	1120	1200
1800	60	120	180	240	300	360	420	480	540	600	660	720	780	840	900
600	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300

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CONTINGENCY PLANS

Abort on trimix or bailout gas if you are not beyond your NDL and use deco gas during safety stops.

For different depth and/or bottom time than planned, use the appropriate schedule and gases.

For lost deco gas, switch to the appropriate schedule for decompressing on back gas (bottom mix).

ABC'S...

Actual

Bailout

Crisis

Planned Gas

Abort Gas

Share Gas

Dive Plan

Abort Plan

Survival Plan

AIR NO-STOP LIMITS

Dive computer NDLs compared with USN table NDLs

	<u>USN/Haldane</u>	<u>ALADIN/ZH-L</u>	<u>VYPER/RGBM</u>
	min	min	min
100 fsw	25	17	17
110 fsw	20	14	13
120 fsw	15	12	10
130 fsw	10	10	9
140 fsw	10	9	7
150 fsw	5	8	6

RGBM TRIMIX NO-STOP LIMITS

TX 16/24/60

TX 16/33/51

TX 16/44/40

	min	min	min
100 fsw	10	9	8
150 fsw	7	6	5
200 fsw	6	5	4

RGBM TRIMIX NO-STOP LIMITS

TX 16/24/60

TX 16/33/51

TX 16/44/40

min

min

min

30 msw

10

9

8

45 msw

7

6

5

60 msw

6

5

4

HELITROX NO-STOP LIMITS

O₂ 26-30%, He 13-17%, N₂ 53-61%

DEPTH	END	RGBM	ZH-L
fsw	fsw	min	min
100	56-70	19	18
110	63-77	16	15
120	70-85	14	13
130	76-93	12	11
140	83-101	11	10
150	90-108	10	9

HELITROX NO-STOP LIMITS

O₂ 26-30%, He 13-17%, N₂ 53-61%

DEPTH	END	RGBM	ZH-L
msw	msw	min	min
30	17-21	19	18
33	19-24	16	15
36	21-26	14	13
39	23-28	12	11
42	25-30	11	10
45	27-33	10	9

ASCEND SAFELY

- ✓ **A**ccess your gauges and deco table
- ✓ **S**elect the correct deco schedule
- ✓ **C**onfirm and communicate your choice
- ✓ **E**xecute ascent, stops, gas switches
- ✓ **N**ote gas pressures, depth, time, partner
- ✓ **D**ecompress accurately

SECTION 4 ANALYZED



- ✓ Time Terminology
- ✓ Descent/Ascent Rates
- ✓ Dive Planning
- ✓ Imperial Calculations
- ✓ Trimix Diver/Team Planners
- ✓ Gas Utilization Charts
- ✓ Contingency Plans
- ✓ ABCs
- ✓ Air, Trimix, Helitrox NDLs
- ✓ ASCEND Safely

TRIMIX DIVER PLAN

DIVER NAUI TX Diver DATE dd / mm / yy
 SITE Atlantic Ocean TYPE OF DIVE Answer to No. 1
 REST SCR 0.4 cf/m WORK SCR 1.0 cf/m AVG. RMV 1.0 cf/m TURN PSI 2400 RULE Thirds
 MAX. DEPTH 170 fsw SCHED. DEPTH 170 fsw BOTTOM TIME 25 mins TOTAL RUN TIME 56 mins
 B. MIX O2% 16 He% 24 N2% 60 CF 240 PSI 3500 D MIN sea level D MAX 297 fsw
 DECO MIX 1 O2% 21 He% 0 N2% 79 CF 30 PSI 3000 D SWITCH 100 fsw MOD 218 fsw
 DECO MIX 2 O2% 100 He% 0 N2% 0 CF 13 PSI 2500 D SWITCH 20 fsw MOD 20 fsw

FSW	DESCENT			ASCENT		STOP TIME	GAS USED			DECO RUN
	ATA	FO2	PO2	FO2	PO2 ata	mins	CNS %	OTU	Cu. Ft.	mins
10	1.3	0.16	0.2	1.00	1.3	6	3.36	8.88	3.12	33
20	1.6	0.16	0.3	1.00	1.6	4	8.88	7.68	2.56	26
30	1.9	0.16	0.3	0.21	0.4	5	-	-	3.80	21
40	2.2	0.16	0.4	0.21	0.5	3	-	-	2.64	15
50	2.5	0.16	0.4	0.21	0.5	3	-	-	3.00	11
60	2.8	0.16	0.5	0.21	0.6	1	0.14	0.27	1.12	7
70	3.1	0.16	0.5	0.21	0.7	1	0.18	0.47	1.24	5
80	3.4	0.16	0.5	0.21	0.7	1	0.18	0.47	1.36	3
90	3.7	0.16	0.6	0.21	0.8	0	-	-	-	
100	4.0	0.16	0.6	0.21	0.8	1	0.22	0.65	1.60	1
110	4.3	0.16	0.7	0.16	0.7					
120	4.6	0.16	0.7	0.16	0.7					
130	4.9	0.16	0.8	0.16						
140	5.2	0.16	0.8	0.16	0.8	2.3	0.51	1.49	11.96	
150	5.5	0.16	0.9	0.16						
160	5.8	0.16	0.9	0.16						
170	6.1	0.16	1.0	0.16	1.0	25	8.25	25.00	152.50	
TOTALS						52.3	24.96	44.91	184.90	

GEAR CK SCHEDULE CK BUDDY GEAR CK BUDDY SCHEDULE CK

DIVER SIGNATURE NAUI Trimix Diver BUDDY VERIFICATION NAUI Trimix Instructor or Partner

SECTION 5 TOPICS

- ✓ **Buoyancy Compensator**
- ✓ **Regulators**
- ✓ **Regulator Performance**
- ✓ **Cylinders**
- ✓ **Rigged Doubles**
- ✓ **Stage Cylinders**
- ✓ **Instruments**
- ✓ **Accessories**
- ✓ **Rigging Options**
- ✓ **Gear Checklist**
- ✓ **Pre-dive Checklist**

BUOYANCY COMPENSATOR

- ✓ **High Capacity BC**
- ✓ **Back-mounted Wings**
- ✓ **Redundant Bladder**
- ✓ **Retractable Bladders**
- ✓ **Deflator/Inflator Hose**
- ✓ **Dump Valves**
- ✓ **Power Inflator**
- ✓ **Nylon Harness**
- ✓ **Backplate**
- ✓ **D-Rings**
- ✓ **Buckles**
- ✓ **Crotch Strap**
- ✓ **Pocket**

REGULATORS

- ✓ **Class A Performance**
- ✓ **DIN Valve Connections**
- ✓ **Primary Second Stage**
- ✓ **Auxiliary Second Stage**
- ✓ **Spare O-rings and Parts**

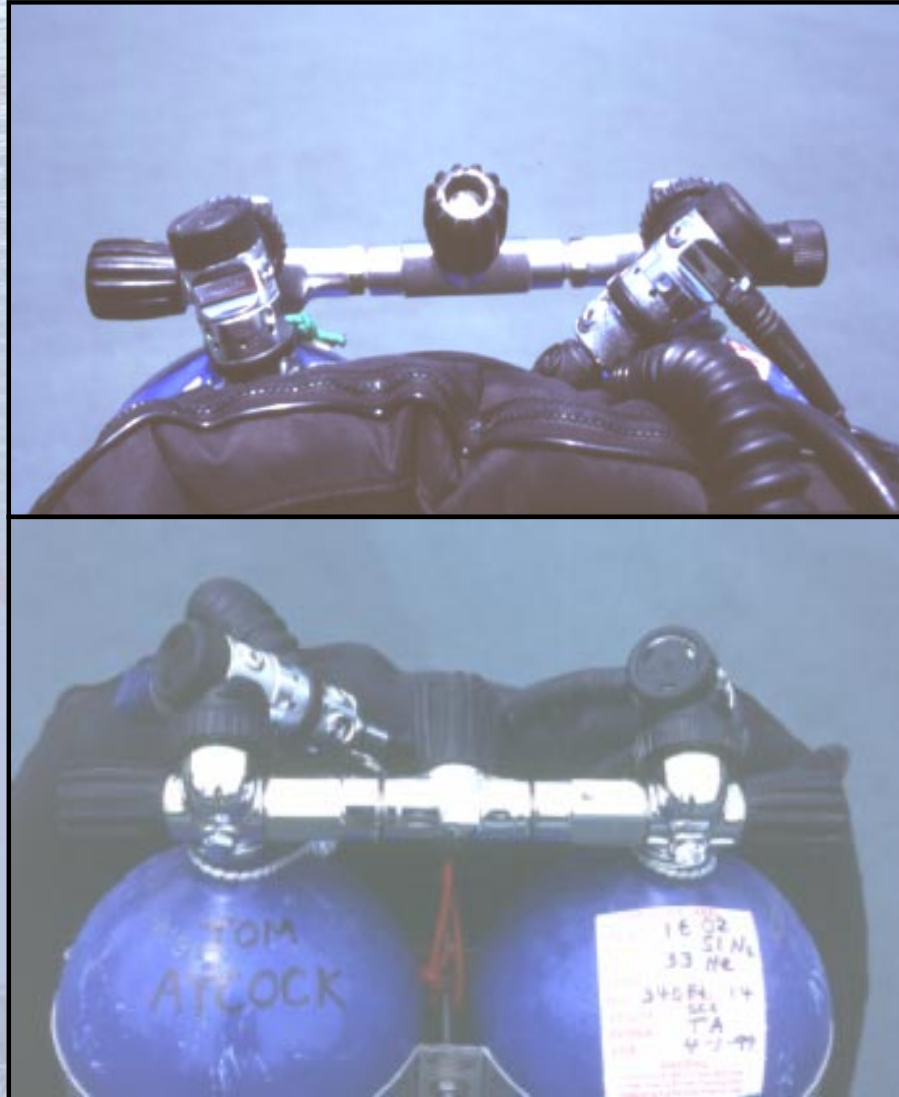
SCUBA REGULATOR PERFORMANCE CRITERIA

VO₂ (L/min)	RMV (L/min)	V_T (L)	BPM	ΔP (kPa)	kPa (J/L)
0.90	22.5	1.5	15	0.147	0.231
1.60	40.0	2.0	20	0.393	0.617
2.50	62.5	2.5	25	0.982	1.542
3.00	75.0	2.5	30	1.375	2.159

CYLINDERS

- ✓ **Sufficient Capacity Cylinders**
- ✓ **Weight and Buoyancy Characteristics**
- ✓ **Dual Outlet Valve / Isolation Manifold**
- ✓ **DIN Valves**
- ✓ **Handwheels**

RIGGED DOUBLES



STAGE CYLINDERS



- ❑ **Soft mounted metal snaps and backup**
- ❑ **Carrying strap next to side**
- ❑ **Barrier under & over hose clamps**
- ❑ **Hot gas on left side, bagged second stage, system closed & pressurized, hose looped along top side - under arm**
- ❑ **Travel gas on right side, unhindered second stage, valve open 1/2 turn, hose looped along outside - away from body**
- ❑ **MOD labels on cylinder crown and horizontally along side**

INSTRUMENTS

- III **Depth Gauges**
- III **Pressure Gauges**
- III **Timing Devices**
- III **Dive Computers**

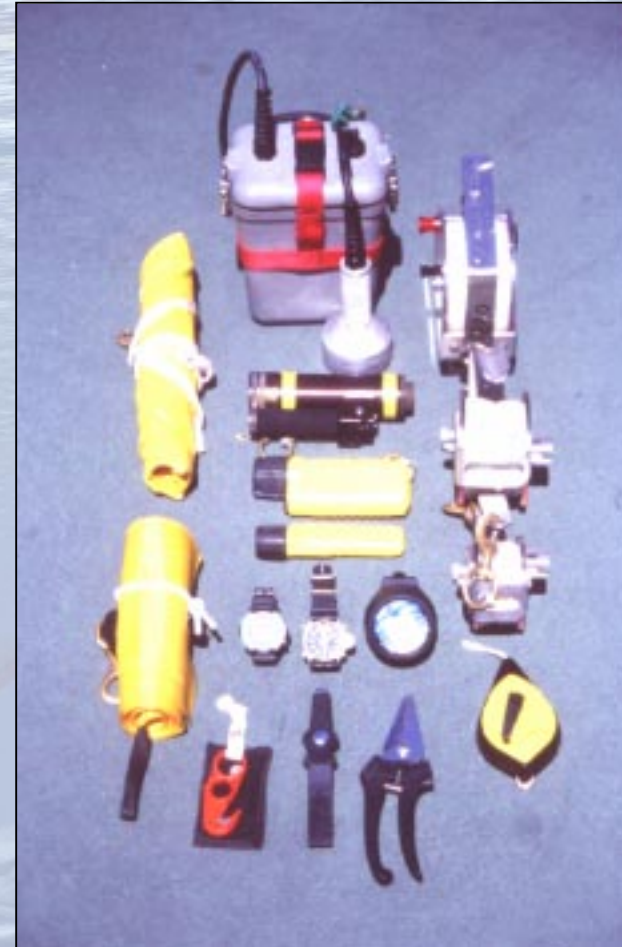
Reliability

Readability

Redundancy

ACCESSORIES

- f* **Mask**
- f* **Fins**
- f* **Thermal Protection**
- f* **Lights**
- f* **Lift Bags**
- f* **Line Reels**
- f* **Cutting Devices**
- f* **Slate(s) and Pencil**
- f* **Tools, O-rings, Parts**
- f* **Line, Snaps, Cable Ties**



RIGGING OPTIONS



GEAR CHECKLIST

- ☑ Valves open and unobstructed, isolator open at least 2 full turns
- ☑ Short hose regulator on left outlet and long hose on right outlet
- ☑ Long second stage hose routed for use and/or to extend quickly
- ☑ Hoses from each regulator are not intertwined
- ☑ Neck straps on second stage mouthpieces (brass snap on short hose)
- ☑ BC secured to backplate and inflated
- ☑ Primary inflator secured in front and backup secured for easy access
- ☑ SPG secured within view and/or to an accessible D-ring
- ☑ Primary light (with snap to clip to D-ring when not used)
- ☑ Red gauge light attached to mask strap or a BC shoulder strap
- ☑ Lift bag held in place by rubber bands on cylinder or backplate
- ☑ Line reels attached to hip D-ring
- ☑ Depth and time monitors and deco schedule on arm, slate in pocket

PREDIVE CHECKLIST

- ❑ **Dirt dive (check placement-confirm access)**
- ❑ **Buoyancy check (weighting and trim)**
- ❑ **Equipment check (functioning & no leaks)**
- ❑ **Safety drill (gas sharing procedure)**
- ❑ **Turn pressure (gas management rule)**
- ❑ **Review signals, skills and dive plan**
- ❑ **Synchronize watches**
- ❑ **Mark time of descent**

SECTION 5 REVIEWED



- ✓ **Buoyancy Compensator**
- ✓ **Regulators**
- ✓ **Regulator Performance**
- ✓ **Cylinders**
- ✓ **Rigged Doubles**
- ✓ **Stage Cylinders**
- ✓ **Instruments**
- ✓ **Accessories**
- ✓ **Rigging Options**
- ✓ **Gear Checklist**
- ✓ **Pre-dive Checklist**

SECTION 6 TOPICS

- ✓ **Team Members**
- ✓ **Players**
- ✓ **Surface Support Team**
- ✓ **Agency Protocols**
- ✓ **Accident Analysis**
- ✓ **Rescue Responses**
- ✓ **Emergency Responses**
- ✓ **Omitted Decompression**
- ✓ **DCS Signs & Symptoms**
- ✓ **Neurological DCS**
- ✓ **Desktop Decompression**
- ✓ **Skills and Techniques**
- ✓ **Technical Diving Symbols**

TEAM MEMBERS SHOULD HAVE SIMILAR...

- * **Abilities**
- * **Experience**
- * **Objectives**
- * **Gas**
- * **Gear**
- * **Getup**

THE PLAYERS

- ♥ **Boat Captain**
- ♣ **First Mate**
- ♦ **Team Leader**
- ♠ **Dive Leader**
- ♠ **Crew Members**
- ♥ **Team Members**
- ♣ **Subordinates**
- ♦ **Observers**
- ♦ **Buddy System**

SURFACE SUPPORT TEAM

- ✓ **Qualified Topside Personnel**
- ✓ **Qualified Rescue Divers**
- ✓ **Sufficient Gear and Gas**
- ✓ **Sufficient First Aid Supplies and Medical O₂**
- ✓ **Communications Equipment**
- ✓ **Written Emergency Plan**
- ✓ **Trimix Diver Plans**
- ✓ **Trimix Team Plan**

AGENCY PROTOCOLS

o **Boat**

∩ **Dive Site**

H **Local**

X **County**

Σ **State**

Γ **Federal**

Certification Agency

ACCIDENT ANALYSIS

- © **Accident Analysis**
- © **Common Crises**
- © **Potential Problems**
- © **Solution Scenarios**

RESCUE RESPONSES

Anxiety

Buoyancy Problems

Confusion

Cramps

DCS

Dehydration

Embolism

Endangerment

Entanglement

Fatigue

Fear

Gas Depletion

Gear Malfunction

Hypo-/Hyperthermia

Injury

Lost

Narcosis

Missing Diver

EMERGENCY RESPONSES

- ⇒ **BC Malfunction**
- ⇒ **Buddy Problems**
- ⇒ **Gas Loss**
- ⇒ **Lost Line**
- ⇒ **Lost Visibility**
- ⇒ **Marine Hazards**
- ⇒ **Panic**
- ⇒ **Regulator Failure**
- ⇒ **Seizure**
- ⇒ **Stress**
- ⇒ **Unconsciousness**
- ⇒ **Wrong/Missed Gas Switch**
- ⇒ **Wrong/Missed Deco Stop**

OMITTED DECOMPRESSION

- ✓ **Omitted Decompression Procedure**
- ✓ **Surface-Decompression (Sur-D-O₂)**
- ✓ **In-Water-Recompression (IWR)**
- ✓ **Surface Oxygen**
- ✓ **Emergency Medical Response**
- ✓ **AAUS and DAN Recommendations**

DCS SIGNS AND SYMPTOMS

- ✓ **Difficulty Breathing**
- ✓ **Pain**
- ✓ **Extreme Fatigue**
- ✓ **Headache**
- ✓ **Nausea**
- ✓ **Itching**
- ✓ **Rash**
- ✓ **Restlessness**
- ✓ **Muscle Twitch**
- ✓ **Bloody Sputum**
- ✓ **Hearing Loss**
- ✓ **Ringing in Ears**
- ✓ **Stiffness**
- ✓ **Hot/Cold Flashes**
- ✓ **Cramps**
- ✓ **Swelling**
- ✓ **Pressure Sensation**
- ✓ **Muscle Ache/Soreness**
- ✓ **Skin Discoloration**
- ✓ **Unequal/Nonreactive Pupils**

NEUROLOGICAL DCS

SEVERE

- ✓ **Convulsions**
- ✓ **Paralysis**
- ✓ **Unconsciousness**
- ✓ **Semi-consciousness**
- ✓ **Visual Disturbance**
- ✓ **Speech Disturbance**
- ✓ **Difficulty Walking**
- ✓ **Bladder Problem**
- ✓ **Bowel Problem**

MILD

- ✓ **Numbness**
- ✓ **Dizziness**
- ✓ **Burning Skin Sensation**
- ✓ **Decreased Skin Sensation**
- ✓ **Personality Change**
- ✓ **Reflex Changes**
- ✓ **Weakness**

DESKTOP DECO SOFTWARE

- ✓ **Select reliable commercially available programs**
- ✓ **Register and use licensed software**
- ✓ **Read written operating instructions**
- ✓ **Take advantage of learning tutorials**
- ✓ **Talk to technical support**
- ✓ **Input realistic personal parameters**
- ✓ **Choose conservative profiles**
- ✓ **Stay abreast of updated changes and versions**

SKILLS & TECHNIQUES

Dive Planning

Gas Analysis

Gear Staging

Gear Check

Streamlining/Trim

Entries/Exits

Depth Control

Descents/Ascents

Don/Doff Gear

Communications

Buoyancy

Kicking

Check-stop

Navigation


















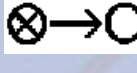

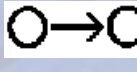




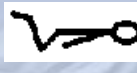




Light Management

Reel Use

Lift Bag Deployment

Emergency Procedures

Drinking/Eating/Eliminating

	ABORT		REEL JAM		BUBBLE CHECK
	LIGHTS		LOST REEL		TURN PRESSURE
	ATTENTION		LIFT BAG & REEL		HALVES TURN PSI
	COME QUICK		JON-LINE		THIRDS TURN PSI
	LIGHT FAILURE		TABLES		REMOVE STAGE CYL
	DECO CEILING		SLATE / LOG		PRIMARY REG FAILURE
	DECO ERROR		MISSING DIVER		OUT OF GAS
	MASK BLACKOUT		NARCOSIS CHECK		SWITCH REG
	NOT OK		DANGER / WARNING		SWITCH GAS
	OK / OK?		WATCH / TIME		UNCONSCIOUS-TOW
	OPEN		ASCENDING FAST		FEET UP / TRIM
	CLOSE		ASCENDING SLOW		CONTACT / HOOKUP
	ON LINE		STOP		CATASTROPHIC GAS LOSS

IN CONCLUSION,
JUST DO IT RIGHT...



**CHECK
EVERYTHING
and DON'T
ASSUME
ANYTHING!**

IF YOU MUST ASSUME
ANYTHING, *ASSUME...*

*A*cademic Achievement

*S*elf-Sufficiency

*S*urvival Skills

*U*nity Underwater

*M*ature Motivation

*E*xperienced Expertise

SECTION 6 COVERED



- ✓ **Team Members**
- ✓ **Players**
- ✓ **Surface Support Team**
- ✓ **Agency Protocols**
- ✓ **Accident Analysis**
- ✓ **Rescue Responses**
- ✓ **Emergency Responses**
- ✓ **Omitted Decompression**
- ✓ **DCS Signs & Symptoms**
- ✓ **Neurological DCS**
- ✓ **Desktop Decompression**
- ✓ **Skills and Techniques**
- ✓ **Technical Diving Symbols**

NAUI RGBM TRIMIX TABLES

Ranged Trimix Tables for 16% oxygen and 24% to 40% helium for maximum depths from 240 fsw to 90 fsw (73 - 27 m), with a switch on ascent to pure oxygen at 20 fsw (6 m) to the surface. The max ascent rate is 33 fsw/min (10 m/min) and the max descent rate is 75 fsw/min (23 m/min). Minimal repetitive interval is 3 hours for 2 dives only, the minimal flying interval is 24 hours after 1 dive and 36 hours after 2 dives. For repetitive dives, use the next deeper and longer schedule than the maximum repetitive dive depth and bottom time.

WARNING: Do not use these tables without proper instruction in their use and trimix certification or supervision by a NAUI Trimix Instructor.

Mild conservatism is built into the model parameters and full-blown RGBM is used for calculations, yielding deeper stops but shorter overall deco times as compared to Haldane staging. The critical radius, r_c , ranges from 0.65 (liberal) to roughly 0.77 (conservative) micrometers, which tags bubble size excited into growth, and replaces Haldane critical tensions (M-values) in staging divers.

NAUI RGBM TRIMIX TABLES

TX 16% O2 / 24 - 40% He / 44 - 60% N2						
fsw	O2 from 20 fsw up to sea level					
10	16	13	10	8	6	2
20	9	8	6	4	2	1
30	19	13	11	9	4	1
40	10	10	8	4	3	1
50	9	8	5	4	2	
60	8	4	4	3	2	
70	5	5	4	3	2	
80	4	3	3	2	1	
90	4	3	2	2	1	
100	3	2	2	1	1	
110	2	2	2	1	1	
120	2	2	1	1	1	
130	2	1	1	1	1	
140	1	1	1	1	1	
150	1	1	1	1		
160	1	1	1			
170	1	1				
180						
190						
200						
210						
220						
230						
240	30	25	20	15	10	5
Max descent 75 fpm / max ascent 33 fpm						
Copyright 1999 NAUI Worldwide						

TX 16% O2 / 24 - 40% He / 44 - 60% N2						
fsw	O2 from 20 fsw up to sea level					
10	15	12	9	7	5	1
20	9	8	6	4	2	1
30	18	12	10	8	4	1
40	10	10	8	4	3	1
50	9	8	5	4	2	
60	8	4	4	3	2	
70	4	5	4	2	1	
80	4	3	2	2	1	
90	4	3	2	2	1	
100	3	2	2	1	1	
110	2	2	2	1	1	
120	2	2	1	1	1	
130	1	1	1	1	1	
140	1	1	1	1		
150	1	1	1			
160	1	1				
170						
180						
190						
200						
210						
220						
230	30	25	20	15	10	5
Max descent 75 fpm / max ascent 33 fpm						
Copyright 1999 NAUI Worldwide						

NAUI RGBM TRIMIX TABLES

TX 16% O2 / 24 - 40% He / 44 - 60% N2						
fsw	O2 from 20 fsw up to sea level					
10	15	12	10	6	4	1
20	8	8	5	4	2	1
30	17	11	10	7	4	1
40	10	9	7	5	2	1
50	9	8	5	4	2	
60	7	4	4	2	1	
70	4	4	3	2	1	
80	4	4	2	2	1	
90	4	2	2	1	1	
100	2	2	2	1	1	
110	2	2	1	1	1	
120	2	2	1	1	1	
130	1	1	1	1		
140	1	1	1	1		
150	1	1				
160						
170						
180						
190						
200						
210						
220	30	25	20	15	10	5
Max descent 75 fpm / max ascent 33 fpm						
Copyright 1999 NAUI Worldwide						

TX 16% O2 / 24 - 40% He / 44 - 60% N2						
fsw	O2 from 20 fsw up to sea level					
10	14	11	10	5	4	1
20	8	8	4	4	2	1
30	15	10	10	6	4	1
40	10	10	6	4	2	
50	9	6	5	4	2	
60	6	4	4	2	2	
70	4	4	3	2	1	
80	4	4	2	2	1	
90	3	2	1	1	1	
100	2	1	2	1	1	
110	2	2	1	1	1	
120	2	1	1	1		
130	1	1	1	1		
140	1	1	1			
150						
160						
170						
180						
190						
200						
210	30	25	20	15	10	5
Max descent 75 fpm / max ascent 33 fpm						
Copyright 1999 NAUI Worldwide						

NAUI RGBM TRIMIX TABLES

TX 16% O2 / 24 - 40% He / 44 - 60% N2						
fsw	O2 from 20 fsw up to sea level					
10	13	10	10	5	5	1
20	9	7	6	4	3	
30	13	11	11	5	6	
40	10	9	8	4	4	
50	8	5	6	3	2	
60	5	4	4	2	3	
70	4	4	4	2	1	
80	4	2	2	1	1	
90	3	2	2	1	1	
100	2	2	2	1	1	
110	1	1	1	1	1	
120	2	1	1	1	1	
130	1	1	1	1	1	
140	1	1	1			
150						
160						
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Copyright 1999 NAUI Worldwide						

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10	13	10	9	4	4	1
20	8	6	4	4	3	
30	11	10	9	5	6	
40	10	9	4	4	3	
50	7	4	5	2	3	
60	5	5	3	2	2	
70	4	3	2	2	2	
80	3	2	2	1	1	
90	2	2	1	1	1	
100	2	2	1	1	1	
110	1	1	1	1	1	
120	1	1	1	1	1	
130	1	1	1	1	1	
140						
150						
160						
170						
180						
190	30	25	20	15	10	5
Max descent 75 fpm / max 33 fpm						
Copyright 1999 NAUI Worldwide						

NAUI RGBM TRIMIX TABLES

TX 16% O2 / 24 - 40% He / 44 - 60% N2

fsw	O2 from 20 fsw up to sea level					
10	11	9	8	5	2	1
20	8	6	4	3	2	
30	11	10	8	4	2	
40	9	8	5	4	1	
50	6	4	4	2	1	
60	5	4	2	2	1	
70	4	3	2	1	1	
80	2	2	2	1	1	
90	2	2	1	1		
100	2	1	1	1		
110	1	1	1			
120	1	1				
130						
140						
150						
160						
170						
180	30	25	20	15	10	5
Max descent 75 fpm / max ascent 33 fpm						
Copyright 1999 NAUI Worldwide						

TX 16% O2 / 24 - 40% He / 44 - 60% N2

fsw	O2 from 20 fsw up to sea level							
10	15	15	10	9	6	5	2	1
20	9	9	7	5	4	4	2	
30	18	16	11	10	7	6	2	
40	10	12	9	6	4	6	1	
50	9	9	5	4	4	3	1	
60	6	5	4	4	2	2	1	
70	4	5	4	2	2	2	1	
80	4	3	2	2	1	2		
90	2	3	2	1	1	2		
100	2	2	1	1	1	1		
110	1	1	1	1				
120	1	1						
130								
140								
150								
160								
170	40	35	30	25	20	15	10	5
Max descent 75 fpm / max ascent 33 fpm								
Copyright 1999 NAUI Worldwide								

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20	9	9	6	4	4	2	1	
30	15	14	10	10	5	4	2	
40	11	11	8	5	4	2	1	
50	8	8	5	4	3	2	1	
60	5	5	4	3	2	1	1	
70	4	5	3	2	2	1		
80	3	3	2	2	1	1		
90	2	2	2	1	1			
100	1	2	1	1				
110	1	1						
120								
130								
140								
150								
160	40	35	30	25	20	15	10	5
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Copyright 1999 NAUI Worldwide								

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20	9	7	6	4	4	2	1	
30	12	11	10	8	5	3	2	
40	10	9	7	5	4	2	1	
50	7	5	4	4	2	2	1	
60	5	4	4	2	2	1		
70	4	3	2	2	2	1		
80	2	2	2	1	1			
90	2	1	1	1	1			
100	1	1	1					
110								
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NAUI RGBM TRIMIX TABLES

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20	8	6	5	4	3	2	1	
30	11	11	10	7	5	3	1	
40	10	8	5	5	3	2		
50	5	5	4	3	2	1		
60	5	4	3	2	2	1		
70	3	2	2	2	1			
80	2	2	1	1				
90	1	1	1					
100								
110								
120								
130								
140	40	35	30	25	20	15	10	5
Max descent 75 fpm / max ascent 33 fpm								
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TX 16% O2 / 24 - 40% He / 44 - 60% N2

fsw	O2 from 20 fsw up to sea level							
10	12	10	9	6	5	3	1	0
20	7	6	4	4	3	2	1	
30	11	10	9	5	4	2		
40	8	6	5	4	3	2		
50	5	5	4	2	1	1		
60	4	3	2	2	1			
70	3	2	1	1	1			
80	1	1	1					
90								
100								
110								
120								
130	40	35	30	25	20	15	10	5
Max descent 75 fpm / max ascent 33 fpm								
Copyright 1999 NAUI Worldwide								

NAUI RGBM TRIMIX TABLES

TX 16% O ₂ / 24 - 40% He / 44 - 60% N ₂										
fsw	O ₂ from 20 fsw up to sea level									
10	13	13	10	10	8	4	5	2	1	0
20	9	7	6	4	4	4	2	2	1	
30	12	12	11	10	7	5	3	2		
40	10	8	6	5	5	3	2	1		
50	5	5	5	4	2	2	2			
60	5	4	2	2	2	1				
70	2	2	2	1	1					
80										
90										
100										
110										
120	50	45	40	35	30	25	20	15	10	5
Max descent 75 fpm / max ascent 33 fpm										
Copyright 1999 NAUI Worldwide										

TX 16% O ₂ / 24 - 40% He / 44 - 60% N ₂										
fsw	O ₂ from 20 fsw up to sea level									
10	12	11	10	9	6	5	4	2	1	
20	8	6	5	4	4	3	2	1		
30	12	11	10	8	5	4	3	1		
40	8	6	5	5	3	3	1			
50	5	5	4	2	2	1				
60	2	2	2	2	1					
70	1									
80										
90										
100										
110	50	45	40	35	30	25	20	15	10	
Max descent 75 fpm / max ascent 33 fpm										
Copyright 1999 NAUI Worldwide										

NAUI RGBM TRIMIX TABLES

TX 16% O2 / 24 - 40% He / 44 - 60% N2

fsw	O2 from 20 fsw up to sea level								
10	11	10	9	7	4	5	3	2	0
20	6	5	5	4	4	2	2	2	
30	11	10	7	5	4	4	1		
40	6	5	5	4	3	1			
50	3	2	2	1					
60	1	1							
70									
80									
90									
100	50	45	40	35	30	25	20	15	10

Max descent 75 fpm / max ascent 33 fpm

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TX 16% O2 / 24 - 40% He / 44 - 60% N2

fsw	O2 from 20 fsw up to sea level								
10	10	9	8	5	4	4	3	3	0
20	5	5	4	4	3	2	2		
30	9	7	5	4	4	1			
40	4	3	3	1					
50	1	1							
60									
70									
80									
90	50	45	40	35	30	25	20	15	10

Max descent 75 fpm / max ascent 33 fpm

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NAUI RGBM HELITROX TABLES

Ranged Helitrox Tables for 26% -30% oxygen and 13% - 17% helium for maximum depths from 150 fsw to 100 fsw (46 -30 m), with a switch on ascent to pure oxygen at 20 fsw (6 m) to the surface.

The maximum ascent rate is 33 fsw/min (10 m/min) and the maximum descent rate is 75 fsw/min (23 m/min). The minimal repetitive interval is 3 hours for 2 dives only. The minimal flying interval is 24 hours after 1 dive and 36 hours after 2 dives. For repetitive dives, use the next deeper and longer schedule than the maximum repetitive dive depth and bottom time.

WARNING: Do not use these tables without proper instruction in their use and trimix certification or supervision by a NAUI Trimix Instructor.

NAUI RGBM HELITROX TABLES

26 - 30% O2 / 13 - 17% He / 53 - 61% N2

fsw	O2 from 20 fsw up to sea level					
10	7	5	4	2	1	0
20	4	3	2	2		
30	6	4	3	1		
40	3	2	1	1		
50	2	2	1			
60	2	1	1			
70	1	1				
80						
90						
100						
110						
120						
130						
140						
150	30	25	20	15	10	5
Max descent 75 fpm / max ascent 33 fpm						

26 - 30% O2 / 13 - 17% He / 53 - 61% N2

fsw	O2 from 20 fsw up to sea level					
10	7	4	4	2	1	0
20	3	3	2	1		
30	5	3	2	1		
40	3	2	1			
50	2	1	1			
60	1	1				
70						
80						
90						
100						
110						
120						
130						
140	30	25	20	15	10	5
Max descent 75 fpm / max ascent 33 fpm						

NAUI RGBM HELITROX TABLES

26 - 30% O2 / 13 - 17% He / 53 - 61% N2

fsw	O2 from 20 fsw up to sea level					
10	6	3	4	2	0	0
20	3	3	1	1		
30	4	3	2			
40	2	1	1			
50	2	1				
60						
70						
80						
90						
100						
110						
120						
130	30	25	20	15	10	5
Max descent 75 fpm / max ascent 33 fpm						

26 - 30% O2 / 13 - 17% He / 53 - 61% N2

fsw	O2 from 20 fsw up to sea level						
10	8	7	5	4	3	1	0
20	4	3	3	2	1		
30	6	4	3	2	1		
40	3	3	2	1			
50	2	1					
60							
70							
80							
90							
100							
110							
120	40	35	30	25	20	15	10
Max descent 75 fpm / max ascent 33 fpm							

NAUI RGBM HELITROX TABLES

26 - 30% O2 / 13 - 17% He / 53 - 61% N2							
fsw	O2 from 20 fsw up to sea level						
10	7	6	3	3	2	1	0
20	3	3	3	2	2		
30	5	3	2	1			
40	2	2					
50							
60							
70							
80							
90							
100							
110	40	35	30	25	20	15	10
Max descent 75 fpm / max ascent 33 fpm							

26 - 30% O2 / 13 - 17% He / 53 - 61% N2							
fsw	O2 from 20 fsw up to sea level						
10	6	4	3	3	3	0	0
20	3	3	2	1			
30	3	1					
40							
50							
60							
70							
80							
90							
100	40	35	30	25	20	15	10
Max descent 75 fpm / max ascent 33 fpm							

CONVERSIONS

When $a = b$; $a/b = a$ and $b/a = b$

Pressure Conversions

1 atm = 1.013247 bar

1 atm = 33.08 fsw

1 atm = 10.13 msw

1 atm = 14.6959 psi

1 bar = 14.50377 psi

Weight Conversions

1 pound = 0.45354 kg

1 kilogram = 2.2046 lb

1 milligram = 0.001 gm

Distance Conversions

1 inch = 2.54 cm

1 foot = 0.3048 m

1 micrometer = 1μ

1 millimeter = 1000μ

Fluid Volume Conversions

1 in.³ = 0.01639 L

1 L = 61.025 in.³

1 ml = 0.001 L

Gas Volume Conversions

1 ft.³ = 0.02832 m³

1 ft.³ = 28.3 L

1 m³ = 35.314 ft.³

Parts Per Million Conversion to Percent

1 ppm = 0.0001%

Temperature Conversions

$^{\circ}\text{C} = (^{\circ}\text{F} - 32) \times (5 \div 9)$

$^{\circ}\text{F} = (^{\circ}\text{C} \times (9 \div 5)) + 32$

Scientific Notation

1234 = 1.234×10^3

0.001234 = 1.234×10^{-3}

TRIMIX TRAINING AFFIRMATION

_____ I affirm that the training objectives for this trimix course, such as written and oral assignments (dive planning, tests, etc.), in-water instruction (diving exercises and skill proficiencies, etc.) and other related course work required by The National Association of Underwater Instructors, Inc. (NAUI) and my instructor _____, have been satisfactorily met.

_____ I confirm I am comfortable and confident to conduct mixed gas scuba dives within the limits of my certification level, diving abilities and experience without supervision or assistance of a trimix scuba instructor.

_____ I understand and agree to adhere to the limitations established for my certification, including but not limited to maximum depth, dive time, equipment requirements and similar environmental conditions under which I received my instruction.

Signature _____ Date _____

Address _____ Phone _____

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NAUI Tri-Mix Instructor Guide

By Bruce Wienke, Ph.D., Jan Neal, and Tim O'Leary

Photos by Denise Morrissette

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Trimix Intro Pg 1

WARNING

This presentation is a training supplement which should only be implemented by a NAUI certified Mixed Gas Scuba Instructor. This material does not contain all there is to know about scuba diving and breathing gas mixtures containing helium (e. g. trimix, heliair, helitrox, and heliox) or nitrogen or oxygen. Mixed gas diving is an inherently dangerous activity and will always carry risk of personal injury or death even if all currently known safety guidelines, limits and training standards are followed. In fact, at the time of this publication there are no validated trimix decompression tables. Use or implementation of any information contained herein is the sole responsibility of the individual. Do not proceed if you do not understand this warning and accept the inherent risks of mixed gas diving.

Your signature below indicates you understand and accept that there are known and unknown hazards of mixed gas diving and you still wish to participate in this training and hereby agree to indemnify and hold harmless the authors, The National Association of Underwater Instructors, Inc. (NAUI), and your instructor for property damage, personal injury or death regardless of its cause.

Student Signature _____ Date _____

Trimix Intro Pg 2

This slide/page should not be omitted or removed from student training materials.

Read this warning out loud to your class. Have each student sign and date a photocopy of this page to indicate they understand and accept these conditions and still wish to participate in trimix training and keep it with their student records.

Inform students that they can get a refund of all monies they have paid for instruction, excluding any contractual deposits used to secure an instructor's time in advance or costs of materials the student wishes to retain, and allow them to leave before proceeding with the rest of this presentation if they decide not to continue with the course of training.

PREREQUISITES

- ✓ **Minimum age 21 years old**
- ✓ **Medical clearance & physically fit**
- ✓ **Decompression Techniques & Technical EANx Diver certification**
- ✓ **Minimum of 250 logged dives**
- ✓ **Minimum of 75 dives deeper than 130 ft. & 10 staged deco EANx dives**
- ✓ **Self sufficient & solo capabilities**



Trimix Intro Pg 3

Obtain a personal diving history from each trimix student. It should include their most recent to past diving and training experiences. Include dive totals within specific depth ranges, no-stop and staged decompression dives, and air, nitrox, and mixed gas dives and the types of environmental conditions, such as night, limited visibility, cavern, cave and so on. By this level in their diver education they should have had rescue training, CPR, first aid and emergency oxygen provider.

If you do not know the trimix candidate and they were not referred to you by a trusted source, you may want to ask them to provide a letter of recommendation from one of their technical instructors or an experienced trimix diver who has dived with them and is familiar with their abilities. You can also have potential students conduct a “check-out dive” with you so that you can assess their comfort level and performance of prerequisite skills, but be sure to have them complete the requisite forms beforehand.

Students are required to develop gear and skill familiarity in confined water before conducting training dives in deep water. This is especially important if students will be **training in unfamiliar scuba equipment** (e.g. doubles, dual regulators, stage cylinders, BC harness, etc). If they are **unfamiliar with the environmental conditions** they will be training under, it is advisable to keep initial training dives shallow until they are comfortable and experienced enough to progress to deeper depths. This is the impetus behind the NAUI standard, rev.1-98, page 2.145, which states, “Each diver is to demonstrate switching and isolating a malfunctioning regulator, first in confined water, and following adequate practice, at a depth between 33 fsw (10 msw) and 66 fsw (20 msw).” Likewise, it is advisable to practice staged decompression skills and gas switches in shallow water before conducting mandatory stops and gas switches during trimix training dives.

The goal is for a program of training that is successful from beginning to end, one that enables students to build on their skill accomplishments instead of having to overcome performance failures.

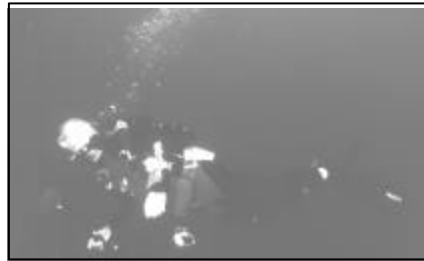
MINIMUM DIVE REQUIREMENTS

Level I Trimix

- ✓ Total of 6 dives
- ✓ 2 decompression dives
- ✓ 190 ft. < 2 dives < 225 ft.

Level II Trimix

- ✓ Level I plus 2 extra dives
- ✓ 225 ft. < 2 dives < 300 ft.



Trimix Intro Pg 4

The ratio of open water students to an active NAUI trimix instructor is 4 to 1. Assistants are recommended, but shall not increase the in-water student ratio.

There is no limiting ratio for academic training as long as the facility and student supplies are adequate.

Refer to the NAUI Standards and Policies Handbook, pages 2.142 to 2.146 in addition to Policies Applying to Technical Diver Training Courses, pages 2.121 to 2.123, revised 1997 and 1998.

SECTIONS

Do not proceed if you have not read and signed a copy of Slide 2.

Section 1.....	Slides	6 - 20
Section 2.....	Slides	21 - 44
Section 3.....	Slides	45 - 54
Section 4.....	Slides	55 - 79
Section 5.....	Slides	80 - 92
Section 6.....	Slides	93 - 109
NAUI RGBM Trimix Tables	Slides	110 - 118
NAUI RGBM Helitrox Tables	Slides	119 - 122
Conversions.....	Slide	123
Training Affirmation.....	Slide	124
References.....	Slide	125
Acknowledgements.....	Slide	126

Trimix Intro Pg 5

Before continuing, each student must sign and date a copy of slide 2 and the instructor should collect them and maintain them with each student's training records.

Section 1: Mixed Gases, Gas Properties, Specific Heat Capacity, Thermal Conductivity, Thermal Conductivity Related to Air, Dropping Core Temperature, Suit Insulation Values, Dry Suit Inflation Gas, Ideal Versus Real Gas Behavior, Determining Best Trimix, Partial Pressure Trimix Blending, Usable Cascade Volume, Helium is an Asphyxiant

Section 2: Helium Versus Nitrogen, Saturation and Desaturation Speed, Halftime Comparisons, Equivalent/Effective Depth Formulas, Dissolved Gas Models, Free Gas Phase Models, Schedule Comparisons, Gas Selection, Normoxic Range, Common O₂/N₂ Deco Mixes, Gas Switching Problems, Oxygen Window, Total Deco Times for Various Deco Gases, Additional Considerations

Section 3: Human Response to PO₂, Average RMV and O₂ Consumption Rates, Metabolic O₂ Consumption, Personal Limitations, Environmental Considerations, Physiological Problems

Section 4: Time Terminology, Descent/Ascent Rates, Dive Planning, Imperial Calculations, Trimix Diver & Team Planners, Metric Calculations, Gas Utilization Charts, Contingency Plans, ABCs, Air No-Stop Limits, RGBM Trimix NDLs, Helitrox NDLs, ASCEND Safely

Section 5: Buoyancy Compensator, Regulators, Regulator Performance, Cylinders, Rigged Doubles, Stage Cylinders, Instruments, Accessories, Rigging Options, Gear Checklist, Pre-dive Checklist

Section 6: Team Members, Players, Surface Support Team, Agency Protocols, Accident Analysis, Rescue Responses, Emergency Responses, Omitted Decompression, DCS Signs & Symptoms, Neurological DCS, Desktop Decompression, Skills and Techniques, Technical Diving Symbols, Conclusion

SECTION 1 TOPICS

- ✓ **Mixed Gases**
- ✓ **Gas Properties**
- ✓ **Specific Heat Capacity**
- ✓ **Thermal Conductivity**
- ✓ **Thermal Conductivity Related to Air**
- ✓ **Dropping Core Temperature**
- ✓ **Suit Insulation Values**
- ✓ **Dry Suit Inflation Gas**
- ✓ **Ideal Versus Real Gas Behavior**
- ✓ **Determining Best Trimix**
- ✓ **Partial Pressure Blending Trimix**
- ✓ **Usable Cascade Volume**
- ✓ **Helium is an Asphyxiant**

Trimix Section 1 Pg 1

Atmosphere absolute is abbreviated as “atm abs,” but for simplicity and to conserve space in this presentation it is written as “ata.”

Abbreviated gas percentages for mixed gases are typically written with the inert gases first (from highest to lowest), followed by oxygen, as their name indicates. But for this presentation abbreviations will be written with oxygen first, followed by the inert gases, with nitrogen last whenever it is included. For example, 16/33/51 represents 16% oxygen, 33% helium and 51% nitrogen, and usually is shortened to 16/33.

Instead of the usual symbol, square root is designated by the exponent of 1/2. For example, the mathematical expression for the square root of the atomic weight of nitrogen would be written as $(28 \text{ g/m})^{1/2}$.

Additional abbreviations may be noted at the beginning of each section and commonly used mathematical conversions for pressure, weight, distance, fluid volume, gas volume, temperature and scientific notation are provided on slide 110.

Fifteen review questions and their answers are located on the notes Slide 20.

MIXED GASES

One or more inert gases combined with O₂ to reduce decompression and/or eliminate narcosis and toxicity.

Heliox - (Helium and Oxygen)

Heliair - (Helium and Air, where Oxygen < 21%)

Helitrox - (Helium and Nitrox, where Oxygen > 21%)

Trimix - (Helium, Nitrogen, Oxygen)

Hydreliox - (Hydrogen and Helium, balance O₂ < 4%)

Hydrox - (Hydrogen, balance Oxygen < 4%)

Neox - (Neon and Oxygen)

Trimix Section 1 Pg 2

Oxygen (O₂) is necessary to sustain life, but at a threshold around 2 ata (PO₂), CNS toxicity can develop rapidly and result in a seizure without any warning. Long exposures at lower doses can produce pulmonary toxicity. Oxygen may also be narcotic at elevated pressures and when consumed in large quantities, may behave like an inert gas, which, could have ramifications on the decompression equation.¹⁴

Hydrogen (H₂) is easiest to breathe because it is lighter than helium, permitting nose breathing deeper than 1500 ft. (457 m). It acts to relieve high pressure nervous syndrome (HPNS), but when deeper than 500 ft. (152 m) hydrogen narcosis produces psychotropic or hallucinogenic like effects similar to LSD. **Above 4% in air at 1 ata hydrogen is highly flammable.**^{8/9/13}

Nitrogen (N₂) begins to produce narcosis around a depth threshold of 4 ata (PN₂ of 3.16 ata) and is the major threat to deep divers breathing mixtures where it is the primary inert gas ingredient.

Helium (He) is non-narcotic and easy to breathe, but causes voice distortion and greater conductive heat loss. Mouth breathing is required deeper than 1500 ft. (457 m).¹⁴ It's very penetrating and can damage vacuum tubes, gauges and electronics not troubled by N₂. HPNS or helium tremors, even seizures, can occur from rapid compression to 500 ft. (152 m) or diving deeper than 1000-1400 ft. (305-427 m). Adaptation during descent will delay the onset of HPNS, but small quantities of N₂ in the breathing mixture will facilitate decompression, ameliorate voice distortion and HPNS, and decrease heat loss.¹⁵

Mixed gas use has a long history, although trimix is still considered experimental by some because currently there are no scientifically validated decompression tables (personal communication Dr. Wienke).

In 1945 Zetterstrom was the first to use trimix on a dive to 500 ft. (152 m) and to use travel mixes, including hyperoxic and hypoxic O₂/N₂ blends before switching to 4/24/72, but he experienced hypoxia and decompression sickness (DCS) and died because a tender hoisted his platform to the surface too soon.

In 1959, Hannes Keller joined Albert Bühlmann in devising a heliox schedule and then he conducted a dive to 730 ft. (222 m) that required only 45 minutes of staged decompression.

In 1962, Keller and Small reached 1000 fsw (305 msw), but both men lost consciousness and Small and a support diver, Whittaker, died due to errors made by a platform tender at the surface.

In 1965, Workman published decompression tables for Nitrox and Heliox.

In 1981, the three man team of Atlantis III made a world-record chamber dive to 2250 ft. (686 m) at Duke Medical Center for a study by Peter Bennett and found that 10% N₂ added to heliox eliminated HPNS.^{9/12}

In the 1990s, trimix certifications became available outside commercial and military diving venues.

In 1994 Jim Bowden breathed mixed gases on his world record scuba dive to 925 ft. (282 m) at Zacaton.

GAS PROPERTIES			
GAS	MOLECULAR WEIGHT (g/m)	WATER / OIL SOLUBILITY	NARCOTIC POTENCY
Hydrogen: H ₂	2.016	0.0170 / 0.050	1.83
Helium: He	4.003	0.0086 / 0.015	4.26
Neon: Ne	20.180	0.0097 / 0.019	3.58
Nitrogen: N ₂	28.020	0.0130 / 0.061	1.00
Argon: Ar	39.440	0.0260 / 0.140	0.43
Oxygen: O ₂	32.000	0.0950 / 0.012	
CO ₂	44.010		
CO	28.010		
Air*	28.810		

Trimix Section 1 Pg 3

Molecular weights in grams per mole, gas solubility in water and oil at 100 °F (38 °C), and narcotic potency relative to nitrogen are shown. The **least narcotic gases have the highest narcotic index and lowest lipid solubility** (1 mole of any gas occupies 22.414 L at STP). Helium and hydrogen perform satisfactorily as inert gases. Hydrogen saturates/desaturates 3.7 times faster than nitrogen. Argon is not acceptable because it's heavier and more soluble than nitrogen. Neon is much lighter, but it's slightly more soluble than helium. **Helium is the least narcotic under pressure and it is less soluble than nitrogen, although its diffusivity is greater. Its solubility is less than nitrogen by a factor of 3 to 5, but its diffusivity is greater by a factor of 2.65.**

Helium is slightly less soluble than nitrogen, thus saturated tissues will hold less dissolved helium. This means no-stop times for helium will be shorter than those for saturated nitrogen tissues and decompression stop times will be shorter for equivalent tissue tensions.^{2/13} Solubility dominates during long exposures. This should also be true for short exposures under 20 minutes if gas exchange is perfusion limited. Where diffusion limits gas exchange, helium's greater diffusivity should override its solubility advantage, thus making nitrogen a better inert gas for bounce dives because some tissues will absorb more helium during short dives than nitrogen. The diffusion transit time (mean extravascular tension) to reach 95-99% of the blood tension is 1 to 5 seconds. Diffusion cannot play a limiting role for diffusivities smaller than water and gas diffusivities in tissues are smaller than water by a magnitude of five (tissue 10⁻¹⁰ cm²/sec). When diffusion constants are smaller, diffusion dominates the tissues-gas exchange process. For special mixes such as trimix, total inert gas uptake and elimination is assumed to be based on the sum of the fraction of nitrogen (FN₂) and helium (FHe).

Oxygen solubility in blood plasma is low. There is only 0.03 ml of O₂ dissolved per liter of blood for each mmHg of oxygen pressure (PO₂). This amounts to only 1.4% of the total O₂ carried in the blood when breathing air at sea level. O₂ binds with hemoglobin and it carries the bulk. Blood PO₂ ranges between 75-100 mmHg breathing air at 1 ata and increases to 500 mmHg breathing pure oxygen.¹⁵

The **Myer-Overton Hypothesis** states the degree of an anesthetic's potency is relative to its solubility in lipid (Henry's Coefficients). The intermolecular attraction (dipolar dispersion) of inert gas molecules (**van deWaals forces**) is believed to also play a role in the narcotic potential of gases, which means **O₂ may be narcotic**.^{5/19} However, it is readily metabolized away and may not have a significant contribution. In any case, assuming O₂ is as narcotic as nitrogen when determining the equivalent narcotic depth (END) is not a bad idea for deep dives. Desktop decompression software applications generally permit this option.*

SPECIFIC HEAT CAPACITY

C_p Btu/lbm · °F @ 70 °F

Gas	C_p
O₂	0.22
N₂	0.25
He	1.24
H₂	3.43
Ar	0.12
CO₂	0.20
Air	0.24

Trimix Section 1 Pg 4

Equivalent: 1 Btu/lbm · °F = 1 cal/g · °C

C_p is the **specific heat capacity at constant pressure**.¹³ Specific Heat (or Heat Capacity) = heat absorbed / mas * degree

One calorie is the amount of heat required to raise the temperature of 1 gram of pure water 1 °C

One BTU (25 calories) is the amount of heat required to raise the temperature of 1 pound of pure water 1 °F (0.55 °C)

It takes 243.3 calories to raise the temperature of 100 grams of air by 10 °C (18°F) and 1204 calories for helium, about **5 times more calories or heat energy**.⁸ $C_{p\text{ air}} 0.2433 \times 100 \times 10 = 243.3 \text{ cal}$

Although the mass of a helium mixture moving in and out of the respiratory system is less than air, the volume is the same. And this is what matters when measuring heat loss via the respiratory tract. The **molecular weight**, M_{mix} , of a gas mixture is the sum of the individual molecular weights, M_i , times their volume fractions, X_i .

$$M_{\text{mix}} = M_i \times X_i \text{ or } M_{\text{mix}} = (M_1 \times X_1) + (M_2 \times X_2) + \dots (M_n \times X_n)$$

For example, the molecular weight of a heliox mixture containing 12% oxygen and 88% helium is 7.362 and it is derived by: $(32 \times 0.12) + (4.003 \times 0.88) = 7.362$

The **specific heat of a gas mixture**, $C_{p\text{ mix}}$, is determined by multiplying each individual molecular weight, M_i , by its volume fraction, X_i , and by its specific heat, C_{pi} , and then dividing this product by the molecular weight of the mixture, M_{mix} .

$$C_{p\text{ mix}} = [M_i \times X_i \times C_{pi}] \div M_{\text{mix}}$$

The specific heat of heliox 12/88 is 0.708 and it's derived by:

$$[(32 \times 0.12 \times 0.22) + (4.003 \times 0.88 \times 1.24)] \div 7.362 = 0.708$$

THERMAL CONDUCTIVITY	
cal/sec · cm · °C × 10 ⁻⁵	
Oxygen	6.6
Helium	36.9
Nitrogen	6.4
Argon	4.4
Air	6.42

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The values listed above are taken from “Physiology of Diving with Special Breathing Gases,” but may be derived or reported differently elsewhere.¹⁴

Equivalents: 1 watt = 3.41 Btu/hr 1 cal/sec·cm·°C = 241.9 Btu/hr·ft·°F

1 cal = 3.09 ft·lb

1 Btu = 777.9 ft·lb = 252 cal

1 kcal = 3.968 Btu

1 watt/cm·°C = 57.79 Btu/hr·ft·°F

Heat loss from the body occurs predominantly by thermal conduction during immersion and is exponential over time, being highest initially and then gradually slowing. Heat loss from being surrounded by a dry suit gas is due to its thermal conductivity and helium is 6 times greater than air.^{5/19} **Convection is the predominant component of respiratory heat loss during a dive**, and relates directly to thermal capacity of a gas. Dr. Hamilton says, “Although helium feels colder compared with nitrogen, respiratory heat loss from helium should be less than air because it’s much less dense.”¹⁴ According to John Crea, at a surface consumption rate of 1 ft³/min, it takes 70 cal/min to raise the temperature of air that is 10 °C (18 °F) below body temperature to normal body temperature of 37 °C (98.6 °F), but it only takes 65 cal/min for the same volume of heliox 20/80, excluding conduction or humidification heat losses.

Thermal conductivity effects O₂ analyzers. Because the thermal conductivity of oxygen and nitrogen are nearly identical, nitrogen contamination in a cylinder of pure oxygen may indicate a positive increase in the oxygen reading on a **thermal conductivity O₂ analyzer**, falsely adding to the oxygen purity rather than subtracting from it. Fortunately, this type of analyzer is fairly expensive and its use within the scuba diving industry is not as popular as an electrochemical O₂ analyzer. An **electrochemical O₂ sensor** converts oxygen to an electrical reading corresponding to the oxygen percentage. Partial pressure and temperature affect the sensor. The signal, which is directly related to the O₂ reading, rises as temperature increases but this is compensated with a thermistor that has the inverse temperature performance. The thermistor and the sensor membrane that oxygen molecules pass through must be at the same temperature. In other words, the gas temperature must equal the sensor temperature, if they are not the reading may be inaccurate. After transferring gas into a cylinder, **wait until the mixture is at the same room temperature as the sensor before conducting an analysis and don’t hold the sensor in your hand during gas analysis.** False high errors can result from temperature differences (static fault) and a too high gas flow rate (dynamic fault). False low readings can occur from contamination of ambient air flowing into the sensor during analysis and weak batteries or fuel cell.

THERMAL CONDUCTIVITY RELATED TO % OF AIR CONDUCTIVITY

EAN	H ₂	He	Ar	CO ₂
100%	704%	586%	68.2%	62.4%

Trimix Section 1 Pg 6

Compared to the thermal conductivity of air or nitrox as a baseline, **carbon dioxide and argon have lower thermal conductivity**, while hydrogen and helium have higher.⁸ Pure helium conducts heat about 6 times faster than air, while heliox 20/80 conducts heat approximately 5 times faster than air. Argon conducts heat 68.2 % as fast as air, but only 13% as fast as heliox 20/80. So except for exceptionally cold or long mixed gas dives, air is an acceptable alternative to argon for dry suit inflation.

Basal metabolic rate is about 82 watts (280 Btu/hr).

Swimming underwater at 0.5 knots burns 924 Btu/hr or 270.7 watts.

Swimming at 0.85 knots, burns 1618 Btu/hr or 474.1 watts.

Swimming at 1.0 knot, burns 2080 Btu/hr or 609.4 watts.

DROPPING CORE TEMPERATURE

98 °F (37 °C) Cold sensations, skin vasoconstriction, increased muscle tension, increased O₂ consumption

97 °F (36 °C) Uncontrollable shivering, sporadic gross shivering, hyperventilation, higher O₂ consumption

95 °F (35 °C) Clinical hypothermia, mental confusion, irrational thought, decreased will to struggle

93 °F (34 °C) Memory loss, and speech, sensory and motor impairment

Trimix Section 1 Pg 7

A diver's **body core temperature** should not drop by more than 1.6 °F or 1 °C and average (mean) skin temperature should not go below 77 °F (25 °C), except for the hands, which shouldn't go below 59 °F (15 °C).⁸

Symptoms of **hypothermia** are confusion, memory lapse, fatigue, apathy, decreased sensation and motor coordination, and hallucinations. Hypothermia increases a diver's susceptibility to DCS, toxicity and narcosis.

When **re-warming a hypothermic diver**, warm their head, groin, underarms and then torso. Do not warm the limbs until the core temperature has risen, otherwise the diver may suffer a severe drop in blood pressure and go into shock.⁷

Gently exercising the limbs during decompression increases the body's production of heat and increases perfusion, which should increase inert gas elimination.^{5/15/19}

Reduction in perfusion due to peripheral vasoconstriction from dropping body temperature upsets blood-gas transfer, which can result in tissue hypoxia although a diver is breathing a normoxic mix.^{9/15}

SUIT INSULATION VALUES

Suit	1 ata	4 ata
0.25 in. (6 mm) neoprene wet suit	0.77	0.25
0.25 in. (6 mm) neoprene dry suit & nylon pile	2.33	0.60
0.4 in. (10 mm) rubber dry suit & 0.3 (8 mm) urethane foam underwear	2.10	0.87
0.4 in. (10 mm) rubber dry & 0.3 (8 mm) thinsulate	2.40	1.20

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Effects of depth on thermal insulation for wet suits and dry suits.

Closed cell foam wet suits are subjected to changes in volume due to ambient pressure according to Boyle's Law, although the change is less than 50% of what the gas law predicts.¹³ Beyond 4 ata or 99 fsw (30 msw, compression of neoprene is essentially complete and a wet suit provides the same thermal protection as that derived from a rubberized fabric suit.⁸ The above chart shows the reduction in thermal protection with the effects of increasing depth.

Effects of depth on wet suit buoyancy loss as percent of total body weight.

4% the first 50 fsw (15 msw)

almost 6% at 100 fsw (30 msw)

6% at 150 fsw (46 msw)

7% at 200 fsw (61 msw)

To calculate the **buoyancy loss from a diver displacing "equal volumes of water" when submerged in salt water and then fresh water**, multiply the total body weight plus gear weight in salt water by -0.025 . Next subtract this amount of weight from your lead ballast. The correction for changing from salt water to fresh water generally results in a 2.5% buoyancy reduction in a diver's total weight.

Considering the increasing loss of buoyancy with depth, it is very important to **conduct a controlled descent** during deep dives. You should only be slightly negatively buoyant when descending so that you can achieve neutral buoyancy upon reaching maximum depth by adding a minimal amount of gas to your BC. Keep in mind that not only will it take proportionately more gas, it will take proportionately longer to fill a BC at depth to achieve the same buoyancy state as in shallow water. For instance, at seven ata/bar, it will take about seven times as long to fill a BC compared to what it takes at the surface or 1 ata/bar. When a diver's increased respiratory demand at maximum depth is factored in, it will take even longer. For this reason some deep divers use a high-flow low-pressure BC inflator, by combining Scubapro's Air 2 adapter for the LP hose quick-disconnect with the BC inflator stem by Trident, or by using the complete super power inflator assemblies, SPI-12 and SPI-16, by Sartek Industries Inc.

DRY SUIT INFLATION GAS

- ✓ **Nitrogen and Argon are “suitable” inert gases**
- ✓ **Ideally inflation gas should sustain life**
- ✓ **10% O₂ is normoxic from 20-495 ft. (6-150 m)**
- ✓ **Purge ambient air from suit after attired**
- ✓ **Fill suit from auxiliary argon supply at surface**
- ✓ **Install a pressure relief valve on first-stage LP port as a precaution against a HP seat failure**
- ✓ **Backup LP inflator hose**

Trimix Section 1 Pg 9

Argon increases insulation over air by 50%, or is twice as warm as air. ⁸

Dry suit inflation gas can react chemically and effect a diver’s physiology via diffusion. **Argon (Ar) is slowly diffusing and has high tissue solubility**, so there is little risk for counter diffusion in typical profiles.¹³ Because it’s easy to obtain and inexpensive, some divers use industrial welding argon, and reportedly do so without problems. However, **welding argon contains approximately 25% carbon dioxide**. When CO₂ is exposed to moisture from perspiration it causes skin irritation and itching.¹⁴

Argon must be handled carefully around life support equipment! Dr. Hamilton suggests **adding aviator or medical oxygen to respirable argon so that it is has an FO₂ of at least 0.10 so that it could support life**.¹⁴ The intent is that breathing dry suit inflation gas would not instantly cause tissue hypoxia and be fatal if it were accidentally consumed within typical trimix training profiles. Argox should only be intentionally breathed in a last ditch, life saving effort when all other options have been exhausted. Keep in mind that argon is highly soluble and is, therefore, much more narcotic than either oxygen and nitrogen, and absorbed argon is harder to eliminate.

It is a good idea to **install a pressure relief-valve** in a regulator first stage low-pressure (LP) port as a precaution against a high-pressure seat failure, which would rupture the dry suit inflator hose from your argon supply cylinder. You can use a LP hose with an air nozzle at the end or second stage that will release over-pressurization caused by a failed HP seat. Use tape, a cable tie or an O-ring to rig a redundant LP inflator hose from your back gas or travel gas next to the hose for your dry suit inflator, but leave enough room from the quick connect/disconnect end to be able to get your hand around the hose to operate it. If you run out of argon or its regulator malfunctions, simply disconnect the argon LP hose and hookup the auxiliary LP hose from the alternate gas source to inflate your dry suit. If you are using your dry suit to maintain buoyancy as well as thermal insulation, first go to your BC to establish adequate lift, then switch inflator hoses on your dry suit if you are setup to do so, in addition to terminating the dive.

Purge your suit of ambient air and fill it from a high capacity cylinder of argon at the surface to conserve your underwater supply.

IDEAL VERSUS REAL GAS BEHAVIOR

- * A gas is said to behave as an ideal gas if its molecules do not exert any force, attractive or repulsive, on one another and the volumes of molecules are negligibly small compared to distance between them.
- * For pressures up to 50 ata (1617 fsw) O₂, He, and H₂ are within 5% of ideal behavior.

Trimix Section 1 Pg 10

An ideal gas is one that behaves exactly. The **Ideal Gas Law** is obeyed approximately by all gases and the formula is $PV = nRT$. The constant, R, conforms to $PV \div T$, for a sample of gas containing a number of moles at standard temperature and pressure (STP), volume $V = n(22.4 \text{ L/mole})$, temperature, $T = 273 \text{ K}$, and pressure, $P = 1 \text{ atm}$. Thus ideal gas law $PV \div T = n(1 \text{ atm})(22.4 \text{ L/mole}) \div 273 \text{ }^\circ\text{K} = nR$. The universal gas constant, R, is equal to $0.0821 \text{ atm}\cdot\text{L/mole}\cdot\text{K}$. It is also written as $P_1V_1 \div T_1 = P_2V_2 \div T_2$. When $T_1 = T_2$ the ideal law becomes Boyle's Law and when $P_1 = P_2$ it becomes Charles's Law.

Ideal gas behavior does not hold for high pressures (intermolecular forces) and/or lower temperatures (kinetic energy). According to Beattie-Bridgeman Equation of State, **oxygen is 10% more compressible than nitrogen or helium at pressures between 2000 to 4000 psi**, but at lower pressures the difference is minimal.^{8/12/13} If gas pressure is held constant and temperature is varied, gas volume changes by $1/273$ of its volume at $0 \text{ }^\circ\text{C}$ for each $1 \text{ }^\circ\text{C}$ temperature change.

Van der Waals Constants are indicators of real gas behavior, although Beattie-Bridgeman gives a better fit (personal communication Wienke). The magnitude of a ($\text{atm}\cdot\text{L}^2/\text{mol}^2$) indicates how strongly a given type of molecule attracts another. Attraction softens how hard molecules hit the sides of their container. **The closer a and b (L/mol) are, the more closely that gas can be approximated as ideal.** Helium has the weakest attraction as indicated by a . One mole of both He and H₂ at $27 \text{ }^\circ\text{C}$ vary from ideal behavior by 1.2 near 300 ata, while O₂ is just slightly below and CO₂ is 0.4 under the same conditions.^{8/13}

The **van der Waals** formula can be written $(P + a/v^2)(v - b) = RT$. Where " a " is the coefficient of linear expansion and " b " is the coefficient of volume expansion and " P " is pressure.⁸ At constant pressure, all gases have nearly the same coefficient of volume expansion b , thus, $b_0 = 0.0037 \div \text{ }^\circ\text{C}$.

Gas	a	b	Gas	a	b
He	0.034	0.0237	N ₂	1.39	0.0391
Ne	0.211	0.0171	O ₂	1.36	0.0318
Ar	1.340	0.0322	CO ₂	3.59	0.0427
H ₂	0.244	0.0266	H ₂ O	5.46	0.0305

DETERMINING BEST TRIMIX

1. $P \text{ ata} = (\text{MOD} \div 33 \text{ fsw/ata}) + 1 \text{ ata}$

2. $\text{Max PO}_2 < 1.44 \text{ ata}$

3. $\text{FN}_2 = [(\text{END} + 33 \text{ fsw}) \div (\text{MOD} + 33 \text{ fsw})] \times 0.79$

4. $\text{FO}_2 = \text{PO}_2 \div P \text{ ata}$

5. $\text{FHe} = 1.0 \text{ ata} - (\text{FO}_2 + \text{FN}_2)$

Trimix Section 1 Pg 11

Determine the **best trimix blend** by finding the optimum gas concentrations for a known dive depth:

1. Convert maximum depth in feet salt water to pressure absolute: $P \text{ ata} = (\text{MOD} \div 33 \text{ fsw/ata}) + 1 \text{ ata}$.
2. Establish a limiting PO_2 at the planned maximum depth that is less than 1.44 ata.
3. Figure the fraction of N_2 from the tolerable END: $\text{FN}_2 = [(\text{END} + 33 \text{ fsw}) \div (\text{MOD} + 33 \text{ fsw})] \times 0.79$
4. Calculate the fraction of O_2 : $\text{FO}_2 = \text{PO}_2 \text{ ata} \div P \text{ ata}$
5. Calculate the fraction of He: $\text{FHe} = 1.0 - (\text{FO}_2 + \text{FN}_2)$

Alternative calculations for best trimix blend using feet salt water units:

1. Determine P fsw e. g. $\text{MOD } 190 \text{ fsw} + 33 \text{ fsw} = 233 \text{ fsw}$
2. Choose a $\text{PO}_2 < 47.52 \text{ fsw}$ e. g. $\text{PO}_2 \text{ } 1.4 \text{ ata} \times 33 \text{ fsw/ata} = 46.2 \text{ fsw}$
3. $\text{PN}_2 \text{ fsw} = (\text{END} + 33 \text{ fsw}) \times 0.79$ e. g. $(100 \text{ fsw} + 33 \text{ fsw}) \times 0.79 = 105.07 \text{ fsw}$
4. $\text{FO}_2 \text{ fsw} = \text{PO}_2 \text{ fsw} \div P \text{ fsw}$ and $\text{FN}_2 \text{ fsw} = \text{PN}_2 \text{ fsw} \div P \text{ fsw}$
e. g. $\text{FO}_2 = 46.2 \text{ fsw} \div 233 \text{ fsw} = 0.198$ and $\text{FN}_2 = 105 \text{ fsw} \div 233 \text{ fsw} = 0.45$
5. $\text{FHe} = 1.0 - (\text{FO}_2 + \text{FN}_2)$ e. g. $\text{FHe} = 1.0 - (0.198 + 0.45) = 0.352$

PARTIAL PRESSURE BLENDING TRIMIX

- √ **Lay cylinders down during filling and cooling**
- √ **Wait for the gas temperature to stabilize and verify the pressure before adding another gas**
- √ **Analyze O₂ content after combining He and O₂**
- √ **A 1% error in O₂ at the heliox stage may cause a 4% or 5% error in the final N₂% and He%**
- √ **Analyze O₂ content at the final target pressure**

Trimix Section 1 Pg 12

Mixed gas should only be prepared by a certified mixed gas blender who is trained and experienced with the particular fill station and is knowledgeable in the particular blending process and the individual gases.¹¹

Filling pressures are calculated:

1. Calculate PHe, PO₂ and PN₂ of the total Trimix cylinder pressure. $P_g \text{ psig} = \text{Trimix psig} \times F_g$
2. Calculate Nitrox psig. $\text{Nitrox psig} = \text{Trimix psig} - \text{Helium psig}$
3. Fraction of Oxygen of the Nitrox psig: $\text{Nitrox FO}_2 = \text{Trimix PO}_2 \text{ psig} \div \text{Nitrox psig}$
4. Oxygen to add: $\text{O}_2 \text{ psig} = [(\text{Nitrox FO}_2 - 0.21) \div 0.79] \times \text{Nitrox psig}$
5. Air to add: $\text{Air psig} = \text{Trimix psig} - (\text{PHe psig} + \text{PO}_2 \text{ psig})$

When using ideal gas equations, increase the helium component in a mixture by approximately 5% or 5 psig per 100 psig to account for real gas compressibility effects.²⁰ However, this will not always hold true from one blender to the next because of variations in blending techniques. Heli-air avoids the hazards of handling pure O₂ and there is less chance for mixing errors. It also takes less time to fill, an important consideration for large classes and when dives will be made on consecutive days and the instructor is the blender. The person who begins the mixing process should finish it because there is a greater likelihood of error if another person takes over in the middle. Write everything down, do not rely on memory, especially when working with multiple cylinder sets. Most **desktop decompression software** will calculate required individual gas pressures from user input gas percentages and the desired cylinder fill pressure.^{1/23}

To obtain trimix on site where an air compressor is available but not helium, a blender can transfill from a full set of doubles containing oxygen-rich heliox (a “**hot mix**”) into an identical set of empty doubles that have the same rated pressure and volume.²⁰ Both twin sets (half full with hot heliox) are then topped off with air to the same initial pressure of the supply heliox. The resulting FO₂ and FHe can be mathematically calculated by $\text{FO}_2 = (\text{Supply Heliox FO}_2 + 0.21) \div 2$ and $\text{FHe} = (\text{Supply Heliox FHe} \div 2)$.

Both the blender and the user should analyze and label the cylinder contents of all special mixes!

USABLE CASCADE VOLUME

1. Rated Cylinder Pressure per Cubic Foot:

$$\text{rated cylinder psi} \div \text{rated cylinder ft}^3 = \text{psi/ft}^3$$

2. Usable Supply Pressure:

$$\text{supply psi} - \text{needed scuba psi} = \text{usable supply psi}$$

3. Available Supply Volume:

$$\text{usable supply psi} \div \text{supply psi/ft}^3 = \text{available supply ft}^3$$

4. Required Scuba Volume:

$$(\text{scuba ft}^3 \div \text{scuba psi}) \times \text{required psi} = \text{required scuba ft}^3$$

5. Number of Cascade Fills:

$$\text{available supply ft}^3 \div \text{required scuba ft}^3 = \text{number of fills}$$

Trimix Section 1 Pg 13

The calculations above will enable you to determine how many cylinders can be filled (with the same amount of gas) from a supply cylinder or storage bank via cascading when partial pressure blending.

The following example shows the steps to calculate how many helium fills are available from a 244 ft³ supply cylinder of helium that has a rated pressure of 2400 psig if you want to make TX 16/24 in 80 ft³ cylinders filled to their rated pressure of 3000 psig.

$$\text{Helium scuba pressure required} = F_{\text{He}} 0.24 \times 3000 \text{ psig} = P_{\text{He}} 720 \text{ psig}$$

$$\text{Helium supply psig/ft}^3 = 2400 \text{ psig} \div 244 \text{ ft}^3 = 9.8 \text{ psig/ft}^3$$

$$\text{Usable helium psi} = 2400 \text{ psig} - 720 \text{ psig} = 1680 \text{ psig}$$

$$\text{Available supply helium ft}^3 = 1680 \text{ psig} \div 9.8 \text{ psig/ft}^3 = 171.42 \text{ ft}^3$$

$$\text{Required scuba helium ft}^3 = (80 \text{ ft}^3 \div 3000 \text{ psig}) \times 720 \text{ psig} = 19.19 \text{ ft}^3$$

$$\text{Number of fills from the supply cylinder of helium} = 171.42 \text{ ft}^3 \div 19.19 \text{ ft}^3 = 8.93 \text{ fills}$$

HELIUM IS AN ASPHYXIANT

! Do not leave pure helium in a scuba cylinder, but if you do — label it

HELIUM - *DO NOT BREATHE!*

! Decant helium in a well-ventilated area.

Trimix Section 1 Pg 14


Helium is an colorless, odorless inert gaseous element occurring in natural gas and with radioactive ores. It is mined from natural gas wells in Texas (the largest), Kansas, Oklahoma, and Saskatchewan within North America and also in Algeria. It's not commercially produced by fractional (cryogenic) distillation of air because it is only about 5.24 ppm by volume and is very cost prohibitive. It's density at 0 °C is 0.1785 grams per liter.

Medical grade helium with a purity Quality Verification Level (QVL) of 99.999% and that is free of oil and moisture is preferable for scuba diving. Air Liquide's Research (D grade) helium has a purity of 99.9999% and specifies limiting values for Ar < 0.5, CO < 0.5, THC < 0.2, H₂ < 0.5, Kr < 0.5, N₂ < 0.5, CO₂ < 0.5, H₂O < 0.5, Ne < 0.5 and O₂ < 0.5, where the total allowable impurities < 1 ppm. Ultra High Pure (UHP) (F grade) has a minimum purity of 99.999% with a Neon free basis and H₂O < 1 ppm. Zero Pure (J grade) has a Total Hydrocarbon Content < 0.5 ppm. Helium for welding or filling balloons should not be used because its specific analysis may or may not be known although it may have a relatively high helium content. Some gas suppliers simply designate their lowest grade for these purposes. Ungraded helium (a purity less than 4 nines) may have oxygen added to prevent a child from asphyxiating if they inhale it and may it have unacceptable levels of contamination. Get and read the material data safety sheet for the gas analysis of respirable helium and follow all the safety guidelines for its handling, labeling and use.

The most common cylinders that Air Liquide supplies are size 49 with a gas contents of 291 ft³ (8.2 m³) at 2640 psi, size 44 with a gas contents of 223 ft³ (6.3 m³) at 2265 psi, size 44H with a gas contents of 323 ft³ at a rated pressure of 3500 psi and the more common 44H with a contents of 244 ft³ at 2400 psi.

Although helium is a nonflammable gas, it is an asphyxiant, meaning a person can be asphyxiated breathing it. When decanting helium into a scuba cylinder, be sure the area is well-ventilated and do not leave helium in a scuba cylinder unless it is has a warning label, "Helium, Do Not Breathe!" An **error proof process is vital to diver safety and to personnel in and around the blending/fill station.**

SECTION 1 EXAMINED



- ✓ Mixed Gases
- ✓ Gas Properties
- ✓ Specific Heat Capacity
- ✓ Thermal Properties
- ✓ Dropping Core Temperature
- ✓ Suit Insulation Values
- ✓ Dry Suit Inflation Gas
- ✓ Ideal Versus Real Gas Behavior
- ✓ Determining Best Trimix
- ✓ Partial Pressure Blending
- ✓ Usable Cascade Volume

Trimix Section 1 Pg 15

1. Identify 7 different names for mixed gas. (Slide 7)
2. Oxygen convulsions occur suddenly above what threshold? 2 ata
3. What kind of narcosis does hydrogen produce and what is the limiting concentration of oxygen it can safely be combined with? Psychotropic; 4% O₂
4. Identify 4 characteristics of breathing He which are different than N₂. Non-narcotic, easier to breathe, voice distortion, and faster heat loss compared to air
5. What is HPNS and when is it likely to occur? High Pressure Nervous Syndrome (helium tremors); rapid compression to depths of 500 fsw or diving beyond 1000 to 1400 fsw.
6. What is the molecular weight of Oxygen, Nitrogen, and Helium and which is the least narcotic?
O₂ = 32 g/m, N₂ = 28 g/m, He = 4 g/m; Helium is the least narcotic.
7. Which is less soluble and diffuses faster, helium or nitrogen? Helium is less soluble than nitrogen by a factor of 3 to 5 and it diffuses 2.65 times faster.
8. List the specific heat of air, oxygen, nitrogen and helium from the lowest to the highest.
O₂ 0.22, air 0.24, N₂ 0.25, and He 1.24
9. List 7 symptoms of hypothermia. Confusion, memory lapse, fatigue, apathy, decreased motor sensation and motor coordination, and hallucinations.
10. Ideal gas behavior does not hold for high pressures and/or low temperatures.
11. What measure can be taken with argon to make it respirable when used around life support equipment? An FO₂ of at least 0.1 will sustain life if accidentally breathed or if needed to as a last resort.
12. According to the Beattie-Bridgeman Equation of State, oxygen is 10% more compressible than N₂ or He at pressures between 2,000 and 4,000 psig, but at lower pressures the difference is minimal.
13. List the seven steps to determine the best trimix? (Slide 16)
14. Regarding the blending and use of trimix, when should an O₂ analysis be done? During analysis, why must the gas and an electrochemical analyzer be at room temperature and the gas flow into the sensor be precise? Analyze when O₂ and He are combined, at the final target cylinder pressure, and before its use. High gas temperature and too high a flow into the sensor causes a false high O₂ reading.
15. Why is it important to decant helium in a well ventilated area? It is an asphyxiant.

SECTION 2 TOPICS

- | | |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> ✓ Helium Versus Nitrogen ✓ Saturation/Desaturation ✓ Halftime Comparisons ✓ Equivalent/Effective Depth Formulas ✓ Dissolved Gas Models ✓ Free Gas Phase Models ✓ Schedule Comparisons | <ul style="list-style-type: none"> ✓ Gas Selection ✓ Normoxic Ranges ✓ Common O₂/N₂ Deco Mixes ✓ Gas Switching Problems ✓ Oxygen Window ✓ Total Deco Times for Various Deco Gases ✓ Additional Considerations |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Trimix Section 2 Pg 1

The following are examples of some of the terms used within this section and here on out. They should help explain similar expressions for other gases.

τ = tissue halftime

μ = micrometer

Δ = delta = change

A_{He} = atomic weight or molecular weight of helium

A_{N_2} = atomic weight or molecular weight of nitrogen

τ_{N_2} = tissue nitrogen halftime

τ_{He} = tissue helium halftime

P_g = gas partial pressure

P = absolute pressure

P_{iO_2} = partial pressure of inspired oxygen

PAO_2 = partial pressure of alveolar (gaseous) oxygen

PaO_2 = partial pressure of arterial (dissolved) oxygen

PtO_2 = tissue oxygen tension

Fifteen questions and answers covering section 2 topics are on slide 44.

HELIUM VERSUS NITROGEN

- **Faster tissues control deep deco stops while slower tissues control shallow stops**
- **Pressure ratios can exceed the typical limiting ratio for compartments with faster halftimes**
- **Lower solubility in oil may yield shorter halftimes for fatty tissue**
- **More rapid diffusion rate calls for deeper deco stops and a slower ascent rate to minimize bubble formation**

Trimix Section 2 Pg 2

Faster tissues permit higher inert gas gradients compared to slower compartments. **Helium's faster diffusion rate calls for deeper decompression staging and slower ascents than is necessary with nitrogen.**¹³ For equivalent dives with short to moderate bottom time to a depth between 100-150 fsw (30-45 msw), helium mixtures produce longer decompression schedules compared to those with air. For dive depths shallower than 150 fsw with a bottom time under 1 to 2 hrs, the shortest to longest decompression is air < helitrox < trimix < heliox.¹³ **Helitrox no-stop limits converge with air NDLS at about 150 fsw. Trimix deco time converges with that of air around 150 fsw and 1 to 2 hours.**^{12/13} For equivalent dives deeper than 150 ft (45 m) with bottom times longer than about 2 hours heliox < trimix < air deco time.

The longer and deeper the first dive, the greater amount of residual inert gas affecting subsequent dives. However, a diver is a new diver after 5 hours of surface interval on some commercial heliox tables.^{3/12/22} Most published recreational trimix tables are based on Bühlmann's ZH-L 16 algorithm and some permit repetitive dives to the same or shallower depth after a surface interval of only 4 hours. But inspection of repetitive stop depths and times reveals deeper stops are unchanged and shallow stop times may vary only slightly. It's important to note that unlike his air tables, Bühlmann's helium tables were not validated before he died. Currently, there are no trimix decompression tables that have been empirically validated. Dissolved gas models that do not take into consideration microbubble formation don't account for altered inert gas elimination which reduces decompression efficiency. This is a compelling reason to use decompression tables that split inert gas uptake into dissolved and free gas, which accounts for the effects of microbubble formation.^{2/13} As a general rule, repetitive dives with helium mixtures are not advised because multiple deep dives are not recommended.

DCS that occurs from a deep long helium dive is more likely to involve the central nervous system and spinal cord and generally requires deeper and longer recompression treatments than shallower dives, which are more likely to produce limb bends.^{9/17} Dr. Bühlmann found that divers doing light work while breathing heliox required 20-40% more decompression than did resting divers.¹⁵ **Adopt conservative practices in addition to staying abreast of developments in safer practices or decompression models.**

Information from one table or meter does not necessarily equate to that of another table or meter. Although total decompression time may be similar or even identical from one table to another, the composition and the depth of specific gas switches may differ as may the ascent rate, and the 10 ft. (3 m) stop time may or may not be conducted at 15 or 20 ft. (4.5 or 6 m).^{3/20} It is imperative to **know all the application procedures and rules for the decompression table or metering device you use** and to always dive conservatively.

SATURATION AND DESATURATION SPEED

\propto Saturation and desaturation speed of an inert gas is inversely proportional to the square root of its atomic mass (molecular weight).

\propto Helium saturates/desaturates about 2.65 times faster than nitrogen, resulting in shorter halftimes for the same critical tensions.

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Helium saturates and desaturates about 2.65 times faster than nitrogen according to $1 \div (A_{He} \div A_{N_2})^{1/2}$. It can be tracked with the same critical tensions as N_2 .¹³ They are derived by $\tau_{He} = \tau_{N_2} \times (A_{He} \div A_{N_2})^{1/2}$. A 5 minute N_2 tissue would extrapolate to a 1.89 minute He tissue; $5 \times (4 \div 28.02)^{1/2} = 1.89$.

Perfusion is the rate that inert and metabolic gases exchange between blood and tissues or blood flow rate. Tissue halftimes are the inverse of the perfusion rates. **Diffusion** refers to gas penetration rate across blood-tissue boundaries. When perfusion constants are smaller than diffusion constants, perfusion dominates the tissue-blood gas exchange process.^{2/13} **Exchange is perfusion limited** when venous tension is closer to the tissue tension at the capillary wall. **Exchange is diffusion limited** when venous tension is closer to arterial tension. When diffusion constants are smaller than perfusion constants, diffusion dominates tissue-blood gas exchange, and visa-versa.^{2/13}

This exchange principle is also true for compartment desaturation halftimes. However, it's assumed that **inert gas uptake and elimination is asymmetric when microbubbles (venous gas emboli) are present** in the circulation, and thus results in longer desaturation rates.¹³

The origin of bubbles is assumed to be **micronuclei**. They are classified according to their origin, homogeneous if their composition and parent media are the same or heterogeneous if they're different. Homogeneous nucleation and bubble formation requires large decompressions while heterogeneous nucleation and bubble formation transpires with very small decompressions.^{2/13}

The theory of **physical adaptation** suggests a diver can increase their tolerance to bends by:

1. Making the first dive a deep, short (crush) dive, constricting micronuclei to a smaller safer size.
2. Making succeeding dives progressively shallower, thus staying within the crush depth of the first dive which minimizes development of new micronuclei.
3. Diving frequently, such as every other day, which depletes the number of micronuclei that can contribute to bubble formation.

Dr. Wienke reports, "If nucleation sites are eliminated, their numbers reduced or they become less predisposed to excitation, the risk to bubble formation is commensurately reduced."¹³

HALFTIME COMPARISONS

		SATURATION HALFTIMES (mins)							
N₂	5	10	23	37	79	114	238	351	795
He	2	4	9	14	30	43	90	133	300
		DESATURATION HALFTIMES (mins)							
N₂	8	15	34	56	119	171	357	527	1193
He	3	6	13	21	45	65	135	199	450

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For identical tissue tensions, helium halftimes are about 2.65 times shorter than those for nitrogen. (Standard rounding was applied to halftime calculations.) Helium halftimes are extracted from nitrogen halftimes by dividing by 2.646 *or* by multiplying by 0.3779. For example, it only takes 2 minutes for a helium compartment to reach the same level of saturation as a 5 minute nitrogen compartment. This is determined by $5 \div 2.646 = 1.89 \approx 2$. A 180 minute helium compartment behaves approximately like a 480 minute nitrogen compartment. For example,

$$480 \text{ min } \tau_{\text{N}_2} \times 0.3779 = 181.39 \approx 180 \text{ min } \tau_{\text{He}} \text{ or } 480 \text{ min } \tau_{\text{N}_2} \div 2.646 = 181.4 \approx 180 \text{ min } \tau_{\text{He}}$$

Halftimes are assumed to be independent of pressure and take 6 halftimes for a compartment to reach saturation. From the values listed above, for a dive of 85 minutes, the first 4 helium compartments would become saturated, compared to only the first 2 nitrogen compartments.¹ Some decompression models compute critical tensions for nitrogen and helium separately and assume elimination is sequential. Fast compartments control short deep exposures and slow compartments control long shallow decompression and saturation exposures.

M-values are the calculated partial pressure of inert gas (expressed in feet salt water) in half-time compartments permitted upon reaching a decompression stop. Dividing the M-value by barometric pressure at sea level (33 fsw) will provide the critical ratio for that half-time compartment.

The following M-values (fsw) are estimated surfacing critical tensions (M_0). Notice that the M-values by Wienke and Yount are not fixed, but vary depending on repetitive exposures.¹³

Halftimes:	5 τ min	10 τ min	20 τ min	40 τ min	80 τ min	120 τ min
Workman M_0 :	104 fsw	88 fsw	72 fsw	58 fsw	52 fsw	51 fsw
Bühlmann M_0 :	102 fsw	82 fsw	65 fsw	56 fsw	50 fsw	48 fsw
Wienke M_0 :	100-70 fsw	81-60 fsw	67-57 fsw	57-49 fsw	51-46 fsw	48-45 fsw

EQUIVALENT / EFFECTIVE DEPTH FORMULAS

EQUIVALENT AIR DEPTH

for air or nitrox at sea level and altitude*

$$\text{EAD} = [(FN_2 \div 0.79) \cdot (d + 33 \text{ fsw})] - 33 \text{ fsw}$$

$$*\text{EAD} = [(FN_2 \div 0.79) \cdot (d + P_h)] - P_h$$

EFFECTIVE DEPTH

for any inert gas and elevation

$$\text{ED} = [(f_k \div f_{ks}) \cdot (d + P_h)] - P_h$$

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The same set of limiting critical tensions (M values) or ratios (R values) are assumed to apply equally to both air and nitrox mixtures using the EAD formula. But the **Effect Depth procedure can be applied to any mixture** by extrapolating equivalent depths from a standard table which employs the same gas components (e. g. He or N₂ with O₂).^{2/13}

For the Effective Depth calculation, **f_k** is the gas fraction in the actual mixture, **f_{ks}** is the gas fraction on the standard decompression table, **k** is the inert gas, **P_h** is atmospheric pressure in fsw, **ED** is the effective depth and **d** is actual depth, both in fsw.¹³ Actual and effective depths are identical at sea level. (Atmospheric pressure decreases about 1 fsw for every 1000 ft. elevation.)

For example, a heliox 14/86 dive to 300 fsw can be equated to a 290 fsw schedule on a heliox 10/90 table according to: $\text{ED} = [(0.86 \div 0.90) \times (300 \text{ fsw} + 33 \text{ fsw})] - 33 \text{ fsw} = 285 \text{ fsw}$.

The EAD theory assumes the partial pressures of dissolved O₂, CO₂ and water vapor do not change with depth or gas mixture. Tissue metabolism normally holds both tissue oxygen tension (PtO₂) and tissue carbon dioxide tension (PtCO₂) at nearly constant levels, but PtO₂ increases when the partial pressure of inspired oxygen (PiO₂) is high. Tissue metabolic requirements are met by dissolved oxygen when venous hemoglobin is saturated. This is why some experts believe oxygen behaves as an inert gas at very elevated PiO₂. Animal experiments have shown that PiO₂ of 3 to 3.5 ata contributes to the incidence of decompression illness, although a human study did not find a statistical difference in DCS for EAD dives with a PiO₂ up to 2 ata compared to standard air dives.¹⁵

A **corrected EAD'** may be appropriate for long dives. It's derived by $\text{EAD}' = \text{EAD} + (\Delta\text{PtO}_2 \div 0.79)$. ΔPtO_2 is the change in tissue oxygen tension due to breathing elevated pressures of oxygen (PiO₂). The oxygen window is predicted to be a linear function of PiO₂ until it reaches its maximum value, which is determined by the percentage of arteriovenous oxygen extraction.^{4/15}

The Equivalent Air Depth (EAD) formula is used to calculate the **Equivalent Narcotic Depth (END)** for trimix when oxygen is not assumed to be narcotic. But when it is assumed to have the same narcotic potency as nitrogen, the calculation changes to: $\text{END} = [(FO_2 + FN_2) \times (D + 33 \text{ fsw})] - 33 \text{ fsw}$. The result is a deeper END. In general, the deeper the dive, the more desirable it is to have a shallower END, although the tradeoff is usually longer decompression. Depending on a diver's personal narcotic tolerance, an END between 80-130 fsw (24-39 msw) is advised, but 100 fsw or shallower is recommended for training dives.

DISSOLVED GAS MODELS

Haldane/Workman

USN

Bühlmann

ZH-L

Hamilton

DCAP

- **Limits tissue saturation**
- **Maximizes elimination gradient**

Trimix Section 2 Pg. 6

Dissolved gas models limit degrees of tissue saturation, assuming gas exchange is controlled by perfusion or gaseous diffusion in blood-tissue. Exchange of inert gas is driven by the local gradient, the differential between arterial blood and local tissue tension and seeks the maximum uptake or elimination by maximizing this gradient. The model may be perfusion limited, with exponential response functions, or diffusion limited. Diffusion dominates in tissues with minimal vascularity and greater distance between capillaries. Haldanian theory limits (N_2) compartment supersaturation by critical M-values with a range between $36 \text{ fsw} \leq M \leq 122 \text{ fsw}$ based on 6 halftimes of 5, 10, 20, 40, 80 and 120 minutes.^{2/13}

Bubble theories are limited by the relative difference between absolute pressure and tissue tension. The critical gradient is $G = M/.79 - P$. Critical ratios, R-values, are critical tensions divided by P. R and M are equivalent values, differing by the multiplicative factor of P (ambient pressure). Critical tensions are linear functions of pressure, dissolved gas tissue tensions (gradually) increase with ambient pressure, and are perfusion limited. Critical ratios are hyperbolic functions of pressure, ratios decrease (rapidly) with increasing pressure and are perfusion limited.

Diffusion limited gas exchange is assumed to be the sum of the exponential response time of arterial and tissue tensions. Early Haldanian (USN) models employed an exponential uptake and elimination algorithm. An **E-E algorithm** (exponential in-exponential out) assumes saturation occurs at the same rate as desaturation. It results in no-stop times remaining the same for repetitive dives to the same depth with the same surface interval time. Originally Bühlmann's decompression theory employed an E-E algorithm using 16 compartments with N_2 halftimes from 2.65 to 635 minutes and helium halftimes from 1 to 240 minutes. Both models later went to **E-L algorithms** (exponential in-linear out) that stipulates inert gas elimination is slower than uptake. ZH-L N_2 halftimes now range from 4 to 635 minutes and He halftimes range from 1.5 to 239 minutes. One of the results for repetitive dives are gradually decreasing no-stop times and increasing deco obligation for dives beyond no-stop limits. **All models are limited by saturation of a slow, single tissue halftime compartment for single bounce dives.** USN tables use 120 minutes with a critical ratio of 1.54 (a limiting surfacing M-value of 52 fsw) and ZH-L tables use 635 minutes.¹³ But supersaturation ratios are now believed to be depth dependent, which means multiple controlling compartments come into play for repetitive dives, long dives and mixed gas usage.

Voyager and Abyss decompression programs employ modified Bühlmann algorithms. Using 50% conservatism on Voyager means the controlling compartment should not exceed 85% of its M-value. Thus, when a 100 fsw ceiling is calculated, the computer generates a 120 fsw ceiling in the schedule.^{14/20} Voyager's M-values are not permitted to reach 95% of the maximum over-pressurization (personal communication Dale Harrod 1998).²³ Dr. Hamilton's Decompression Computation and Analysis Program (DCAP) KW Consortium tables rely on 12 compartments limited to 80% of tolerated M-values.

FREE GAS PHASE MODELS

VPM by Yount & Hoffman

Varying Permeability Model

RGBM by Bruce Wienke

Reduced Gradient Bubble Model

- Phase separation or bubbles trigger simple DCS
 - DCS prevention » bubble prevention
- Gradual pressure reduction minimizes bubble formation

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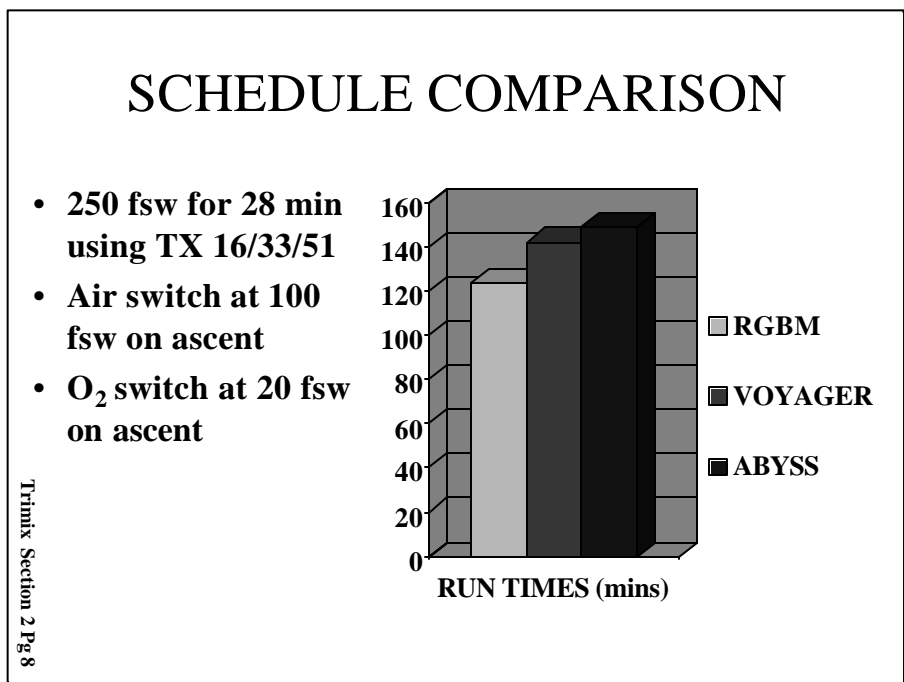
Yount's and Hoffman's **Varying Permeability Model (VPM)** is a perfusion limited model that focuses on the amount of separated gas, with the pressure balance bubble gradient increasing with depth (opposite of dissolved gas models) and uses an iterative algorithm. Free gas phase dynamics require deeper decompression staging formats.^{2/12/13} **VPM Model features include:**

1. Reduced no-stop times
2. Safety-stop at 10-20 ft.(3-6 m) for 1-2 minutes for dives to 40-90 ft (12-27 m) and for 2-3 minutes for dives to 90-240 ft (27-73 m)
3. Ascent rate not to exceed 60 fpm
4. Restricted repetitive exposures above 100 fsw to reduce permissible bubble excess over time
5. Restricted spike (shallow to deep) exposures based on excitation of micronuclei
6. Restricted multi-day dives due to regeneration of micronuclei
7. Smooth coalescence of bounce and saturation limit points
8. Consistent model constraints for altitude diving

Dr. Wienke devised a modern phase algorithm that addresses repetitive diving and diving at altitude with the use of air, nitrox, heliox or trimix. It's called the **Reduced Gradient Bubble Model (RGBM)**. It employs an iterative approach using a weighted split between free-blood and dissolved-blood gradients, with the weighting fraction proportional to the amount of separated gas per unit of tissue volume. Bounce gradients can be applied to repetitive diving if they are reduced for successive exposures. This dual phase model tracks both dissolved gas and free phases by limiting critical excitation radii computed according to the free-dissolved gas gradient across the bubble film interface. Deeper deco stops maximize free phase elimination, which increases as pressure increases, directly opposite from elimination of dissolved phases, which increases as pressure decreases.^{2/13} **For repetitive applications the RGBM:**

1. Reduces permissible bubble numbers and thus, bottom time
2. Reduces permissible gradients and thus, multi-day exposures
3. Penalizes deeper than previous dives
4. Affects all tissue compartments (fast and slow)

RGBM recovers Haldane's approach to decompression modeling. **For dives shallower than 200 fsw, RGBM schedules for air are between USN and RNPL** (Royal Navy Physiological Laboratory) table limits, but **RGBM schedules are shorter for deeper dives**. Helium schedules are close to the total times for USN, but call for deeper stops and shorter shallower stops (personal communication Wienke).



fsw	RGBM	ABYSS	VOYAGER	Schedules for free phase models are made longer by dialing in “larger” bubbles and “smaller” permissible phase separation. ¹³ This RGBM schedule factors the sum of the inert gas fractions by 1.22 to approximate Abyss 1.5 conservatism. ¹ The Voyager schedule is computed at 50% conservatism. ²³
180	1			
170	1			
160	1			
140	2			
130	2			
120	2			
110	2		1	
100	2	1	1	
90	3	1	2	
80	3	3	2	
70	4	3	4	
60	6	6	6	
50	7	7	8	
40	9	12	14	
30	13	18	23	
20	11	20	16	
10	18	42	29	
Run Times:	123.66 min.	148.7 ins.	142 min.s	

TX16/24 @ 170 FSW FOR 25 MIN

VOYAGER (ZH-L)			RGBM		
fsw	mix	mins	fsw	mix	mins
10	O ₂	12	10	O ₂	6
20	O ₂	7	20	O ₂	4
30	air	9	30	air	5
40	air	4	40	air	3
50	air	2	50	air	3
60	air	1	60	air	1
100	air	0	70	air	1
170	16/24	25	80	air	1
Deco Time = 35 minutes			90	air	0
			100	air	1
			170	16/24	25
			Deco Time = 25 minutes		

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These two schedules are for the same mix, depth, bottom time and 30 fpm descent/ascent rate, but **RGBM stops begin much deeper and shallow stops are shorter than those for the ZH-L model** generated on Voyager. Dr. Wienke reports, “Deeper stops provide increased off-gassing pressures that reduces bubble growth rates dramatically in shallow zones, while impacting dissolved gas buildup in the slowest compartments minimally.”¹³

Post dive Doppler ultrasound monitoring of divers is being used to predict safer decompression procedures. Doppler bubble Grade 1 means an occasional bubble is heard. Grade 2 means bubbles are present, but in less than half the cardiac cycles. Grade 3 indicates bubbles are heard during every cardiac cycle. Grade 4 means there are continuous bubbles, which obscure normal cardiac sounds. In one study of 84 decompression incidents, 87% of all DCS was associated with Doppler bubble Grades 2, 3, and 4, but 100% of Type II DCS was associated with Grades 3 and 4. The presence of low bubble Grades are good predictors of decompression safety (development of safer procedures), but not necessarily a tool for early diagnosis of DCS as was once hoped for with Doppler.

A high workload at maximum depth can increase a diver’s physiological decompression requirements (total deco time) by a factor of 3 and the depth of the first deco stop. Lightly exercising (stretching) during deco stops may assist dissolved gas elimination and Lippmann says could provide a physiological **reduction in the decompression time by 30%**.^{5/15} Raising the body temperature during deco aids inert gas elimination. Being cold during deco decreases off-gassing and can greatly increase a diver’s physiological need for additional decompression.^{6/15/19} Research has shown that divers who are cold throughout a dive had fewer detectable Doppler bubbles (limited to < 20 microns) than divers who were warm throughout a dive.¹³ But being warm at depth and then cold during deco inhibits inert gas elimination, underestimating actual off-gassing. For dive sites where there is a dramatic thermocline at a known depth, it is wise to program in a deco stop at this transition depth to allow the body to warm up and blood perfusion to normalize before ascending further.

TX16/24 @ 52 MSW FOR 25 MIN

VOYAGER (ZH-L)

msw	mix	mins
3	O ₂	12
6	O ₂	7
9	air	9
12	air	4
15	air	2
18	air	1
30	air	0
52	16/24	25
Deco Time = 35 minutes		

RGBM

msw	mix	mins
3	O ₂	6
6	O ₂	4
9	air	5
12	air	3
15	air	3
18	air	1
21	air	1
24	air	1
27	air	0
30	air	1
52	16/24	25
Deco Time = 25 minutes		

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RGBM & ZH-L COMPARISONS

RGBM & ZHL stop time comparisons, 30 fpm descent & ascent, TX down and up, air up from 100 fsw, O2 up from 20 fsw										
Total Deco	47	78	50	83	98	72	59	157	115	93
O2 10	10	16	11	17	31	23	19	48	35	28
O2 20	6	10	6	11	19	14	11	28	20	16
AIR 30	8	12	9	13	17	14	12	28	22	18
AIR 40	5	9	5	9	11	9	7	18	14	12
AIR 50	4	6	3	7	8	5	4	12	9	7
AIR 60	3	5	3	5	5	3	3	8	6	5
AIR 70	2	3	3	3	3	3	2	5	4	3
AIR 80	1	2	1	2	2	1	1	4	3	2
AIR 90	1	2	1	2	2			3	2	2
AIR 100	1	2	1	2				2		
TX 16/33 110	2	2	2	3				1		
TX 16/33 120	1	2	1	2						
TX 16/33 130	1	2	1	2						
TX 16/33 140	0	2	1	2						
TX 16/33 150	1	1	1	1						
TX 16/33 160	1	1	1	1						
TX 16/33 170		1		0						
TX 16/33 180				1						
TX 16/33 190										
TX 16/33 250	8.33 min	8.33 min	8.33 min	8.33 min	8.33 min	8.33 min	8.33 min	8.33 min	8.33 min	8.33 min
TX 16/33 250	20 min	30 min	20 min	30 min	20 min	20 min	20 min	30 min	30 min	30 min
generated on:	RGBM	RGBM	RGBM	RGBM safer	A150	A120	A100	A150	A120	A100
corresponds to:	A100	A100	A120	A120	ZHL	ZHL	ZHL std	ZHL safer	ZHL	ZHL std

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This chart is a **comparison of RGBM and ZH-L schedules for identical dives**. “RGBM safer” employs a bubble R_0 of 1.068 microns to correspond to nearly the same level of conservatism employed by ABYSS 150, which employs out-gassing halftimes that are 1.5 times longer than in-gassing halftimes (personal communication Wienke). “A100” is the chart abbreviation used to identify the ABYSS 100 algorithm.¹ It is the Abyss algorithm normally used for healthy, hydrated, physically fit divers without any known susceptibilities to DCS. Of interest is the fact the **RGBM total decompression time is significantly shorter than the companion ZH-L schedule even though conservatism is matched**.

Dr. Wienke generated the values for this chart to illustrate the differences between RGBM and ZH-L schedules. **Information on this chart should not be used to plan actual dives**. It is vitally necessary to read, understand and follow all the directions supplied with any table or metering device you use for actual decompression purposes.

GAS SELECTION

- » **Bottom Mix, Back Gas**
- » **Bailout Mix**
- » **Travel Mix, Transition Gas**
- » **Deco Gas/Mix, Hot Gas/Mix**
- » **Surface Supplied/Staged Gas**
- » **Suit Inflation/Insulation Gas**
- » **Medical O₂, Treatment Gas**

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Bottom Mix (back gas) is planned around the desired END and PO₂. The doubles content's tag should include the mix gas fractions, maximum operating depth (MOD), analysis date and the diver's name, all in permanent ink. It should be installed on the right cylinder crown behind the manifold where it can be read when the set is fully rigged. Personally owned tanks should have the owner's name painted or inscribed in permanent ink on the cylinder crown. Rented cylinders should have the user's name inscribed in black permanent ink on a strip of duct tape adhered to the left cylinder crown behind the manifold.

Bailout Mix is a separate supply of bottom mix, light trimix or air that is not toxic to breathe at the maximum planned dive depth.

Travel Mix is breathed in the depth range where the back gas is hypoxic or the PO₂ is less than 0.16 ata.

Deco Mix (Deco Gas or Hot Gas) accelerates inert gas elimination and is used for safety or to reduce deco time. Nitrox or helitrox is typically used during shallower stops. Air, trimix or heliox is used during deeper stops. Switching to a deco/travel mix at the first deco stop is common because it's simpler when generating custom tables on desktop decompression software and when making a gas switch. For instance, DCIEM tables call for a switch to air at the first deco-stop, while DECAP Key West Consortium Tables call for a switch to EAN36 at 110 fsw (33 m). Because **oxygen decompression is independent of depth the 10 ft. (3 m) stop time can be conducted at 20 ft. (6 m)** to increase the bubble off-gassing gradient. But when generating a computerized schedule, input your decision to pull the 10 ft. stop at 20 ft. to calculate the correct O₂ exposure. Take 5-minute breaks on bottom mix every 20 minutes during O₂ breathing. Do not count "air" breaks as deco time when the schedule calls for use of oxygen-enriched gas or O₂. Normoxic breaks are **considered "dead time" when they are not part of mandatory deco time.**

Surface Supplied Gas via a tethered umbilical that is staged at or on a bar/platform/anchor line is generally done to conserve diver carried gas in sling cylinders for subsequent dives or may be deployed only for emergency use. To prevent the possibility of making a lethal gas switch, NAUI recommends trimix students stage cylinders of pure oxygen at or shallower than 20 ft. (6 m) whenever operational and environmental conditions permit without increasing risk to the divers.

All gas cylinders, including those for suit inflation, must be analyzed, labeled and tagged after they are filled. Users should analyze them again to confirm their contents before entering the water!

Medical (USP) or Aviator Oxygen (ABO) must be available in sufficient quantity to treat all the afflicted divers (possibly the dive team) until they reach a hospital or paramedics arrive with additional O₂. The most effective in-field first-aid is 100% O₂ supplied by a demand-valve mask. Scuba supplied oxygen will suffice as a backup supply, but the victim must not nose breathe because doing so will dilute the percentage of O₂ delivered to their tissues, but wearing a nose clip will prevent this.

NORMOXIC RANGES

$$0.16 \text{ ata} \leq \text{PO}_2 \leq 1.44 \text{ ata}$$

- **Heliair 16/24/60 - Normoxic 0 - 264 fsw**
END 136 fsw at 190 fsw & 163 fsw at 225 fsw
- **Heliair 14/33/53 - Normoxic 5 - 306 fsw**
END 117 fsw at 190 fsw & 140 fsw at 225 fsw
- **Trimix 16/40/44 - Normoxic 0 - 264 fsw**
END 91 fsw at 190 fsw & 111 fsw at 225 fsw
- **Trimix 14/50/36 - Normoxic 5 - 306 fsw**
END 69 fsw at 190 fsw & 85 fsw at 225 fsw

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The **normoxic scuba diving ranges above comparing heliair and trimix** are based on a PO_2 range of 0.16 ata to 1.44 ata. Oxygen is not considered narcotic in END calculations and the comparison depths are based on the minimum training depths for the deep dives in Level I and in Level II. The limiting PO_2 for nitrox scuba dives is 1.6 ata, but NAUI standards require dropping this to 1.4 ata at maximum depth for all deep or mixed gas dives and when mandatory staged decompression is performed. The USN reduced the limiting PO_2 for Navy scuba divers to 1.3 ata and when only making one dive per day they do not track oxygen exposures.^{19/22} PO_2 limits should be decreased as dive depth increases because the time to return to the surface increases. Also, as gas density increases, ventilation is less efficient and the partial pressure of carbon dioxide (PACO_2) increases, factors that lower the onset point for oxygen convulsions when O_2 exposures are high. Helium decreases gas density in proportion to the amount of nitrogen it replaces in a diver's bottom mix, which reduces CO_2 and its concomitant contribution to oxygen toxicity.¹⁴

To produce trimix, typically oxygen, helium and air are transferred into a scuba cylinder according to partial pressures. Without helium or nitrogen analysis, there always is some degree of uncertainty. An error proof process is paramount. Pressure gauge accuracy is the first step in mix accuracy, then analyzing at the heliox stage before topping off with air and again after the final target pressure is obtained.

Obviously this requires an accurate O_2 analyzer. A 1% error can mean a 4% error in the nitrogen content or a 5% error in the helium content.²⁰ Compounded errors resulting in a different mix than planned means the decompression schedule will not match a diver's true physiological obligation.

The advantages of diving trimix are having an optimum oxygen content as safely possible and limiting nitrogen content to an acceptable narcotic dose at the maximum planned depth. The advantages of heliair are not handling pure O_2 and less chance for mixing error because both the helium and nitrogen content can be calculated from the analyzed oxygen content. In addition, topping off a partially full cylinder of heliair does not carry the uncertainty of topping off trimix. One drawback is at high helium percentages, heliair tends to be hypoxic, which necessitates use of a travel mix. To calculate the gas fractions of heliair, **divide the analyzed heliair FO_2 by 0.21 and subtract the answer from 1.0 to get the FHe. The balance gas fraction is the FN_2 .**¹¹ $\text{FHe} = 1 - (\text{FO}_2 \div 0.21)$ and $\text{FN}_2 = 1.0 - (\text{FO}_2 + \text{FHe})$.

NORMOXIC RANGES

$$0.16 \text{ ata} \leq \text{PO}_2 \leq 1.44 \text{ ata}$$

- **Helair 16/24/60 - Normoxic 0 - 80 msw**
END 41 msw at 58 msw & 50 msw at 69 msw
- **Helair 14/33/53 - Normoxic 1.5 - 93 msw**
END 36 msw at 58 msw & 43 msw at 69 msw
- **Trimix 16/40/44 - Normoxic 0 - 80 msw**
END 28 msw at 58 msw & 34 msw at 69 msw
- **Trimix 14/50/36 - Normoxic 1.5 - 93 msw**
END 21 msw at 58 msw & 26 msw at 69 msw

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Metric values for normoxic scuba diving ranges comparing heliair and trimix.

COMMON O₂/N₂ DECO MIXTURES

DECO MIX	MOD	STOP DEPTH
OXYGEN	£ 20 fsw	20 fsw
EAN80	£ 33 fsw	30 fsw
EAN70	£ 42 fsw	40 fsw
EAN50	£ 72 fsw	70 fsw
EAN36	£ 113 fsw	110 fsw
EAN32	£ 132 fsw	130 fsw
AIR	£ 218 fsw	210 fsw

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This list of **common oxygen-nitrogen decompression mixtures** is not meant to be an exhaustive list of a diver's decompression alternatives. Although it's more costly, substituting helium for part of the nitrogen will minimize nitrogen uptake over mixtures with comparable O₂ percentages.

Heliox and helitrox decompression mixtures may offer physiological advantages over their nitrogen based counterparts. Dr. Lanphier found mean PACO₂ was significantly less at depth when exercising breathing heliox 45/50 compared to EAN45. Heliox 50 (50% O₂ and 50% He) can be used to accelerate decompression for stops 70 fsw (21 m) and shallower. Some experienced trimix divers use a combination of 50% O₂, 25% He and 25% N₂ within this same depth range. For deeper stops, helitrox mixtures with 26-30% O₂, 13-17% He, and the balance N₂ are beneficial.

No matter what gases you use, it's imperative to abide by oxygen depth and time limits and to calculate the planned cumulative oxygen exposure before each dive to stay well within the single dive and daily exposure limits established by NOAA or the USN and recommended by NAUI.

Calculated depth limits **should be rounded shallower to the closest 10 ft. (3 m) depth to avoid confusion**. Do not use values that do not coincide with a tabulated increment when designating practical in-water depth limits. Rounding toward safety leaves a margin for error to compensate for minor depth variations, such as waves passing overhead and holding onto an anchor line during decompression. (A Jon-line attached to an anchor line will help alleviate depth fluctuations.)

When labeling a stage cylinder, use two large labels for the MOD, but do not write anything else on the sticker. This means there is only one decision to be made before breathing a gas, "Is my depth shallower than the identified MOD?" Minimally, put one decal at the top of the cylinder facing the diver when they are outfitted and another horizontally down the outside so others can read it - right side up. Use paint or permanent ink to inscribe the appropriate **DEPTH** and **UNITS** in large bold numerals. For example, if the mix is EAN80, the MOD decal should read **30 ft.** (or 9 m depending on which system is recognized by all team members). The small contents sticker should have the mix analysis and other standard accompanying information. **Keep it simple!** Human error, not equipment failure, is the leading reason for most technical diving fatalities!

COMMON O₂/N₂ DECO MIXTURES

DECO MIX	MOD	STOP DEPTH
OXYGEN	£ 6 msw	6 msw
EAN80	£ 10 msw	9 msw
EAN70	£ 13 msw	12 msw
EAN50	£ 22 msw	21 msw
EAN36	£ 34 msw	34 msw
EAN32	£ 40 msw	40 msw
AIR	£ 66 msw	64 msw

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Metric comparisons

GAS SWITCHING PROBLEMS

- √ **Omitted Decompression (Gas Loss)**
- √ **Hyperoxic Seizure (Off Oxygen Effect)**
- √ **Hypoxic Blackout (Extraction Effect)**
- √ **Squeeze (Middle Ear Oxygen Absorption)**
- √ **DCS and VGE (Isobaric Counter Diffusion)**
- √ **Narcosis and HPNS**

Trimix Section 2 Pg 17

Decompression should dictate the gas path, but keep gas switches to a minimum. With every switch there is potential for problems, mainly making the wrong switch and having an O₂ seizure. There is always a chance of **unintentional gas loss** and, if reserves are not sufficient, it can lead to inadequate decompression.

Breathing a hypoxic mix can cause an **extraction effect**, a reverse transfer of oxygen from the tissues back into the lungs, which results in tissue hypoxia.^{10/16} Deficient PtO₂ can lead to a shallow water blackout. Due to affects of the extraction effect, hypoventilation and reduced circulatory efficiency, it's probably best to use a minimum PO₂ of 0.2 ata. But Dr. Hamilton says the threshold for hypoxic blackout is about 12% (personal communication 1999).^{4/15} It can occur in as little as 30 seconds, but warning signs include loss of night vision, headache, formication, dizziness, bluish lips and fingernail beds (hard to see underwater).¹⁴

The **off oxygen effect** is a phenomenon where a seizure occurs several minutes after a person stops breathing pure oxygen. This is more a concern for divers in saturation and divers conducting long decompressions on oxygen and patients receiving HBO because their blood is saturated with oxygen.

Another problem from pure oxygen consumption is **middle ear oxygen absorption syndrome**. Oxygen is metabolized away after the dive, which results in negative pressure (squeeze) and possibly fluid in the middle ear.²² Alternobaric vertigo is attributed to a pressure differential between the ears. If you experience a middle ear squeeze after breathing 100% O₂, perform a very gentle Valsalva maneuver to relieve it.

DCS can be precipitated by switching gases when ambient pressure is constant if the gas mixtures have entirely different densities and solubilities. **Isobaric counterdiffusion** causes tissue supersaturation and subsaturation. **Deep tissue supersaturation involves transient inert gas counterdiffusion** between internal tissues and their capillaries from making a switch from a mix diluted with nitrogen, neon or argon to a mix diluted with helium or hydrogen.^{2/13} Lighter gases diffuse into tissues faster than the heavier gases diffuse out (positive flux permeability), inducing isobaric tissue supersaturation. It can culminate in **deep tissue bends**, which is why **ambient pressure should always be increasing, not at a steady state or decreasing, when switching from a heavy to a light mix.**¹⁶ **Potentially lethal superficial tissue supersaturation** that occurs from continuous counterdiffusion through surface structures can produce gas lesions in the skin (skin bends), venous gas embolism (VGE) and vestibular DCS (spins). It's attributed to being surrounded by a much lighter (inert) gas than what the diver is breathing. Isobaric counterdiffusion problems are primarily issues for commercial saturation divers or divers decompressing from long dives in a deck chamber (DDC). A **sudden switch from a lighter gas (heliox, hydreliox, neox) to a heavier gas (air) can cause inner ear DCS**. Commercial divers found it can be avoided if the change is made gradually, at a deco stop.¹⁵ Some divers decrease breaths of back gas in stages by alternating breaths of deco gas if ascending. Light to heavy switches can also cause HPNS (hydreliox to heliox) and narcosis (TX or heliox to air or nitrox). Plan switches to mixtures with progressively lower inert gas percentages.

OXYGEN WINDOW					
	Dry Air	Alveolar Air	Arterial Blood	Venous Blood	Tissue
33 fsw Pressure	O ₂ : 6.6	H ₂ O: 2.0	H ₂ O: 2.0		
		CO ₂ : 1.8		H ₂ O: 2.0	H ₂ O: 2.0
		O ₂ : 4.5	CO ₂ : 1.8	CO ₂ : 1.8	CO ₂ : 2.1
		N ₂ : 24.7	O ₂ : 3.8	O ₂ : 1.6	O ₂ : 0.5
	N ₂ : 26.4	N ₂ : 24.7	N ₂ : 24.7	N ₂ : 24.7	N ₂ : 24.7

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The Dry Air values shown above in this chart on the Oxygen Window are approximated. They were derived by, $FN_2 0.80 \times 33 \text{ fsw} = PN_2 26.4 \text{ fsw}$ and $FO_2 0.20 \times 33 \text{ fsw} = 6.6 \text{ fsw } PO_2$.

The difference in oxygen between dry inspired air and alveolar (expired) air is estimated at about 6%.

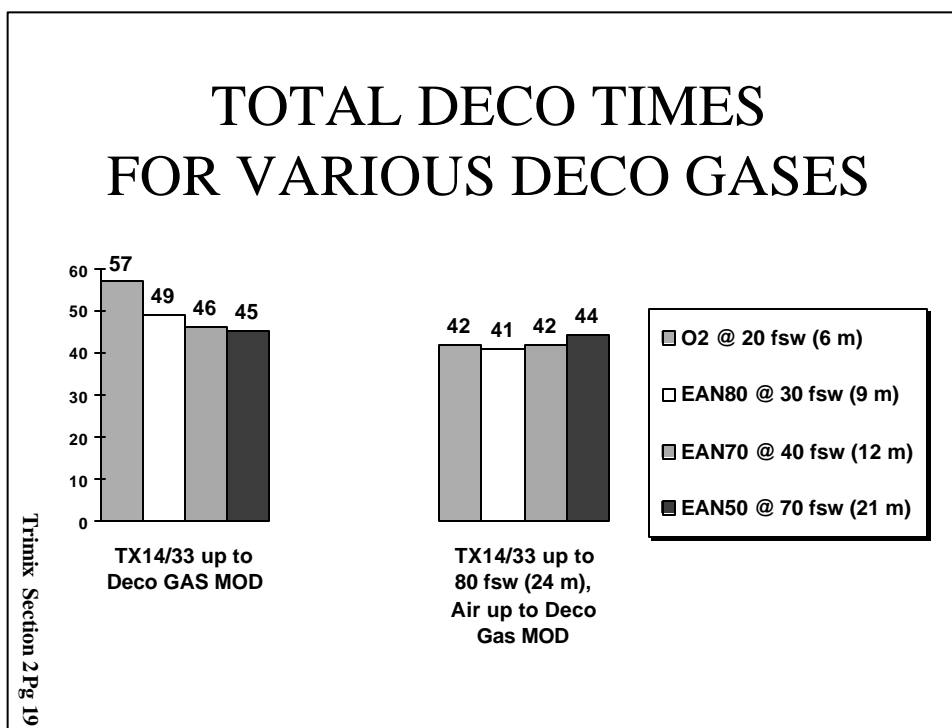
The **Oxygen Window** refers to undersaturated tissues and blood in relation to ambient pressure. The summed partial pressures of O₂, N₂, water vapor (H₂O), and CO₂ are always less than ambient pressure. Tissue and venous blood are **8-13% unsaturated** in relation to ambient pressure.

Tissue and blood O₂ tensions are metabolically reduced during each transition, and as a result, CO₂ increases at the tissue phase. **CO₂ is 21 to 25 times more soluble than the consumed O₂** and in accordance with Henry's Law exerts a smaller partial pressure than the O₂ it replaces. **Oxygen uptake exists because tissue oxygen tension (PtO₂) is always lower than the partial pressure of alveolar oxygen (PAO₂)**. A CO₂ elimination gradient exists because tissue tensions are always higher than PACO₂. Research suggests that the degree of undersaturation increases linearly with pressure, but decreases linearly with increases in the inert gas fraction of the breathing mixture.^{13/15}

The predicted and actual oxygen window differs depending on oxygen extraction in critical tissues. Inert gas partial pressure in a bubble is greater than the tissue tension because of the oxygen window. **The driving force of inert gas elimination from a bubble in tissue is based on the magnitude of the oxygen window.**¹⁵

Arterial tensions reach a steady state between alveolar (inspired) gas partial pressures in less than one minute and are nearly the same as alveolar air. **To allow time for arterial tissue tensions to equilibrate with alveolar gas partial pressures wait until consuming several breaths of the new gas or breathe the new gas for about one minute before starting the stop time after making a gas switch established by the decompression schedule.**

At 1 ata, alveolar oxygen gas pressure is 103 mmHg, arterial oxygen tension is 88 mmHg, venous oxygen tension is 37 mmHg and tissue tension is 10 mmHg. Corresponding carbon dioxide values are 41 mmHg, 47 mmHg, and 49 mmHg, respectively. Nitrogen gas pressure and tissue tensions are 569 mmHg.¹⁵



In this example, the descent and ascent rates are 30 fpm (9 mpm), **TX 14/33 is breathed down to 240 fsw (73 m) for 15 minutes bottom time and throughout the ascent until a gas switch is made.** The left bar graph depicts total decompression times when a switch is made to the deco gas at its MOD and the right bar graph depicts the total deco times when a switch is made to air at 80 fsw and then to nitrox or oxygen at its respective MOD. The total decompression times are shown for pure oxygen which is begun at 20 fsw (6 m) until surfacing, EAN80 at 30 fsw (9 m) until surfacing, EAN70 at 40 fsw (12 m) until surfacing, and finally EAN50 at 70 fsw (21 m) to the surface. The shortest deco time occurs for the dive where EAN50 is initiated at its MOD. EAN50 is the shortest at 45 minutes, EAN70 is next at 46 minutes, EAN80 follows at 49 minutes and last, O₂ with 57 minutes. The length of time breathing an oxygen-rich gas, as opposed to having the highest off-gassing rate at each deco stop, is the reason. Note, **this comparison is for a solution based model**, not a free gas phase model.²³

When two gas switches are made, the initial switch to air at 80 fsw (24 m) and then switching to nitrox at its MOD; total deco times across all four profiles are nearly identical. Air and EAN80 produce the shortest schedule and air and EAN50 are the longest.

In general, when only one gas switch is made, switching to a nitrox mix at the first scheduled stop (deepest) will yield the shortest decompression time compared to nitrox mixes that must be implemented significantly shallower.

Keep in mind, the decompression advantage may be offset by accumulating a high percentage of CNS Oxygen exposure and is the limiting factor for decompression planning.

WHY USE AIR OR AN AIR ALTERNATIVE?

- ✍ **Performs as a deep decompression gas**
- ✍ **Abort gas during descent or at training depth**
- ✍ **Life saving bailout option if back gas is lost**
- ✍ **Less expensive**
- ✍ **Air avoids blending and potential analysis error**

Trimix Section 2 Pg 20

Air or an air alternative can be used as a decompression gas from deep long dives when the helium uptake is significant and when more than one gas switch is made during the ascent.^{9/20} It offers some operational advantages over nitrox, but they must be weighed against the possible uptake of too much nitrogen. Dr. Wienke advocates using **trimix with 17% O₂ and 26% He (TX 17/26) as a bailout mix for depths down to 240 fsw (73 msw) because it is less narcotic than air and it produces a decompression schedule that is nearly identical to air using the RGBM algorithm.** However, heliair 16/25 may be a more practical alternative with little difference in the decompression schedule. TX 18/35 is used as an air alternative with some deep exploration divers.

If the choice is made for a deep decompression gas in lieu of a bailout gas because the first deco stop is between 100-130 fsw (30-40 m), a hyperoxic trimix with 17% helium may be preferable. Trimix with 32% O₂, 17% He and 51% N₂ (TX 32/17) may provide a decompression advantage over air because there is less nitrogen uptake and an advantage over EAN50 because a diver can go on it at 130 fsw (40 msw) compared to 70 fsw (21 m). Some divers use helitrox to reduce narcosis (and fatigue) for dives shallower than its MOD. Tim O'Leary has been diving helitrox successfully for several years for just these reasons (personal communication in 1998). It's customary to label a cylinder of air with the word AIR, but **for heliair, write all the gas fractions on the contents label and use MOD decals.**

If travel gas can be used to bailout from maximum depth, keep the cylinder valve 1/4 turn open and the second-stage stationed along the outward side of the bottle for fast access in the event of an emergency. When two stage bottles are carried throughout the dive, it's probably best to stage the mix with the lowest FO₂ on the right side because most divers are right handed and they are taught "right-side" air delivery from their initial scuba training. Position the second stage on the sling bottle where your right hand will be when your arm is bent forward at the elbow so that you can instantly grab it if you or another diver needs it. This leaves your left hand free to manipulate your BC inflator, assuming you use a traditionally rigged BC and second stages. Staging the bailout gas on the left means a right-handed diver will have to reach across their body and over a stage bottle to get to the second stage, thus wasting precious time.

ADDITIONAL CONSIDERATIONS

- ! **Depending on the depth, a switch to air can cause the sudden onset of nitrogen narcosis**
- ! **The physiological transition may be smoother using TX 17/26 or a similar Heliair alternative**

Trimix Section 2 Pg 21

A widely used procedure for commercial heliox divers was to switch from heliox to air at depths between 100-200 ft. to save helium, improve voice communications, keep the diver warm and accelerate decompression. However, they found the **air switch could cause inner ear decompression sickness if the switch was made too deep or too quickly**. Helium diffuses from the middle ear gas space into the inner ear faster than nitrogen can diffuse out from blood and tissues, causing inner ear supersaturation. Later they discovered it was not a problem if the **switch to air from heliox occurred shallower than 165 fsw (49.5 msw)**.¹⁵ It's not certain if the switch from trimix to air would produce the same results, but an air switch should be made significantly shallower with regards to decompression. In any case, it may be more prudent to **make the first stop for several minutes on back gas to accommodate the initial outrush of helium**. Then, while at the same depth, switch to the heavier deco gas and continue the decompression schedule. **A gradual switch (alternating breaths of back gas and travel gas) is better than rapidly switching from a helium-rich mixture, especially when ascending**. Make a gas switch to either air, nitrox, heliair or helitrox shallower than 100 fsw (30 msw) to minimize nitrogen uptake.

Switching to air from a back gas with a significantly shallower END may produce sudden debilitating nitrogen narcosis. Such a switch should only be done in a life saving situation when there are no better options available and then with due regard to keep the activity level as low as possible.

Using TX 17/26 instead of air would produce less narcosis, provide smoother decompression transition, which would probably cause less physiological insult (personal communication Dr. Wienke). The MOD for TX 17/26 is 277 fsw (84 msw), while it's 218 fsw (66 msw) for air at a PO₂ of 1.6 ata. TX 17/26 is a better bailout mix for the Level 1 Trimix diver because the depth limit for training is 225 fsw (69 msw). It also provides a larger bailout window for the Level 2 Trimix diver. Keep in mind, one should never plan a dive to any limit — be it a depth or time limit for oxygen or nitrogen. For similar reasons, but mainly because it is less expensive, some mixed gas divers select heliair 17/17 as a bailout mix. This blend is achieved by putting about 500 psi of helium into a cylinder and then topping it off with air to 3000 psi.

Considering that a diver (mixed gas student) is generally only going to carry two gas mixtures in addition to their back gas, **it's important to weigh the physiological consequences of various mixtures. Then a decision must be made to either reduce deco time (total time in the water) or to have a life-saving bailout option.**

WHY USE OXYGEN?

- ✓ **No inert gas uptake**
- ✓ **Fastest inert gas washout - highest gradient**
- ✓ **The 10 ft. (3 m) stop can be made at 20 ft. (6 m) to benefit from increased hydrostatic pressure**
- ✓ **Available as a treatment gas upon surfacing**
- ✓ **No mixing and avoids potential analysis error**

Trimix Section 2 Pg 22

Oxygen is viewed as the great equalizer. **With the RGBM algorithm, when oxygen is used from 20 fsw (6 m) to the surface, total decompression time is very nearly the same regardless if the first deco gas is air, nitrox or trimix** (personal communication Dr. Wienke). Identical dives on TX 10/80 to 140 fsw for 47 minutes bottom time generates 48 minutes of total decompression time regardless if air, EAN26 or TX 35/25 is breathed from 60 fsw up to 20 fsw where 100% O₂ is breathed until reaching the surface. (Assuming identical descent and ascent rates, bubble parameters, surfacing altitude and maneuver depths). The same conclusion was found with RGBM profiles generated for 180 fsw dives for 38 minutes on TX 10/80 with three gas switches: TX 35/25, TX 50/15 and O₂, or EAN26, EAN36 and O₂, or air and O₂. This does not hold true with dissolved gas algorithms, but oxygen use still reduces total decompression time by 40% compared to air alone.¹⁵ If the total time in the water is not increased significantly, it may be beneficial to use oxygen during shallow stops for physiological safety, not to shorten deco time.

Dissolved inert gas washout is independent of depth when breathing pure oxygen.¹⁶ This means that the 10 ft. (3 m) stop time can be conducted at 20 ft. (6 m). After finishing the 20 ft. deco time you would remain at 20 ft. until finishing the 10 ft. stop time and then would surface. Remember to calculate O₂ exposures before the dive to stay within acceptable limits. The deeper stop is not only beneficial for eliminating dissolved inert gas, it also keeps a greater hydrostatic cap on microbubbles if they are present. The following are **7 recommendations regarding the labeling, staging and use of oxygen:**

1. Affix a contents label and a MOD decal on the top and down the sides of the cylinder.
2. Use a yellow or green LP hose and tape a MOD sticker on the second stage exhaust cover.
3. Put a small MOD label on the face of the submersible pressure gauge.
4. Permanently attach a neck strap on the O₂ second-stage that is tight enough to hold the second stage in your mouth if you shake your head vigorously. It should be a different color than the neck straps used on second stages delivering back gas.
5. Team members rig and stage their deco gases the same. It's advisable to carry O₂ on the left side.
6. Keep the second stage bagged and the system pressurized, but the valve closed until time to use it.
7. The instructor verifies the depth and gas just before a student makes a gas switch to be sure they are shallower than its MOD and they do not switch gases until all the students have switched. Dive team members should check one another's gas, its MOD and the depth whenever a switch is made.

ADDITIONAL CONSIDERATIONS

- √ **5 minute normoxic breaks every 20 minutes**
- √ **Vasoconstrictor, free radicals and reduced breathing stimulus compared to nitrox**
- √ **Volume requirement is difficult to meet without use of an O₂ compatible HP booster**

Trimix Section 2 Pg 23

When breathing O₂, it is important to take **normoxic (air or back gas) breaks every 20 minutes to limit CNS toxicity or every 12 - 18 minutes to limit effects of vasoconstriction or cold**. The deco-clock only runs when you are breathing the gas for which the schedule was generated. Typically air breaks are not counted as part of mandatory decompression time when using an accelerated schedule.^{16/19}

Oxygen breathing results in a greater quantity of **free radicals (O₂⁻) or superoxides**. They inactivate cell enzymes, co-enzyme A, and damage DNA and lipid membranes, and have been linked to accelerated cataract growth and decreased visual acuity in patients undergoing long term HBO therapy (HBOT). In any case, the benefits of oxygen use during a dive may outweigh the associated risks. Some technical divers take vitamin E, C, and A as well as antioxidants, such as pycnogenol[®] or coenzyme Q-10 to counter the effects of high oxygen exposures. The benefits to divers is subjective, and in any case, taking supplements does not relinquish the need to stay well within established O₂ depth and time limits.

Vasoconstriction begins after about 12 minutes of breathing pure O₂, which reduces blood perfusion and gas exchange. Although this helps to reduce edema, it can also decrease blood supply to areas that are poorly perfused. This is why an injured diver may experience symptom rebound during HBOT. Moreover, the rate of inert gas exchange is altered. In fact, some experts speculate at PO₂s of 2.0 ata and higher, oxygen may begin to behave as an inert gas.¹⁴


Some experts believe 90% to 95 % oxygen is just as effective for decompression and does not cause as much free radical formation nor the same reduction in breathing stimulus that pure oxygen does.¹⁵

Oftentimes the volume of pure oxygen required for a lengthy dive cannot be achieved without the use of a high-pressure booster pump. This is one reason EAN80 is often used instead of oxygen. It is simply made by filling a 3000 psig cylinder designated for oxygen service to 2240 psi with pure O₂ and then completing the fill with hydrocarbon-free air.

Every mixed gas diver needs to weigh the benefits of using oxygen against the risks and make an informed decision about the decompression gases best for them.

Pycnogenol is a register trademark of Horphag Overseas, Ltd, Geneva Switzerland, who has a US patent for its use as a free radical scavenger.

SECTION 2 COMPARED



- ✓ Helium Versus Nitrogen
- ✓ Saturation/Desaturation Speed
- ✓ Halftime Comparisons
- ✓ Equivalent/Effective Depth Formulas
- ✓ Decompression Models
- ✓ Schedule Comparisons
- ✓ Gas Selection
- ✓ Common O₂/N₂ Deco Mixtures
- ✓ Gas Switching Problems
- ✓ Deco-Gas Comparisons

Photo by Andy Ogburn

Trimix Section 2 Pg 24

1. Which He halftimes have the same tensions as 5, 10, and 23 minute N₂ halftimes? $\tau_{He} = \tau_{N_2} \times 0.3779$
2. How does the effective depth equation differ from the EAD formula? It considers altitude and calculates the equivalent depth for any inert gas % for which there is a standard table with the same component gases.
3. Describe 3 characteristics of dissolved gas models. Limits tissue saturation, gas exchange is driven by the gradient between arterial blood and tissue tension and elimination is maximized by shallower deco staging.
4. What is exponential uptake and elimination and exponential uptake and linear elimination? E-E, saturation occurs at the same rate as desaturation according to the sum of the inverse square root of the molecular weight of the component inert gases. E-L assumes desaturation is slower than saturation.
5. What is a practical outcome of an E-E decompression algorithm? No-stop times for repetitive dives to the same depth with the same surface interval time remain the same.
6. Name three dissolved gas decompression models. Haldane/Workman's USN tables, Canada's DCIEM tables, Bühlmann's ZH-L tables and Hamilton's DCAP KW tables.
7. Describe the distinctions of a free gas phase model and identify two models. Calculates separated gas, inert gas elimination gradient from bubbles increases with depth, gradually reduces pressure to minimize bubble formation and provides deeper decompression staging. VPM and RGBM
8. What are deep decompression stops designed to do? Maximize free phase elimination.
9. Deeper stops decrease total decompression time for a free gas phase model compared to a dissolved gas model, but what does adding deeper stops to a dissolved gas model do? Increases shallow stop times.
10. Deco time for trimix and air converge at about 1 and 2 hours for dives to 150 fsw (46 m), but for shorter and shallower dives, total decompression time is shortest on air, followed by trimix and then heliox.
11. List 5 possible problems with gas switches. Hyperoxia, hypoxia, middle ear squeeze, isobaric counter diffusion causing inner ear DCS or deep tissue bends, and unintentional gas loss.
12. Describe the extraction effect and its consequence. When PAO₂ is less than PtO₂, tissue oxygen transfers back into the lungs. Blackout occurs when critical tissues become hypoxic.
13. What is inherent unsaturation and what causes it? CO₂ that replaces O₂ that is metabolically consumed is 21-25 times more soluble and exerts less partial pressure. The summed tissues pressures are less than ambient pressure at a steady state. O₂ window provides the gradient for O₂ uptake and CO₂ elimination.
14. Describe 4 advantages for using oxygen during decompression. Less chance of mixing or analysis error, highest inert gas elimination, 10 ft. stop pulled at 20 ft. and it is readily available as treatment gas.
15. Describe 3 additional considerations for using O₂. 5 minute air breaks every 20 minutes, free radical formation, increased oxygen exposures and volume requirement is hard to meet without a booster pump.

SECTION 3 TOPICS

- ✓ **Human Response to PO_2**
- ✓ **Average RMV and VO_2 Rates**
- ✓ **Metabolic O_2 Consumption**
- ✓ **Personal Limitations**
- ✓ **Environmental Considerations**
- ✓ **Physiological Problems**

Trimix Section 3 Pg 1

Fifteen questions and their answers covering section 3 are on slide 54.

HUMAN RESPONSE TO PO₂

PO ₂ ata	RESPONSE
0.21 - 0.18	Normal, no noticeable effects
0.17 - 0.12	accelerated breathing, incoordination
0.12 - 0.10	Tires easily, emotional, insensitive to pain, abnormal fatigue
0.10 - 0.06	Lethargy, apathy, confusion, collapse, unconsciousness, nausea, vomiting
0.06 or less	Gasping, convulsions, respiratory arrest

Trimix Section 3 Pg 2

This slide provides symptoms resulting from low PO₂ or **hypoxia**. Respiratory centers in the brain and chemoreceptors on the aorta and carotid arteries are sensitive to blood levels of CO₂ and control the rate and volume of breathing. Blood levels of CO₂ must increase enough to decrease the blood pH, which triggers an increase in respiratory minute volume (RMV) to return CO₂ levels to normal. The very dangerous aspect of breathing a hypoxic mix is that a person can pass out before feeling air hunger or before receiving the stimulus to increase their breathing rate from elevated CO₂. **Hypoxic induced unconsciousness can occur in as little as 30 seconds.**^{6/7/10} It is unadvisable to descend on a hypoxic mix. Instead, use your travel/deco mix to descend to the depth where your back gas is normoxic, a depth where the PO₂ is 0.16 to 0.2 ata, and then switch breathing mixtures. In addition, do not make a strenuous surface swim prior to descent because it can also lead to an underwater blackout.

Hyperoxia is a condition whereby the tissues receive a poisonous level of oxygen. The maximum depth threshold for exposures during a scuba dive are associated with a PO₂ of 1.6 ata. NOAA established time limits for PO₂s that range from 0.6 ata to 1.6 ata for normal exposures, and higher and longer limits for life saving situations.^{16/19} During trimix training dives, the maximum PO₂ should be limited to 1.4 ata, but for deeper and longer dives it would be prudent to decrease this to 1.3 ata.^{2/13}

Some experts believe the biologic half-life of oxygen to be only 20 minutes, while some say it's 72 minutes and still others report it's 90 minutes. Several modern dive computers and decompression software programs base residual oxygen on a half-life of 90 minutes.^{12/23} Tracking residual O₂ toxicity to monitor pulmonary exposure should not be necessary if a diver limits their total dive O₂ exposure to conservative CNS limits and repetitive or saturation dives are not made.

CONVENTID is the acronym for **signs and symptoms of CNS oxygen toxicity**. It stands for Convulsions, Visual symptoms (loss of acuity, dazzle, lateral movement, visual collapse), Euphoria or Acoustic (Ears) symptoms (music, bells, knocking), Nausea (severe), Twitching lips, cheeks, nose or Tingling hands and arms, Irritability (disinterest, clumsiness), and Dizziness.^{12/16/19} Additional symptoms include facial pallor, sweating, bradycardia, palpitations, choking sensation, sleepiness, depression, unpleasant olfactory or gustatory sensations, respiratory changes, panting, hiccoughs, diaphragmatic spasms, vomiting, vertigo, epigastric tensions, and syncope.¹⁵ If you experience these or any unusual symptoms, immediately switch to back gas, signal your partner and ascend if possible. A seizure can occur without any premonition or so suddenly after the onset of a symptom to be of no practical help and underwater it's likely to cause drowning or death by embolism.

AVERAGE RMV AND VO₂ RATES

	RMV	VO ₂
Slow Swim	0.6 ft³/min	0.8 L/min
Average Swim	1.0 ft³/min	1.5 L/min
Fast Swim	1.4 ft³/min	1.8 L/min
Max Swim	2.5-3.5 ft³/min	3-4 L/min

Trimix Section 3 Pg 3

Respiratory minute volume (RMV) is the amount of gas the lungs process in one minute (liters/breath × breaths/minute). RMV is unaffected by ambient pressure, but it increases when breathing trimix because breaths per minute (BPM) increase due to helium's decreased density.¹⁴ **Variation in gas consumption rate with altitude is a density effect as well as a regulator function.** Atmospheric pressure decreases exponentially with altitude by about 1 fsw for every 1000 ft. of elevation (Density = Ph ÷ P). Density decreases with increases in altitude as a function of the ratio of ambient pressure to sea level pressure.¹³ For example, the pressure at 1000 ft. elevation is equivalent to 32 fsw which means the air is 0.969 as dense as that at sea level (32 fsw ÷ 33 fsw = 0.969).^{2/13} Helium decreases the mechanical and physical resistance of breathing and offsets some of the resistance of breathing at depth.

Surface consumption rate (SCR) is the consumption rate at 1 atmosphere. It must be adjusted for changes in ambient pressure to account for consumption at depth.^{5/8} Students should calculate resting and working SCR on trimix at depth. $SCR \text{ ft}^3 = (\text{rated cylinder ft}^3 \div \text{rated cylinder psig}) \times [(\text{psig used} \div \text{minutes}) \div \text{ata}]$

Physiologists base personal fitness on the oxygen cost of energy expenditure measured at rest. **MET is the metabolic equivalent of one unit of oxygen consumption (VO₂)** and is equal to approximately 3.5 ml (0.0035 L) of oxygen consumed per kilogram of body weight per minute at rest. Multiples of MET are used to estimate the oxygen cost of an activity; 3 to 5 for light work and more than 9 for heavy work. A fast scuba swim at a speed of 1 knot (100 ft./min) requires 8 METs. For healthy individuals, 2/3 of VO₂ max is met by aerobic metabolism alone. For 60 minutes or more of continuous work, oxygen consumption should not exceed 1/2 of VO₂ max.^{8/13} Physical conditioning improves VO₂ max and the higher the VO₂, the greater workload a person can handle. As a general rule, to sustain the rigors of scuba diving, a diver should have a maximum MET of 13.

Variation in consumption with activity is a metabolic effect that depends on an individual's cardiovascular system, lung capacity, metabolism, temperature, body morphology, drag and mental state. A person's **VO₂ is the same for the same amount of work** regardless if it's performed at the surface or underwater. A steady state consumption of 3.0 L/min can be maintained for 10 minutes by good swimmers, but uptakes of 3.0 to 4.0 L/min could only be maintained a few minutes before fatigue would intervene.

CO₂ levels up to 0.5% stimulate respiration, but higher levels lead to hypercapnia and air hunger. CO₂ narcosis, headache, dizziness, weakness, incoordination, perspiration, nausea, and confusion occurs at a SEV of 2-3%. At 10% (PCO₂ 0.1 ata) convulsions, then unconsciousness and eventually death occurs.^{8/10/19} Decreased density of helium and lower oxygen content help lower CO₂ buildup during a trimix dive.

AVERAGE RMV AND VO₂ RATES

	RMV	VO ₂
Slow Swim	18 L/min	0.8 L/min
Average Swim	28 L/min	1.5 L/min
Fast Swim	40 L/min	1.8 L/min
Max Swim	70-100 L/min	3-4 L/min

Trimix Section 3 Pg 4

These RMV and oxygen consumption rates on scuba are surface equivalency volumes (SEV) for both imperial and metric values. Liters are standard liters at 32 °F (0 °C) and 1 atmosphere of pressure.⁸

The respiratory loads and oxygen consumption values on this and the previous slide were measured at the following swimming speeds:

Slow swim = 0.5 knot (50 ft./min)

Average swim = 0.8 knot (80 ft./min)

Fast swim = 1.0 knot (100 ft./min)

Maximum swim = 1.3 knots (130 ft./min)

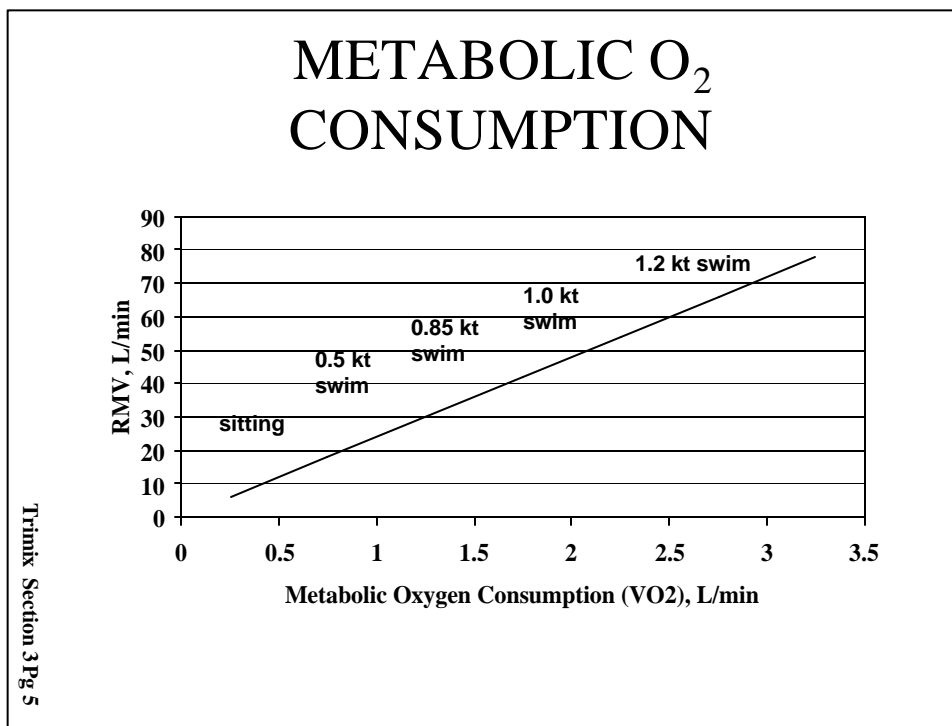
Note: A nautical mile is approximately 6000 feet; 1 knot equals 6000 feet ÷ 60 minutes = 100 ft./min.

1 MET is approximately 3.5 ml of oxygen per kg of weight per minute. Swimming at 1 knot on scuba requires 8 METs of work and is equal to 28 (ml/kg)/min: $3.5 \text{ (ml/kg)/min} \times 8 = 28 \text{ (ml/kg)/min VO}_2$.

A diver who weighs approximately 65 kg (143 lbs.) would consume about 1.8 L/min of oxygen during a fast scuba swim, $[28 \text{ (ml/kg)/min} \times 65 \text{ kg}] \div 1000 \text{ ml/L} = 1.82 \text{ L/min}$.

The minimum number of times an instructor should check students' back gas pressure is 5 times. Check at the 1. surface 2. check-stop 3. bottom 4. planned time to ascend 5. during the ascent.

Check deco gas pressure when the valve is opened and at each scheduled deco stop.



Oxygen metabolism ranges from 0.25 standard liters per minute (SLPM) for a person at rest to a high 3 SLPM for strenuous activity over a short duration.⁸ **Cellular oxygen consumption (VO₂) is unaffected by ambient pressure** and the relationship of VO₂ and RMV at different workloads is linear according to $RMV \text{ L/min} \div VO_2 \text{ L/min} = 24$ (e.g. $60 \text{ L/min} \div 2.5 \text{ L/min} = 24$). When calculating a working RMV on scuba, time a continuous swim over a measured distance to determine the speed (distance \div time) and compare this to this chart to verify O₂ consumption and gas consumption.

Additional factors are involved in the onset of CNS toxicity aside from reaching a depth (PO₂) or time limit (NOAA single dive or daily exposure). **Tissue oxygen consumption increases by about 7% for each degree Celsius increase in body temperature.**

Increased VO₂ and the concomitant rise in CO₂ pushes a diver closer to the physiological limit for toxicity. CO₂ has an additive effect to toxicity and narcosis. It's difficult to say with absolute certainty where the onset threshold actually is because sensitivity or susceptibility varies between individuals and within the same person from one day to the next. But this is the reason to dive well within set limits and to avoid overexertion during a deep dive and when breathing oxygen. Gentle exercise, such as stretching the limbs to increase the body temperature and increase perfusion is recommended during decompression but not when breathing oxygen.

Respiratory Quotient (RQ) is the rate of CO₂ generated relative to oxygen uptake.^{13/19}

It is expressed as $RQ = VCO_2 \div VO_2$

For a diet consisting mainly of carbohydrate consumption, $RQ = 1.0$. Breaking down fats for metabolism reduces it to 0.7, while a normal diet of carbohydrates, fats and proteins results in an RQ of 0.82.^{13/15}

PERSONAL LIMITATIONS

- **Equivalent Narcotic Depth (END)**
- **Oxygen Depth Limits (MOD)**
- **Oxygen Time Limits (NOAA, USN)**
- **Intellectual Capability**
- **Psychological Stability**
- **Physical Ability**

Trimix Section 3 Fig 6

The **Equivalent Narcotic Depth (END)** is the ratio of nitrogen in a special mix to that in air. For dives at sea level, it's calculated with the EAD equation; $[(FN_2 \times 0.79) \times (d + 33 \text{ fsw})] - 33 \text{ fsw}$. Use the Effective Depts calculation when diving at altitude. The END should not exceed 130 ft (40 msw) in training, but a lower EAD is advisable, especially when task loading or workload is high.

NOAA set the maximum operating depth (floor) for a scuba diver breathing air at a PO_2 of 1.6 ata. It can be stated as $d_{max} = 52.8 \text{ fsw} = 1.6 \text{ ata} \times 33 \text{ fsw/ata}$.^{2/13} The minimum depth ceiling for an air diver is commonly based on a PO_2 of 0.16 ata, also expressed as $d_{min} = 5.28 \text{ fsw} = 0.16 \text{ ata} \times 33 \text{ fsw/ata}$. (There is no minimum constraint up to 7,000 ft. elevation and Ph is 33 fsw at sea level). The working depth should satisfy $d_{min} \leq d \leq d_{max}$; where $d_{max} = (52.8 \text{ fsw} \div FO_2) - Ph$ and $d_{min} = (5.28 \text{ fsw} \div FO_2) - Ph$. The working PO_2 limit should be based on $d_{max} - d_{min}$.

$1.6 \text{ ata} - 0.16 \text{ ata} = 1.44 \text{ ata}$ $1.44 \text{ ata} \times 33 \text{ fsw/ata} = 47.52 \text{ fsw}$ or $52.8 \text{ fsw} - 5.28 \text{ fsw} = 47.52 \text{ fsw}$

Therefore, the **MOD for $d_{work} = (47.52 \text{ fsw} \div FO_2) - Ph$**

However, to avoid an extraction effect when breathing a hypoxic mix, use a PO_2 of 0.2 (6.6 fsw) for d_{min} . This changes the PO_2 for d_{work} to 1.4 ata or 46.2 fsw. The following are time limits at various PO_2 s:

NOAA Normal Single Dive		USN Max Bottom Times	NOAA O_2 Exposure Limit	
Limits for O_2/N_2 Mixtures		Surface-supplied Heliox	%CNS/min	OTU/min
PO_2	time limit			
1.0 atm	300 min		0.33	1.00
1.1 atm	240 min		0.42	1.16
1.2 atm	210 min		0.48	1.32
1.3 atm	180 min	Unlimited	0.56	1.48
1.4 atm	150 min	50 min	0.67	1.63
1.5 atm	120 min	40 min	0.83	1.78
1.6 atm	45 min	30 min	2.22	1.92

Intellectual Capability- Divers must be able to understand problems, reason logically, handle task loading calmly, calculate dive limits, schedules and survival solutions. If not, then they should not dive.

Psychological Stability- Divers prone to anxiety or panic shouldn't be allowed to dive.

Physical Ability- Divers must be able to carry/swim with their equipment under strenuous conditions or their scuba rig and type of diving should be restricted to their ability.

ENVIRONMENTAL CONSIDERATIONS

- | | |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> √ Location √ Depth √ Visibility √ Current √ Temperature √ Exposure Time | <ul style="list-style-type: none"> √ Time of Day √ Marine Life √ Weather √ Sea State √ Tides √ Sunlight |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Trimix Section 3 Pg 7

Diving at a **remotely located site** requires a well rehearsed emergency plan to get an injured diver medical care in the shortest time. A portable cellular phone and/or radio should be located at the exit point so that no time is wasted if an emergency call must be made. In addition to O₂ administration, emergency planning may require a portable recompression chamber, intravenous hydration, anti-inflammatory steroids and helicopter evacuation to keep the diver stabilized during transport to a hospital based chamber.

Diving where the bottom is deeper than your planned **depth** poses a greater risk of exceeding a MOD. Use a line for making descents/ascents and in the event of a BC malfunction or lost buoyancy.

The eyes are extremely sensitive to decreases in oxygen and underwater **visibility** may be poor or can become worse during the course of a dive as the sun goes down or water conditions change. Write the schedule on your slate large enough to see with reduced visual acuity and in low light. Use a red gauge light to maintain your “night” vision and avoid being blinded by white light when viewing instruments.

Because **current** can change dramatically during a dive, it can be difficult to plan for. A wall dive may have a considerable down draft or the bottom current could be inverted (opposite from that at the surface). If you are unexpectedly caught in an rip current or down draft, swim across the flow to get out of it and don't forget to monitor gas pressure, depth and time.

Prevent **hypothermia** by wearing adequate thermal protection and limiting underwater exposure time to everyone's comfort level.

Be aware of changing conditions with the **time of day**, such as loss of sunlight, rougher seas, drop in visibility, changing currents, storms, and so on.

Even a minor **marine life** injury may send a sensitive/allergic diver into anaphylactic shock. Wear adequate protection against man-o-war, jelly fish, fire corals, etc. An Epi-pen (injection of epinephrine) can be administered to alleviate life threatening anaphylactic shock, but its purchase requires a prescription and its administration is regulated within the United States and possibly other areas.^{6/7/19}

The **sea state and tidal fluctuations** influence where and how divers make an entry and exit from a boat and from shore. Entries can be off either side or the bow of a boat, but the stern is the most common entry and exit point, and certainly the most practical when wearing doubles. For shore dives, find out the time of the tidal change, how much the depth changes, the current direction and strength, and visibility changes, and then plan accordingly.

Seasonal **weather** changes must be anticipated otherwise a good day of diving can be tragic if a diver fails to make it back to the boat or if the boat fails to make it back to land. Remember, it's very hard to spot a diver or even a lift bag at the surface against background glare from a **setting sun** in choppy seas.

PHYSIOLOGICAL PROBLEMS

- √ Narcosis
- √ Toxicity
- √ Dehydration
- √ DCS
- √ HPNS
- √ Hypoxia
- √ Hyperoxia
- √ Hypercapnia

Trimix Section 3 Pg 8

Narcosis - Nitrogen is a CNS depressant and impairs judgement. Inappropriate responses or failure to respond indicates impairment and reason to ascend/abort. Show hand signals for narcosis/narcosis check.

Acute CNS toxicity can result in a seizure with little or no warning. Do not rely on VENTID symptoms to provide a warning. **Chronic pulmonary toxicity** is primarily a concern for mixed gas and saturation divers who undergo exceptionally long, low dose exposures.¹⁴ Show hand signal for oxtox: "O - 2 - narcosis."

Dehydration decreases the body's blood handling capability. Increased urine output results from immersion diuresis, due in part to a reduction in insensible water loss, and contributes to dehydration. This raises a diver's risk to DCS. Divers who wear a dry suit and who avoid drinking fluids to avoid urinating are cautioned to stay well hydrated, as should all divers.

DCS - 3 Causes: **1. Incorrect Decompression Theory:** Inaccurate pressure-time profiles or poor tables. **2. Incorrect Decompression Practice:** Intentional or unintentional omitted decompression. **3. Anomalous Susceptibility:** An individual's physiology is outside normal tolerance.

3 Categories of Triage: **Category A-Emergent:** severe symptoms involving the inner ear, cardiorespiratory system or CNS, or are progressive or relapsing. **Category B-Urgent:** severe pain and/or slow progression. **Category C-Timely:** symptoms are not severe or obvious and progress slowly over hours. Treat all DCS with 100% O₂, prevent shock, provide CPR if needed, immediately transport to a recompression chamber.

4 Classifications: **Type I:** skin and limbs. **Type II:** CNS & respiratory. **Type III:** vestibular. **Type IV:** dysbaric osteonecrosis. Type I and II are caused by bubbles and blood chemistry changes. Type III involves bubbles, inert gas counter diffusion and fluid shifts in vestibular organs. It's not clear if Type IV results from bubbles, ischemia, emboli, rapid pressure change, CO₂ retention or all of these. Doppler doesn't detect Type II, III or IV. DCS is typically more severe with helium mixtures than air because of its greater diffusivity. Short deep dives are 50% more likely to produce CNS DCS than long shallow dives.

HPNS produces intention and postural tremors of the hands and feet from a rapid compression or diving to 1000 to 1500 feet breathing a helium mix.^{9/15} A small amount of nitrogen alleviates tremors, voice distortion and makes the mix warmer to breathe. Adaptation (delays in descent) is also instrumental in minimizing HPNS and preventing **hyperbaric arthralgia** (arthritic-like pains) during descent or after reaching maximum depth, but is mainly an affliction limited to saturation divers.¹⁴

Hypoxia: Generally, an O₂ deficiency caused by breathing a PO₂ less than 0.18 ata. If a diver loses consciousness, change their mix to one that's normoxic if possible, abort the dive and seek medical care.

Hypercapnia: Excess CO₂ from breathing contaminated gas or inadequate ventilation from poor regulator performance, skip breathing or over-exertion. Ten minutes at a PCO₂ of 0.02 ata increases tidal volume. At 0.03 ata air hunger and then headache, tipsiness, nausea, tunnel vision and confusion occurs. At 0.08 - 0.10 ata helplessness and blackout occurs. Limit PCO₂ to 0.005 ata for no noticeable effects on long dives.⁸ Someone who exhibits lower than normal ventilatory response to elevated CO₂ is a "**CO₂ Retainer.**"

PHYSIOLOGICAL PROBLEMS

- √ **Hypothermia**
- √ **Hyperthermia**
- √ **Hypoglycemia**
- √ **Squeeze**
- √ **Reverse Block**
- √ **Vertigo**
- √ **Blackout**
- √ **Drowning**

Trimix Section 3 Pg 9

Hypothermia from immersion occurs when the core temperature falls to 95 °F (35 °C), but a diver would be impaired before then.¹⁵ Blood vessels in the head do not constrict, therefore, vasoconstriction does not limit heat loss from the head as it does the rest of the body. Wear a hood along with other adequate protective garments. Eat and drink properly, get plenty of rest and limit cold exposure before dives.

Hyperthermia can begin with dehydration and over heating and progress to heat stroke. Drink plenty of fluids, reduce workload and rest in a cool area. Dry suit divers must take extra precautions to avoid over-heating prior to a dive because they are unable to cool off once they are suited up.

Hypoglycemia is abnormally low blood sugar (glucose) that can cause acute fatigue, restlessness, irritability, weakness, mental disturbances, delirium, coma, and even death. It is not uncommon for normal blood sugar levels to fall during a dive, sometimes by as much as 50%. Nor is it unusual for an insulin dependent diabetic's blood sugar to fall by as much as 25%. Hydrate before a dive with drinks that replenish blood sugar and electrolytes. Diabetics who dive should carry a squeeze tube of glucose gel to consume during a dive whenever their blood sugar level becomes low. It's a good idea for others too.⁷

Squeeze (middle ear, mask, suit) is avoided by equalizing frequently or aborting the dive if equalization is impossible. A **reverse block** is avoided by not diving with a cold or congestion and avoiding nasal decongestants.

Vertigo may result from a pressure (alternobaric) or temperature (caloric) differential between the ears.


Caloric vertigo occurs when descending, but typically disappears after being at depth for some time.

Alternobaric vertigo can occur anytime and tends to persist throughout the dive and afterwards.²²

Blackout can be caused by toxicity, hypercapnia, hypoxia or heart attack. Drowning is likely without immediate intervention. Elevated CO₂ resulting from a strenuous surface swim prior to descent or pulling down the anchor line against a current can cause deep water blackout without any warning.¹⁰

Drowning is likely to occur from panicked actions or physiological problems when underwater. Students with a low tolerance to anxiety or who are prone to panic should not engage in deep or mixed gas dive training and should be counseled to not dive at all.

SECTION 3 IDENTIFIED



- ✓ **Human Response to PO₂**
- ✓ **Average RMV and VO₂ Rates**
- ✓ **Metabolic O₂ Consumption**
- ✓ **Personal Limitations**
- ✓ **Environmental Considerations**
- ✓ **Physiological Problems**

Photo by Jan Neal

Trimix Section 3 Pg 10

1. Describe N₂ narcosis, the signals for it and what to do if experienced. Inability to reason or behave correctly. Circling finger at side of head; add one finger to number shown. Ascend or abort the dive.
2. Describe the ultimate outcome and symptoms that pertain to the acronym VENTID and what to do if you experience any symptoms. Oxygen convulsions (CNS seizure), visual disturbances, euphoria or auditory sounds, nausea, tingling face or extremities, irritability, and dizziness. Immediately signal your partner, decrease the PO₂, and ascend if possible.
3. Identify the 3 causes, the 3 categories of triage and the 4 classifications of DCS. *3 Causes* are incorrect decompression theory, incorrect decompression practice and anomalous susceptibility. *3 Categories* are Category A: emergent- severe inner ear, CNS or cardiorespiratory system involvement. Category B: Urgent- severe pain but slow progression. Category C: Timely - nonsevere symptoms and slow progression. *4 Classifications*: Type I: skin and limb bends, II: CNS & respiratory, III: vestibular, IV: dysbaric osteonecrosis.
4. What are the differences between hypoxia and hyperoxia? Hypoxia is inadequate tissue oxygenation when PO₂ drops below 0.16 ata. Unconsciousness can occur in as little as 30 seconds. Hyperoxia is too much O₂. Pulmonary toxicity is caused by low doses (0.6 ≤ PO₂ < 1.0 ata) over a long exposure and CNS toxicity is caused by high doses (PO₂ ≥ 1.0 ata) over short duration, which culminates in a seizure.
5. Hypothermia is caused from becoming too cold and hyperthermia is caused from becoming overheated.
6. Define hypoglycemia and list 6 symptoms. Low blood sugar causing fatigue, restlessness, irritability, weakness, mental disturbances, delirium and eventually coma then death.
7. Name 3 types of squeeze. Mask, middle ear, suit/body.
8. Alternobaric vertigo is caused by a pressure differential between the ears (tends to persist). Caloric vertigo is caused by a temperature differential (tends to go away).
9. List 4 possible causes of underwater blackout. Toxicity, hypoxia, hypercapnia, heart attack.
10. Thirteen environmental considerations are location, depth, visibility, current, temperature, exposure time, time-of-day, marine life, weather, sea state, tides and sunlight.
11. What is one of the most dangerous aspects of hypoxia? Pass out in 30 seconds with no warning.
12. Why does a diver's SCR increase when breathing trimix compared to breathing air? Breaths per minute increases because gas density is less.
13. VO₂ is unaffected by changes in ambient pressure, but increases with workload.
14. Ten minutes at a PCO₂ of 0.02 ata will cause air hunger, headache, tunnel vision, and confusion.
15. Divers who avoid drinking fluids to avoid urinating increase their risk to DCS.

SECTION 4 TOPICS

- ✓ **Time Terminology**
- ✓ **Descent / Ascent Rates**
- ✓ **Dive Planning**
- ✓ **Imperial Calculations**
- ✓ **Trimix Diver Plan**
- ✓ **Trimix Team Plan**
- ✓ **Metric Calculations**
- ✓ **Gas Utilization Charts**
- ✓ **Contingency Plans**
- ✓ **ABCs**
- ✓ **Air No-Stop Limits**
- ✓ **RGBM Trimix NDLs**
- ✓ **Helitrox NDLs**
- ✓ **ASCEND Safely**

Trimix Section 4 Pg 1

Fifteen questions and their answers covering section 4 are on slides 78 and 79.

TIME TERMINOLOGY

- ① **Descent Time**
- ① **Ascent Time**
- ① **Stop Time**
- ① **Deco Time**
- ① **Run Time**
- ① **Total Time**
- ① **Surface Interval Time**

Trimix Section 4 Pg 2

Descent Time is the maximum dive depth divided by the descent rate (distance per minute) and any additional delays, planned or otherwise. Too fast a descent will contribute to narcosis and can lead to more inert gas uptake than planned for by the decompression schedule, increasing the risk to DCS.

Ascent Time is the maximum dive depth divided by the ascent rate, including intentional or unintentional delays. Too fast an ascent from what the schedule calls for can lead to critical supersaturation in faster compartments because they do not have enough time to desaturate and is a leading contributor to DCS. Too slow an ascent causes additional inert gas uptake in slower compartments above what is calculated by the decompression schedule and contributes to decompression problems. Under normal conditions a slower ascent is always better than a faster ascent.

Stop Time is the time in minutes a deco schedule calls for a diver to remain at a specific depth increment so that tissue tensions can fall enough to permit ascent to the next decompression ceiling. It starts when you reach the scheduled depth and ends when you leave that depth.

Deco Time is the running stop time in minutes incremented at each stop depth, which may or may not include travel time (ascent time). It starts at the first deco stop and ends upon leaving the last deco stop before reaching the surface. The deco clock should only run when you are breathing the deco gas designated for in the deco schedule. For instance, time breathing air during O₂ decompression is “dead time” and should not be counted as part of mandatory decompression.

Run Time is the incremented time to leave each depth (maximum depth and stop depths) until reaching the surface. Total Run Time is the Total Time in the water minus the residual inert gas time or the penalty time incurred from repetitive dives.

Total Time is the entire time underwater and residual inert gas time or penalty time from repetitive dives.

Surface Interval Time is the time (normally expressed in hours and minutes) between repetitive dives. A diver must complete all repetitive dives on the same table/meter.

Stop times should be monitored with a watch or a digital bottom timer because **minutes displayed on a dive computer denoting deco time or the time to reach the surface are not necessarily 60 seconds long**. Delays in ascent, imprecise depth management and being too deep or too shallow at a deco stop will lengthen stop time even though the displayed deco obligation may be unchanged. In other words, one minute of deco time may take longer than one minute to pass although the computer only displays one minute.

DESCENT / ASCENT RATES

- ❖ **Too fast or too slow a descent rate**
- ❖ **Too fast or too slow an ascent rate**
- ❖ **Ascent rate between stops**
- ❖ **Delays in the descent or ascent**

Trimix Section 4 Pg 3

Descending at a fast rate has an additive effect on narcosis and can cause HPNS for dives to 500 ft. and deeper and exceeding the rate set by your decompression schedule can contribute to DCS. When generating a custom schedule, you can program in an instantaneous descent to maximum depth, meaning descent time is simultaneous with your arrival at max depth, and it would not matter what your actual descent rate was, outside of the impact on your available cylinder time, and ultimately, bottom time.

The **ascent rate** is part of mandatory decompression. Too fast a rate means inadequate decompression. The advantage of a slow rate is that increased pressure minimizes phase separation, minimizes bubble expansion and permits greater desaturation from bubbles compared to faster rates, especially important aspects for mixed gas dives because He desaturates so much faster than N₂. **It's advisable to adopt an ascent rate no faster than 30 fpm (9 mpm) and to limit momentary rate variations between 20-40 fpm (6-12 mpm).** However, some research suggests once bubbles have formed, improper delays during ascent may permit microbubbles to reach the lungs while they are still small enough to pass through the pulmonary capillary bed and enter arterial blood flow. Depending on the amount of separated gas, bubbles entering the pulmonary veins and aorta may give rise to cerebral AGE, while bubbles entering the systemic circulation can lead to DCS, especially if a repetitive dive is made.

An ascent rate between deco stops of 30 fpm (9 mpm) or slower is advised. A slow rate helps maintain a hydrostatic cap on bubbles. Rapid pressure changes permit greater bubble expansion and less time for inert gas to diffuse from bubbles. Slow rates are advisable when critical tissue tensions or critical ratios are approached, but even slower rates are necessary when inert gas bubbles are present.^{13/22}

Ascent rates may vary because of the dive objective, maximum depth, available cylinder time, gas mixtures used, environmental conditions, surfacing pressure (altitude), bubble formation and personal risk factors, etc. For example, the ascent rate does not exceed 1 fpm during HBOT. Deep exploration divers who decompress in a bell at 30 ft. adopt this rate when ascending to the surface. Helium-oxygen saturation divers do not perform staged decompression in increments, but are continuously decompressed at an ascent rate of 4 fsw per hour (fph) from 1000 to 200 fsw, 2.5 fph from 200 to 50 fsw and then 2 fph from 50 to the surface (or less than 1/2 inch per minute).

If you are **ascending too fast**, slow down the ascent or halt the ascent momentarily. If **delayed more than 1 minute when shallower than your first deco stop**, add the time of delay to the required deco-time of the next scheduled deco stop. If **delayed more than 1 minute when deeper than your first planned deco stop**, conduct the next longer decompression schedule that includes the delay time.

DIVE PLANNING

- **Trimix Diver Plan**
- **Equivalent Narcotic Depth**
- **CNS and Pulmonary O₂ Exposures**
- **Deco schedule and contingency plan**
- **Gas requirements and gas management rules**
- **Label MOD for each mix with depth units**
- **Establish objectives**
- **Trimix Team Plan**
- **Communications (diver-diver, diver-surface)**

Trimix Section 4 Pg 4

Use the **Trimix Diver Plan** to determine gas requirements for each gas that will be used based on the planned depth(s) and time(s) according to personal SCR and past experience diving with similar gear configurations and environmental conditions. Select the **gas management rule** and choose cylinders with the correct capacities to satisfy the dive requirements, including reserves. Determine the **END** of the bottom mix and the bailout mix using the EAD or ED formula. Calculate the %CNS exposure and the Oxygen Tolerance Units (OTU) for the entire dive using the exposure index on the **NAUI OCEANx** or use the following equation $\%CNS\ OXTOX = (\text{exposure time at } PO_2 \div \text{time limit at } PO_2) \times 100\%$.

When breathing O₂ or when approaching 100% of the maximum permitted tolerance, implement 5-minute normoxic (bottom gas or air) breaks every 20 minutes, but do not count them as part of mandatory decompression. Most technical divers assume a 90 minute O₂ half-life. This means regardless of the %CNS exposure that is accumulated, the percentage of **residual O₂ exposure is predicted to fall by half every 90 minutes of surface interval time (SIT)**. Therefore, after the next 90 minutes (3:00 SIT) it decreases by half again, and is subsequently reduced by half again following another 90 minutes (4:30 SIT) and so forth. Of course, such mathematics means it would take an infinity to completely desaturate and this obviously isn't the case.

Write out the planned dive schedule and contingency schedule on an arm slate or flat slate. **A laminated table provides a schedule matrix, but a penciled version of the planned schedule is still needed in case the laminate leaks and the ink bleeds, making the schedule unreadable.** Or write the schedule in black permanent ink on duct tape or clear packing tape (on light colored fins) and paste it down the middle of the top of one of your fins, but make sure it sticks and won't fall off when wet. Put the main schedule on one fin and the bailout profile on the other. The idea is to **keep the schedule within view** so you don't have to unclip it or dig it out of a pocket to refer to it. Define team limits by going over individual limits together when completing a **Trimix Team Plan** and leave it with the surface support team.

Review the dive plan, deco schedule and communication signals a minimum of 3 times:

1. After everyone has completed their Trimix Diver Plans
2. After everyone's equipment is assembled, but before they gear up
3. After the pre-dive bubble check, but just before descending.

Review this 5 times if more than two divers are diving together.

Some divers report that having a clearer head or experiencing little or no nitrogen narcosis makes them bolder than they would be normally. This actually makes it easier to veer from the dive plan. Remember, "There are old divers and bold divers, but no old bold divers." **Rehearse the plan and stick to it!**

IMPERIAL CALCULATIONS

- * $END (NED) = [(FN_2 \div 0.79) \times (Depth + 33 \text{ fsw})] - 33 \text{ fsw}$
- * $AED = [(FO_2 + FN_2) \times (Depth + 33 \text{ fsw})] - 33 \text{ fsw}$
- * $FN_2 = [(END + 33 \text{ fsw}) \div (Depth + 33 \text{ fsw})] \times 0.79$
- * $P_g = F_g \times P \text{ ata and MOD} = PO_2 \div FO_2$
- * $\%CNS \text{ Exposure} = (\text{exp. time} \div \text{time limit}) \times 100\%$
- * $OTU \text{ Totals} = (\text{exp. min.s} \times OTU \text{ per min})$
- * $SCR \text{ pressure} = (\text{pressure} \div \text{minutes}) \div P \text{ ata}$
- * $SCR \text{ volume} = (\text{rated vol.} \div \text{rated psi}) \times SCR \text{ psi}$
- * $Cylinder \text{ Time} = (\text{cyl. vol.} \div SCR \text{ vol.}) \div P \text{ ata}$
- * $Thirds \text{ Turn Pressure} = \text{cyl. psi} - (\text{rounded cyl. psi} \div 3)$
- * $Thirds \text{ Supply Capacity} = (\text{planned use} \div 2) \times 3$

Trimix Section 4 Pg 5

Dive limitations include personal limits and team limits based on PO_2 , END (Nitrogen Equivalent Depth, NED, or Air Equivalent Depth, AED) and MOD.

The threshold for nitrogen narcosis is normally 100 fsw (30 msw). The typical performance limit for recreational divers is between 130-150 fsw (40-46 msw), but experienced extended range divers may tolerate an END of 170 fsw (52 m) to 180 fsw (55 msw). When determining best trimix and you know the END you want, solve for FN_2 with the following calculation: $FN_2 = [(END + 33 \text{ fsw}) \div (Depth + 33 \text{ fsw})] \times 0.79$.

CO_2 Retainers have a lower threshold for toxicity and narcosis. They generally consume less gas than another diver of comparable size, fitness and workload and they typically get post dive headaches. Their narcotic depth limits should be shallower to compensate for anomalous sensitivity. To include oxygen in the equivalent narcotic depth calculation for trimix use: $END = [(Depth + 33 \text{ fsw}) \times (FO_2 + FN_2)] - 33 \text{ fsw}$. The following are selected examples of different calculations used in dive planning.

SCR psi = (pressure used \div time) \div absolute pressure

SCR psi = (390 psi \div 5 minutes) \div 3 ata = 26 (psi/min)/ata *Only for the cylinder used to get this SCR.

Calculate SCR at rest and at work. Modify either rate by 1.5, 2 or 3 when physical conditions warrant.

SCR psi to SCR ft³ = (rated cylinder volume \div rated cylinder pressure) \times SCR pressure

SCR Vol. = (80 ft³ \div 3000 psi) \times 26 (psi/min)/ata = 0.69 (ft³/min)/ata

*Calculate SCR volume with the rated cylinder values used to determine SCR pressure.

Cylinder Supply Time = (cylinder volume \div SCR volume) \div absolute pressure

CST = [200 ft³ \div 0.7 (ft³/min)/ata] \div 7 ata = 40.8 minutes at 200 fsw

Cylinder Volume = (rated volume \div rated pressure) \times cylinder pressure

CV = (80 ft³ \div 3000 psi) \times 2000 psi = 53.33 ft³

Thirds Turn Pressure = cylinder pressure - (psi rounded down to nearest number divisible by three \div 3)

TTP = 3200 psi - (3000 psi \div 3) = 2200 psi

Thirds Supply Capacity = (planned gas volume needed \div 2) \times 3 TSC = (133 ft.³ \div 2) \times 3 = 199.5 ft.³

TRIMIX DIVER PLAN								
SITE _____		DIVER _____		DATE _____				
RESTING SCR _____		WORKING SCR _____		RMV _____	B. GAS TURN PSI _____		RULE _____	
MAX. DEPTH _____		SCHED. DEPTH _____		BOTTOM TIME _____		TOTAL RUN TIME _____		
B. MIX O2% _____		He % _____	N2% _____	CF _____	PSI _____	D MIN _____	D MAX _____	
DECO MIX 1 O2% _____		He % _____	N2% _____	CF _____	PSI _____	D SWITCH _____	MOD _____	
DECO MIX 2 O2% _____		He % _____	N2% _____	CF _____	PSI _____	D SWITCH _____	MOD _____	
FSW	ATA	FO2	PO2	STOP TIME	%CNS	OTU	CF GAS	RUN TIME
10	1.3							
20	1.6							
30	1.9							
40	2.2							
50	2.5							
60	2.8							
70	3.1							
80	3.4							
90	3.7							
100	4.0							
110	4.3							
120	4.6							
130	4.9							
140	5.2							
150	5.5							
160	5.8							
170	6.1							
180	6.4							
190	6.7							
200	7.0							
TOTALS								
GEAR CK <input type="checkbox"/>		SCHEDULE CK <input type="checkbox"/>		BUDDY GEAR CK <input type="checkbox"/>		BUDDY SCHEDULE CK <input type="checkbox"/>		
DIVER SIGNATURE _____				BUDDY VERIFICATION _____				

Trimix Section 4 Pg 6

SCR: Surface Consumption Rate. **RMV:** Respiratory Minute Volume, the amount of gas breathed in and out (tidal volume) times the respiratory rate (number of breaths per minute).

Turn Psi: Planned gas pressure to start the ascent. **Rule:** Gas management rule used to determine your turn around pressure.

Max Depth: planned target depth. **Schedule Depth:** Actual or next deeper depth used to enter a table.

Bottom time: Total time from start of descent until leaving the bottom for a direct ascent to the surface.

Total Run Time: Total time in minutes to complete the dive, start of descent to reaching the surface.

B. Mix: Bottom mix or back gas, trimix carried on your back.

Deco Gas 1: Initial decompression gas or travel gas used.

Deco Gas 2: Second decompression gas used.

CF: Actual cubic feet of the mix in surface volume equivalency.

PSI: Gauged gas pressure in a scuba cylinder.

D Min: Minimum depth you can safely breathe a mix, where the $PO_2 \geq 0.16$ ata.

D Max: Maximum depth you can safely breathe a mix, where the PO_2 is ≤ 1.6 ata.

D Switch: The depth where you will switch to using a specific gas mixture.

MOD: The maximum operating depth of the gas mixture based a $PO_2 < 1.44$ ata.

FO₂: Fraction of O₂ of a mix.

PO₂: Partial pressure of O₂ breathed at a specific depth.

Stop Time: Mandatory scheduled decompression time in minutes at each stop depth.

Run Time: Time to leave max depth and each deco stop.

%CNS: Percentage of CNS O₂ exposure incurred at a specific PO₂ for a specific time.

OTU: Oxygen Tolerance Units are calculated per minute and are found on the OCEANx exposure index.

TRIMIX DIVER PLAN

DIVER Jane D. DATE dd/mm/yy
 SITE Atlantic Ocean TYPE OF DIVE Wall Dive
 REST SCR 0.3 cf/m WORK SCR 0.7 cf/m AVG. RMV 0.6 cf/m TURN PSI 1800 RULE thirds
 MAX. DEPTH 240 fsw SCHED. DEPTH 240 fsw BOTTOM TIME 20 mins TOTAL RUN TIME 103 mins
 B. MIX O2% 14 He% 33 N2% 53 CF 200 PSI 2400 D MIN 5 fsw D MAX 306 fsw
 DECO MIX 1 O2% 17 He% 26 N2% 57 CF 50 PSI 3000 D SWITCH 100 fsw MOD 247 fsw
 DECO MIX 2 O2% 80 He% 0 N2% 20 CF 40 PSI 3000 D SWITCH 30 fsw MOD 30 fsw

DESCENT			ASCENT			STOP TIME	CNS %	OTU	CF GAS	DECO RUN
FSW	ATA	FO2	PO2	FO2	PO2					
10	1.3	0.17	-	0.80	1.04	24	8.0	24.00	9.36	88
20	1.6	0.14	-	0.80	1.28	13	7.2	19.24	6.24	63
30	1.9	0.14	-	0.80	1.52	8	6.7	14.24	4.56	49
40	2.2	0.14	-	0.17	-	13	-	-	8.58	40
50	2.5	0.14	-	0.17	-	8	-	-	6.00	26
60	2.8	0.14	-	0.17	-	5	-	-	4.20	17
70	3.1	0.14	-	0.17	-	2	-	-	1.86	11
80	3.4	0.14	-	0.17	0.58	2	0.28	00.54	1.81	8
90	3.7	0.14	-	0.17	0.63	2	0.28	00.54	2.22	5
100	4.0	0.14	0.56	0.17	0.68	2	0.35	00.94	2.40	2
110	4.3	0.14	0.60	0.17	0.73					
120	4.6	0.14	0.64	0.14	0.64					
130	4.9	0.14	0.69	0.14	0.69					
140	5.2	0.14	0.73	0.14	0.73					
150	5.5	0.14	0.77	0.14	0.77					
160	5.8	0.14	0.81	0.14	0.81					
170	6.1	0.14	0.85	0.14	0.85	4.2	1.18	3.49	15.37	
180	6.4	0.14	0.90	0.14	0.90					
240	8.3	0.14	1.16	0.14	1.16	20	9.6	26.40	116.20	
TOTALS						103.2	33.59	89.39	178.80	

GEAR CK SCHEDULE CK BUDDY GEAR CK BUDDY SCHEDULE CK
 DIVER SIGNATURE Jane Diver BUDDY VERIFICATION Joe Instructor

Trimix Section 4 Pg 7

This example schedule was generated with Voyager Desktop Decompression software for TX 14/33 to 240 fsw for a bottom time of 20 minutes. The descent rate is 45 fpm and the ascent rate is 33 fpm. The travel gas of TX 17/26 (Deco 1) is breathed from the surface (sea level) to 10 fsw where the back gas is breathed to the bottom and back up to 100 fsw, where a switch is made back to TX 17/26, and then at 30 fsw a switch is made to EAN80 (Deco 2), which is breathed up to the surface. The Resting SCR is 0.3 ft.³/min during deco and the Working SCR for the bottom time of 20 minutes is 0.7 ft.³/min. Note, an average PO₂ and average SCR was used for calculations from 100 to 240 fsw.

Disclaimer: This schedule is not to be used to conduct actual dives. It is for illustrative purposes only. Divers must consult Diverse Technologies to purchase the Voyager Desktop Decompression software.

TRIMIX TEAM PLAN

DATE _____

SITE _____

TYPE OF DIVE _____

ENTRY POINT _____ EXIT POINT _____ GEAR SCH DIVER 1 _____ ROLL _____ B. GAS CF _____ TIME IN _____ OUT _____ DIVER 2 _____ ROLL _____ B. GAS CF _____ TIME IN _____ OUT _____

B. MIX: O2% _____ He% _____ N2% _____ D MIN _____ D MAX _____
 DECO MIX 1: O2% _____ He% _____ N2% _____ D SWITCH _____ MOD _____
 DECO MIX 2: O2% _____ He% _____ N2% _____ D SWITCH _____ MOD _____

PLANNED MAX DEPTH _____ FSW SCHEDULE DEPTH _____ FSW
 PLANNED BOT TIME _____ MINS TOTAL RUN TIME _____ MINS

10 FSW _____ MINS	90 FSW _____ MINS	170 FSW _____ MINS	NOTES
20 FSW _____ MINS	100 FSW _____ MINS	180 FSW _____ MINS	
30 FSW _____ MINS	110 FSW _____ MINS	190 FSW _____ MINS	
40 FSW _____ MINS	120 FSW _____ MINS	200 FSW _____ MINS	
50 FSW _____ MINS	130 FSW _____ MINS	_____ FSW _____ MINS	
60 FSW _____ MINS	140 FSW _____ MINS	_____ FSW _____ MINS	
70 FSW _____ MINS	150 FSW _____ MINS	_____ FSW _____ MINS	
80 FSW _____ MINS	160 FSW _____ MINS	_____ FSW _____ MINS	

COLOR/TYPE LIFT BAG _____

EMERGENCY SIGNAL _____

EMERGENCY CONTACT _____
 DAN 1- (919) 684-4326

Trimix Diver Condition 4 Div 0

Entry Point is the physical location where you enter the water.

Exit Point is the physical location where you leave the water.

Diver 1 and Diver 2 are the names of divers in a two-man buddy team.

Roll is the responsibility of the diver, such as instructor, student, dive leader, etc.

Color/Type Lift Bag is the color, lift capacity and design of the *non-emergency* lift bag.

Emergency Signal is the color, lift capacity and design of the *emergency* lift bag.

Emergency Contact should be the name and telephone number of the person the diver wants contacted in case they have an emergency.

See the **Trimix Diver Plan** for definitions of terms not listed here and refer to the example Trimix Team Plan on slide 60 as a visual aid.

TRIMIX TEAM PLANDATE TodayTIME 10:00 AMSITE Atlantic OceanTYPE OF DIVE Trimix Training Dive 2ENTRY PT Mooring Buoy off Bow EXIT PT Drift Deco with Lift BagGEAR TBL DIVER 1 John I. ROLL Instructor B. GAS CF 240 TIME IN 10:00 am OUT 10:58 am DIVER 2 Jane D. ROLL Student B. GAS CF 240 TIME IN 10:00 am OUT 10:58 am

B. MIX:	O2 %	<u>16</u>	He %	<u>24</u>	N2 %	<u>60</u>	D MIN	<u>sea level</u>	D MAX	<u>297 fsw</u>
DECO MIX 1:	O2 %	<u>21</u>	He %	<u>0</u>	N2 %	<u>79</u>	D SWITCH	<u>100 fsw</u>	MOD	<u>218 fsw</u>
DECO MIX 2:	O2 %	<u>100</u>	He %	<u>0</u>	N2 %	<u>0</u>	D SWITCH	<u>20 fsw</u>	MOD	<u>20 fsw</u>

PLANNED MAX DEPTH 170 FSW
 PLANNED BOT TIME 25 MINS

SCHEDULE DEPTH 170 FSW
 TOTAL RUN TIME 56 MINS

10 FSW <u>6</u> MINS	90 FSW <u>0</u> MINS	170 FSW <u>25</u> MINS
20 FSW <u>4</u> MINS	100 FSW <u>1</u> MINS	180 FSW <u> </u> MINS
30 FSW <u>5</u> MINS	110 FSW <u> </u> MINS	190 FSW <u> </u> MINS
40 FSW <u>3</u> MINS	120 FSW <u> </u> MINS	200 FSW <u> </u> MINS
50 FSW <u>3</u> MINS	130 FSW <u> </u> MINS	FSW <u> </u> MINS
60 FSW <u>1</u> MINS	140 FSW <u> </u> MINS	FSW <u> </u> MINS
70 FSW <u>1</u> MINS	150 FSW <u> </u> MINS	
80 FSW <u>1</u> MINS	160 FSW <u> </u> MINS	

NOTES:
RGBM Schedule
30 fpm descent/ascent
Deploy lift bag at 10:25 am

COLOR/TYPE LIFT BAG
50 lb yellow lift bag
 EMERGENCY SIGNAL
4 ft red inflatable tube

EMERGENCY CONTACT Spouse's Name & Telephone No.
 DAN HOTLINE 1-919-684-4326

Dr. Wienke generated this **RGBM schedule for 25 minutes bottom time at 170 fsw** using a 30 fpm descent and ascent rate with switches to air at 100 fsw and oxygen at 20 fsw during the ascent.

Disclaimer: This schedule is not to be used to conduct actual dives. It is for illustrative purposes only. Divers must consult Dr. Wienke to obtain RGBM decompression tables.

METRIC CALCULATIONS

- * **END (NED) = [(FN₂ × 0.79) × (Depth + 10 msw)] - 10 msw**
- * **AED = [(FO₂ + FN₂) × (Depth + 10 msw)] - 10 msw**
- * **FN₂ = [(END + 10 msw) ÷ (Depth + 10 msw)] × 0.79**
- * **P_g = F_g × bar and MOD = PO₂ ÷ FO₂**
- * **%CNS Exposure = (exp. time ÷ time limit) × 100%**
- * **OTU Totals = (exp. min.s × OTU per min)**
- * **SCR pressure = (pressure ÷ minutes) ÷ bar**
- * **SCR volume = (cyl. vol. × cyl. pres.) × SCR pres.**
- * **Cylinder Time = (cyl. vol. ÷ SCR vol.) ÷ bar**
- * **Thirds Pressure = cyl. pres. - (rounded cyl. pres. ÷ 3)**
- * **Thirds Supply Capacity = (planned use ÷ 2) × 3**

* Trimix Section 4 Pg 10

To include oxygen in the equivalent narcotic depth when using the EAD equation to determine the best trimix gas components use: $END = [(FO_2 + FN_2) \times (Depth + 10 \text{ msw})] - 10 \text{ msw}$.

TRIMIX DIVER PLAN DIVER _____ DATE _____

SITE _____ TYPE OF DIVE _____

RESTING SCR _____ WORKING SCR _____ RMV _____ B. GAS TURN BAR _____ RULE _____

MAX. DEPTH _____ SCHED. DEPTH _____ BOTTOM TIME _____ TOTAL RUN TIME _____

B. MIX O2% _____ He % _____ N2% _____ L _____ BAR _____ D MIN _____ D MAX _____

DECO MIX 1 O2% _____ He % _____ N2% _____ L _____ BAR _____ D SWITCH _____ MOD _____

DECO MIX 2 O2% _____ He % _____ N2% _____ L _____ BAR _____ D SWITCH _____ MOD _____

MSW	BAR	FO2	PO2	STOP TIME	%CNS	OTU	L GAS	RUN TIME
3	1.3							
6	1.6							
9	1.9							
12	2.2							
15	2.5							
18	2.8							
21	3.1							
24	3.4							
27	3.7							
30	4.0							
33	4.3							
36	4.6							
39	4.9							
42	5.2							
45	5.5							
48	5.8							
51	6.1							
54	6.4							
57	6.7							
60	7.0							
TOTALS								

GEAR CK SCHEDULE CK BUDDY GEAR CK BUDDY SCHEDULE CK

DIVER SIGNATURE _____ BUDDY VERIFICATION _____

Trimix Section 4 Pg 11

See imperial version.

TRIMIX TEAM PLAN

DATE _____

SITE _____

TYPE OF DIVE _____

ENTRY POINT _____ EXIT POINT _____ GEAR SCH

DIVER 1 _____ ROLL _____ B. GAS L _____ TIME IN _____ OUT _____

DIVER 2 _____ ROLL _____ B. GAS L _____ TIME IN _____ OUT _____

B. MIX: O2% _____ He% _____ N2% _____ D MIN _____ D MAX _____
 DECO MIX 1: O2% _____ He% _____ N2% _____ D SWITCH _____ MOD _____
 DECO MIX 2: O2% _____ He% _____ N2% _____ D SWITCH _____ MOD _____

PLANNED MAX DEPTH _____ MSW
 PLANNED BOT TIME _____ MINS

SCHEDULE DEPTH _____ MSW
 TOTAL RUN TIME _____ MINS

3 MSW _____ MINS _____	27 MSW _____ MINS _____
6 MSW _____ MINS _____	30 MSW _____ MINS _____
9 MSW _____ MINS _____	33 MSW _____ MINS _____
12 MSW _____ MINS _____	36 MSW _____ MINS _____
15 MSW _____ MINS _____	39 MSW _____ MINS _____
18 MSW _____ MINS _____	42 MSW _____ MINS _____
21 MSW _____ MINS _____	45 MSW _____ MINS _____
24 MSW _____ MINS _____	48 MSW _____ MINS _____

51 MSW _____ MINS
 54 MSW _____ MINS
 57 MSW _____ MINS
 60 MSW _____ MINS
 MSW _____ MINS
 MSW _____ MINS

COLOR/TYPE LIFT BAG _____

EMERGENCY SIGNAL _____

EMERGENCY CONTACT _____
 DAN 1-919-684-4326

Trimix Section 4 Pg 12

Metric version of the Trimix Team Plan.

SINGLE CYLINDERS GAS VOLUME UTILIZATION CHART																	
CYLINDER PRESSURES (PSIG)																	
4/5 CYL PSIG			3/4 CYL PSIG				2/3 CYL PSIG				1/2 CYL PSIG						
3700	3400	3300	3200	3100	3000	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800
3600	3300	3200	3100	3000	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700
3500	3200	3100	3000	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600
3400	3100	3000	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500
3300	3000	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400
3200	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300
3100	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200
3000	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100
2900	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000
2800	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900
2700	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	
2600	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900		
2500	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	800		
2400	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	800			
2300	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	800				
2200	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	800					
2100	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	800	700					
2000	1700	1600	1500	1400	1300	1200	1100	1000	900	800	700						
1900	1600	1500	1400	1300	1200	1100	1000	900	800	700							
1800	1500	1400	1300	1200	1100	1000	900	800	700	600							
1700	1400	1300	1200	1100	1000	900	800	700	600								
1600	1300	1200	1100	1000	900	800	700	600									
1500	1200	1100	1000	900	800	700	600	500									
1400	1100	1000	900	800	700	600	500										
Rated ft ³			SINGLES GAS VOLUME (FT ³) USED (SEV)														
ST 131	15	20	25	30	35	40	45	50	55	60	65	69	74	79	84	89	
ST 125	14	19	24	28	33	38	43	47	52	57	62	66	71	76	80	85	
HP 120	10	14	17	21	24	27	31	34	38	41	45	48	51	55	58	62	
HP 100	9	11	14	17	20	23	26	29	31	34	37	40	43	46	49	51	
ST 104	12	16	20	24	28	32	35	39	43	47	51	55	59	63	67	71	
ST 98	11	15	19	22	26	30	33	37	41	45	48	52	56	59	63	67	
ST 95	11	14	18	22	25	29	32	36	40	43	47	50	54	58	61	65	
AL 80	8	10	13	15	18	21	23	26	28	31	33	36	39	41	44	46	
Single cylinder volumes.			Red values are nearest 1/3 rated capacity.											Copyright 1998, Underwater Dynamics, Inc.			

The **Gas Utilization Chart** is useful for cylinder matching or matching gas usage requirements among dive team members.

The top portion of the chart, Cylinder Pressures, enables you to quickly find the turn pressure for your cylinder and actual pressure. The bottom portion, Singles Gas Volume Used, allows you to quickly find out how much gas will be used at a specific turn pressure.

For example, if your starting cylinder pressure is 3000 psig, you would look for that pressure in the far left column and then follow that row to the right until you come to the desired turn pressure. If you want to determine the turn pressure for the rule of thirds, you would go to 2/3 cylinder pressure, which is color coded blue, and see the turn pressure is 2000 psig. Next follow that column down to the lower half of the chart, Singles Gas Volume Used (ft³) in surface equivalency volume (SEV), until you come to the row designated for your cylinder volume. If you were diving an aluminum 80 cubic foot cylinder, you would find 26 ft³. This is a close approximation of how much gas that will be consumed or used up when the cylinder pressure is 2000 psig for a single 80 that had a starting pressure of 3000 psig. (Note, the true capacity of a Luxfer AL 80 is 77 ft³, not 80 ft³ as is commonly believed.) If your dive partner is using a ST 104 filled to 2500 psig, their thirds turn pressure will be 1700 psig and they will have used up 32 ft³ of gas at their turn pressure.

Keep in mind that gas usage depends on an individual's surface consumption rate related to depth, time, BC inflation, lift bag deployment, gas sharing, and accidental gas loss, among other things. Use this chart during dive planning to match cylinder capacities and turn around pressures between divers. Instructors and students alike can **laminates a small version** and stow it in a pocket to reference turning pressures prior to descent.

DOUBLE CYLINDERS GAS VOLUME UTILIZATION CHART																
CYL PSIG		CYLINDER PRESSURE (PSIG)														
4/5 CYL PSIG				3/4 CYL PSIG				2/3 CYL PSIG				1/2 CYL PSIG				
3700	3400	3300	3200	3100	3000	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900
3600	3300	3200	3100	3000	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800
3500	3200	3100	3000	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700
3400	3100	3000	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600
3300	3000	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500
3200	2900	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400
3100	2800	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300
3000	2700	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200
2900	2600	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100
2800	2500	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000
2700	2400	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900
2600	2300	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	
2500	2200	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900		
2400	2100	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	800		
2300	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	800			
2200	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	800				
2100	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	800	700				
2000	1700	1600	1500	1400	1300	1200	1100	1000	900	800	700					
1900	1600	1500	1400	1300	1200	1100	1000	900	800	700						
1800	1500	1400	1300	1200	1100	1000	900	800	700	600						
1700	1400	1300	1200	1100	1000	900	800	700	600							
1600	1300	1200	1100	1000	900	800	700	600								
1500	1200	1100	1000	900	800	700	600	500								
1400	1100	1000	900	800	700	600	500									
Rated ft ³	DOUBLES GAS VOLUME (FT ³) USED (SEV)															
ST 131	30	40	50	60	69	79	89	99	109	119	129	139	149	159	169	179
ST 125	28	38	47	57	66	76	85	95	104	114	123	133	142	152	161	170
HP 120	21	27	34	41	48	55	62	69	75	82	89	96	103	110	117	123
HP 100	17	23	29	34	40	46	51	57	63	69	74	80	86	91	97	103
ST 104	24	32	39	47	55	63	71	79	87	95	102	110	118	126	134	142
ST 98	22	30	37	45	52	59	67	74	82	89	97	104	111	119	126	134
ST 95	22	29	36	43	50	58	65	72	79	86	94	101	108	115	122	130
AL 80	15	21	26	31	36	41	46	51	56	62	67	72	77	82	87	92
Twin cylinder volumes.				Red values are nearest 1/3 rated capacity.											Copyright 1998, Underwater Dynamics, Inc.	

This **Gas Volume Utilization Chart is for doubles**. The doubles volumes are based on manifolded twin cylinders. Cylinder capacity (ST 131) is the rated capacity of each cylinder in a twin set, not the doubles volume. ST is steel, AL is aluminum and HP refers to high pressure (3500 psi) cylinders. This chart can be used to match gas consumption between divers so that both divers would have enough gas remaining to share with an-of-gas buddy and make it to the surface. First each diver in a dual team needs to determine the usage for the planned bottom time. Let's say the instructor's planned usage is 65 ft³ at their thirds turn pressure of 1800 psi for twin LP 95s filled to 2700 psi. This leaves 125 ft³ of gas to exit and surface. However, his student is diving dual low pressure 104s filled to 2700 psi and will use 71 ft³ at their thirds turn pressure of 1800 psi, leaving 137 ft³ of gas. Because the instructor has smaller volume doubles, he must modify his turn pressure to have enough gas to get them both back to the surface if the student has a catastrophic gas loss at their turn pressure. The sum of each diver's thirds gas volume is 136 ft³, therefore each diver should have at least this much gas when the dive is turned. The instructor's smaller volume twins would supply his 65 ft³ and the student's 71 ft³ if he has to perform a gas sharing retreat. To determine what pressure the instructor will have 136 ft³ from the chart, he must subtract 136 ft³ from 190 ft³ to get 54 ft³ and then locate the Gas Volume Used that is closest to 53 ft³ in the row for dual 95s, which is 50 f.³. Read up this column to get the turn pressure that intersects the row with his starting pressure. The modified turn pressure is 2000 psi, which leaves 141 ft³, enough for both to surface on should the student run out of gas at their thirds turn point.

This table concept was devised by NAUI Instructor Alan Williams and is reproduced with his permission. It's modified to include additional capacities, pressures and designations for imperial and metric versions.

GAS VOLUME UTILIZATION CHART															
CYL (BAR)	CYLINDER PRESSURES (BAR)														
	3/4 CYL PRESSURE				2/3 CYL PRESSURE				1/2 CYL PRESSURE						
300	290	280	270	260	250	240	230	220	210	200	190	180	170	160	150
290	280	270	260	250	240	230	220	210	200	190	180	170	160	150	140
280	270	260	250	240	230	220	210	200	190	180	170	160	150	140	130
270	260	250	240	230	220	210	200	190	180	170	160	150	140	130	120
260	250	240	230	220	210	200	190	180	170	160	150	140	130	120	110
250	240	230	220	210	200	190	180	170	160	150	140	130	120	110	100
240	230	220	210	200	190	180	170	160	150	140	130	120	110	100	90
230	220	210	200	190	180	170	160	150	140	130	120	110	100	90	80
220	210	200	190	180	170	160	150	140	130	120	110	100	90	80	70
210	200	190	180	170	160	150	140	130	120	110	100	90	80	70	60
200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50
190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40
180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30
170	160	150	140	130	120	110	100	90	80	70	60	50	40	30	20
160	150	140	130	120	110	100	90	80	70	60	50	40	30	20	10
150	140	130	120	110	100	90	80	70	60	50	40	30	20	10	
140	130	120	110	100	90	80	70	60	50	40	30	20	10		
130	120	110	100	90	80	70	60	50	40	30	20	10			
120	110	100	90	80	70	60	50	40	30	20	10				
110	100	90	80	70	60	50	40	30	20	10					
100	90	80	70	60	50	40	30	20	10						
90	80	70	60	50	40	30	20	10							
80	70	60	50	40	30	20	10								
70	60	50	40	30	20	10									
60	50	40	30	20	10										
50	40	30	20	10											

Rated VOL	GAS VOLUME (LITERS) USED														
	SURFACE EQUIVALENCY VOLUMES (SEV)														
5400	180	360	540	720	900	1080	1260	1440	1620	1800	1980	2160	2340	2520	2700
4500	150	300	450	600	750	900	1050	1200	1350	1500	1650	1800	1950	2100	2250
3600	120	240	360	480	600	720	840	960	1080	1200	1320	1440	1560	1680	1800
3000	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500
2700	90	180	270	360	450	540	630	720	810	900	990	1080	1170	1260	1350
2400	80	160	240	320	400	480	560	640	720	800	880	960	1040	1120	1200
1800	60	120	180	240	300	360	420	480	540	600	660	720	780	840	900
600	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300

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This **Gas Volume Utilization Chart** is for metric values. Pressures are in bars and volumes are in liters. Refer to the instructions on slide 67.

This is the calculation to find the modified turn pressure based upon the instructor’s SCR and doubles on the previous slide. Modified Turn PSI = starting psi - [starting psi ÷ (2 + (buddy SCR ÷ your SCR))]

For double 95s: 2700 psi - [2700 psi ÷ (2 + (buddy SCR 1.0 cfm ÷ your SCR 0.5 cfm))]

$$\text{modified turn pressure} = 2700 \text{ psi} - [2700 \text{ psi} \div (2 + 2)]$$

$$\text{modified turn pressure} = 2700 \text{ psi} - 675 \text{ psi}$$

$$\text{instructor’s modified turn pressure} = 2025 \text{ psi}$$

The student’s thirds turn pressure would be 1800 psi and their **modified turn pressure** would be 1620 psi. The instructor must use 2025 psi and the student must use 1800 psi for their turn pressures, but the dive is called when the first diver reaches their turn pressure so that either diver will have enough gas for the partner if they have a catastrophic gas loss at the turning point.

Keep in mind that determining modified turn pressure is normally figured for penetration dives, but it is often used for deep long dives requiring lengthy staged decompression. Instructor’s should always plan to have enough back gas for just such scenarios.

CONTINGENCY PLANS

Abort on trimix or bailout gas if you are not beyond your NDL and use deco gas during safety stops.

For different depth and/or bottom time than planned, use the appropriate schedule and gases.

For lost deco gas, switch to the appropriate schedule for decompressing on back gas (bottom mix).

Trimix Section 4 Pg 16

If a problem occurs during descent and you are within your NDL, ascend at a safe rate and switch to deco gas during a safety stop.

If a problem occurs at max depth at maximum bottom time or either or both are exceeded, begin ascending and switch to the appropriate schedule and gases. Always carry the next longer and deeper contingency schedule, but you should carry a matrix of several plus and minus depths and bottom times.

If back gas is compromised, share a buddy's back gas or use bailout mix and abort on the decompression schedule for the available gases used.

If travel mix is compromised, conduct the decompression schedule for the bottom mix and available deco mix used.

If deco gas is compromised, switch to the appropriate schedule for conducting decompression on back gas.

If there is any catastrophic gas loss situation, as soon as it's safely possible to do, send up an emergency signal asking for additional gas if plans have not already been made to have backup cylinders staged on the ascent line.

Factor in repetitive trimix and air dives made within the previous 24 to 48 hours to account for all residual inert gas when generating a mixed gas decompression schedule. This is especially a concern when conducting consecutive training courses or making multiple dives per day. If a dive computer is used for decompression during previous dives, download the profiles and input the repetitive dive data (with a margin of conservatism). It's not a bad idea to continue diving with the same dive computer to supply redundant or training information during and after the trimix dive, but also to recover its decompression schedule to account for its calculated inert gas penalty; that is if doing so does not pose additional operational or physiological risks.

ABC'S...		
Actual	Bailout	Crisis
Planned Gas	Abort Gas	Share Gas
Dive Plan	Abort Plan	Survival Plan

Trimix Section 4 Pg 17

The **actual plan** is the scheduled depth, bottom time, gas switches and deco stops. Write “Plan” above or next to the schedule on your table before laminating it and on the penciled schedule on your slate and/or inked on tape on your fins. To help prevent the “droopy finger” syndrome when reading a matrix of table values, highlight the row with your planned schedule in yellow. You may also want to highlight the gas mixtures and draw a heavy line between the depth increments wherever a gas switch is made. For instance, darken the line separating the 20 ft and 30 ft (6-9 m) stop when a gas switch will be made at 20 ft (6 m).

The **bailout plan** generally includes the schedule for the next deeper planned depth and/or next longer planned bottom time with the planned gases and gas switches. One should also determine the “abort” depth and the time at which the dive can be called without incurring mandatory stop time. For example, computing a dive on Voyager Desktop Decompression software to 200 fsw (61 msw) using TX 16/44 with an instantaneous descent provides 2 minutes of no-stop time at 200 fsw, 3 minutes at 150 fsw (46 msw) and 7 minutes at 100 fsw (30 msw). For an actual descent rate of 50 fpm (15 mpm), the dive can be aborted on back gas with just precautionary safety stops until reaching 150 fsw (46 msw). For deeper dives, it may also be necessary switch to an “abort gas.” It’s important to establish appropriate abort schedules and bailout plans and identify them from the actual plan with the label “abort” or “bailout” or a similar word because most problems generally occur during descent.

The **crisis plan** is the schedule for completing the dive on back gas because deco gas is lost or depleted. Crisis contingencies for signaling surface crew for underwater emergencies must be planned and reviewed.

Keep in mind that in most situations, problems are easier to deal with at shallower depths where nitrogen does not impair judgement and the approach to time and gas pressure limits is more relaxed. It’s best to go to the redundant backup in the event of an equipment or gas problem and terminate the dive, then investigate the cause at a deco stop where there are less gas and time pressures. A diver who develops a life threatening problem must first be physically controlled by holding onto their BC harness or manifold. Then terminate the dive within safe limits. Just as proper action supercedes diagnosis of a diver suspected of having decompression illness, the specifics of a problem do not need to be known before action should be taken. Signal other dive team members and make a controlled ascent. Repeated training is the best way to ensure that a crisis plan will work smoothly. Develop “**What if... scenarios**” and make certain everyone knows the most appropriate response to different problems as well as “who does what” in each emergency.

AIR NO-STOP LIMITS

Dive computer NDLs compared with USN table NDLs

	<u>USN/Haldane</u>	<u>ALADIN/ZH-L</u>	<u>VYPER/RGBM</u>
	min	min	min
100 fsw	25	17	17
110 fsw	20	14	13
120 fsw	15	12	10
130 fsw	10	10	9
140 fsw	10	9	7
150 fsw	5	8	6

Trimix Section 4 Pg 18

This slide shows **air NDLs** for depths ranging from 100 to 150 fsw (30 to 45 msw) from the **USN tables** and those generated on an **Aladin (UWATEC) computer** using the ZH-L 16 algorithm and those generated on **Suunto's new VYPER** computer using Dr. Wienke's RGBM algorithm.

Knowing the no-stop time limits for your back gas and any travel or bailout gas you carry during a dive is the first bailout option when a dive must be aborted during the descent, typically because of equipment malfunction, such as light failure or faulty mask, etc. It's also important to know the no-stop limits for the specific meter or table you use or carry as a backup device.

RGBM TRIMIX NO-STOP LIMITS			
	TX 16/24/60	TX 16/33/51	TX 16/44/40
	min	min	min
100 fsw	10	9	8
150 fsw	7	6	5
200 fsw	6	5	4

Trimix Section 4 Pg 19

This slide shows **RGBM no-stop limits for three different bottom mixtures**. Air is breathed at sea level prior to and after the dive and the surfacing pressure is sea level. Knowing the NDL is the first safety option if the dive must be aborted during the descent on back gas.

TRIMIX NDLs computed on Voyager Desktop Decompression Software.

	16/24	16/33	16/44
	min.s	min.s	min.s
100 fsw (30 msw)	8	8	7
150 fsw (45 msw)	4	3	3
200 fsw (60 msw)	2	2	2

A simultaneous descent is employed and the schedules were generated with 40% conservatism. At 0% conservatism, no-stop times increase by about only one minute (2 minutes for 16/24 at 100 fsw).²³

RGBM TRIMIX NO-STOP LIMITS

TX 16/24/60 TX 16/33/51 TX 16/44/40

	min	min	min
30 msw	10	9	8
45 msw	7	6	5
60 msw	6	5	4

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See previous slide.

HELITROX NO-STOP LIMITS

O₂ 26-30%, He 13-17%, N₂ 53-61%

DEPTH	END	RGBM	ZH-L
fsw	fsw	min	min
100	56-70	19	18
110	63-77	16	15
120	70-85	14	13
130	76-93	12	11
140	83-101	11	10
150	90-108	10	9

Trimix Section 4 Pg 21

These **NDLs were generated on ABYSS software.**¹ Air is breathed at sea level prior to and after the dive and the surface pressure is sea level. Times are approximate and will vary slightly depending on the specific mix fractions. The RGBM NDL for 90 fsw is 23 minutes and it's 28 minutes for 80 fsw.

Helitrox is oxygen-enriched trimix. The easiest way to make it is by partially filling a scuba cylinder with some helium and then topping it off with premixed nitrox to produce a normoxic trimix. It is still important to analyze the oxygen content in the supply nitrox before blending it with helium and again after the final mix is made. It becomes a simple matter to mathematically verify the gas fractions from the helium and nitrox partial pressures. Naturally, helitrox can also be produced by combining oxygen, helium and air.

Compared to heli-air or trimix that is hypoxic at the surface, the higher oxygen content decreases mandatory decompression and the lower nitrogen content decreases narcosis at depth. Some divers dive helitrox as though it were air to reduce narcosis and because they experience less post-dive fatigue, which is more often associated with diving air.

HELITROX NO-STOP LIMITS

O₂ 26-30%, He 13-17%, N₂ 53-61%

DEPTH	END	RGBM	ZH-L
msw	msw	min	min
30	17-21	19	18
33	19-24	16	15
36	21-26	14	13
39	23-28	12	11
42	25-30	11	10
45	27-33	10	9

Trimix Section 4 Pg 22

Metric version. See the previous slide.

ASCEND SAFELY

- ✓ **Access your gauges and deco table**
- ✓ **Select the correct deco schedule**
- ✓ **Confirm and communicate your choice**
- ✓ **Execute ascent, stops, gas switches**
- ✓ **Note gas pressures, depth, time, partner**
- ✓ **Decompress accurately**

Trimix Section 4 Pg 23

Write the schedules legibly so that you, as well as your partner, can read them easily.

Keep the planned schedule in view, such as on an arm slate or on your fins.

Carry the contingency schedules where they are quickly accessible, preferably in separate places.

Familiarize yourself with the contingency schedules to know when to implement them.

Imprecise depth control during stops is the most common error made during staged decompression.

To **ASCEND** safely do the following:

Access your depth gauge for maximum depth, your timing device for bottom time and your deco table.

Select the correct decompression schedule.

Confirm and communicate your choice to your partner to be sure they agree to the same plan of action.

Execute the proper ascent rate, deco stop depths and stop times, and gas switches for the correct schedule.

Note your gas pressure, depths, times, and your partner's status throughout decompression.

Decompress accurately, paying close attention to not violate a decompression ceiling or an ascent rate.

For increased conservatism, **deep and/or mixed gas divers are recommended to rest immediately after surfacing for at least 30 minutes** during the time that microbubble formation is approaching its highest point. Breathing pure oxygen during this rest period will speed up elimination of residual dissolved inert gas and will help minimize its evolution and reduce bubble size. Some divers even elect to breathe oxygen at the surface immediately before a deep dive to lower their nitrogen levels. This is done either to provide an increased margin of safety or to accelerate the decompression schedule to reduce their overall time in the water.

SECTION 4 ANALYZED



Trimix Section 4 Pg 24

- ✓ Time Terminology
- ✓ Descent/Ascent Rates
- ✓ Dive Planning
- ✓ Imperial Calculations
- ✓ Trimix Diver/Team Planners
- ✓ Gas Utilization Charts
- ✓ Contingency Plans
- ✓ ABCs
- ✓ Air, Trimix, Helitrox NDLs
- ✓ ASCEND Safely

1. Using the RGBM schedule, complete the Trimix Diver Plan for a dive to 170 fsw (52 msw) using TX 16/24 for a bottom time of 25 minutes. Air is breathed from 100 fsw (30 msw) up to 20 fsw (6 msw) and oxygen is breathed from 20 fsw to the surface (See slide 29). For all gas calculations, assume an instantaneous descent and a 30 fpm ascent rate. SCR is 1.0 ft³/min (28 L/min) during the dive, but decreases to 0.4 ft³/min (11.2 L/m) during staged decompression.
2. What is the diver's consumption for each gas and what is the total requirement if they plan their supply according to thirds? TX = 152.50 ft³ / 228.75 ft³, Air = 14.76 ft³ / 22.14 ft³, O₂ = 5.68 ft³ / 8.52 ft³
3. What is the total %CNS exposure and the total OTUs? %CNS = 24.96 OTUs = 44.91
4. What are the PO₂ and the END at maximum depth? PO₂ = 0.976 ata, END 121.17 fsw
5. What is this diver's VO₂ (SEV) during the 25 minutes bottom time? 1.5 L/m (Slide 47)
6. What is the minimum capacity twin cylinder set this diver can use? What is the minimum capacity stage bottles they can use? Dual 125 ft³ cylinders of TX, 30 ft³ cylinder of air and 13 ft³ pony of O₂
7. What is the available supply time at max depth for the doubles you selected? 41 minutes
8. What is the turn pressure based on thirds if the diver starts with 2600 psig? How much gas will have been used at this point? 1800 psig, 75.7 ft³ (See formulas on Slide 59 or the Gas Utilization Chart on 68)
9. From slide 73, what no-stop time is appropriate for this dive? 6 minutes
10. List and define 7 different diving terms for time. Descent, ascent, stop, deco, run, total, SIT (Slide 56)
11. What should the diver in question 1 do if he has a catastrophic gas loss 4 minutes into the dive? Terminate on air and an air schedule or terminate on the partner's TX and follow its schedule, make safety stop on O₂.
12. What should he do if at 29 minutes run time a sling cylinder becomes tangled in line at 90 fsw and it takes him 2 minutes get it free? Deco 2 extra minutes at 80 fsw and then follow the planned schedule.
13. What should he do if he has no air for deco? Decompress according to the contingency schedule for back gas and use O₂ for safety during shallow stops.
14. Provide 2 reasons for using helitrox. Reduced mandatory decompression and nitrogen narcosis compared to that of air.
15. What does ASCEND stand for? Access depth/time/table, Select schedule, Communicate it to buddy, Execute ascent/stops/gas switches, Note depths/times/pressures/partners, and Decompress accurately.

TRIMIX DIVER PLAN

DIVER NAUI TX Diver DATE dd/mm/yy

SITE Atlantic Ocean

TYPE OF DIVE Answer to No. 1

REST SCR 0.4 cf/m WORK SCR 1.0 cf/m AVG. RMV 1.0 cf/m TURN PSI 2400 RULE Thirds

MAX. DEPTH 170 fsw SCHED. DEPTH 170 fsw BOTTOM TIME 25 mins TOTAL RUN TIME 56 mins

B. MIX O2% 16 He% 24 N2% 60 CF 240 PSI 3500 D MIN sea level D MAX 297 fsw

DECO MIX 1 O2% 21 He% 0 N2% 79 CF 30 PSI 3000 D SWITCH 100 fsw MOD 218 fsw

DECO MIX 2 O2% 100 He% 0 N2% 0 CF 13 PSI 2500 D SWITCH 20 fsw MOD 20 fsw

FSW	DESCENT			ASCENT		STOP TIME	CNS %	OTU	Cu. Ft.	DECO RUN	
	ATA	FO2	PO2	FO2	PO2 ata						mins
10	1.3	0.16	0.2	1.00	1.3	6	3.36	8.88	3.12	33	
20	1.6	0.16	0.3	1.00	1.6	4	8.88	7.68	2.56	26	
30	1.9	0.16	0.3	0.21	0.4	5	-	-	3.80	21	
40	2.2	0.16	0.4	0.21	0.5	3	-	-	2.64	15	
50	2.5	0.16	0.4	0.21	0.5	3	-	-	3.00	11	
60	2.8	0.16	0.5	0.21	0.6	1	0.14	0.27	1.12	7	
70	3.1	0.16	0.5	0.21	0.7	1	0.18	0.47	1.24	5	
80	3.4	0.16	0.5	0.21	0.7	1	0.18	0.47	1.36	3	
90	3.7	0.16	0.6	0.21	0.8	0	-	-	-	-	
100	4.0	0.16	0.6	0.21	0.8	1	0.22	0.65	1.60	1	
110	4.3	0.16	0.7	0.16	0.7						
120	4.6	0.16	0.7	0.16	0.7						
130	4.9	0.16	0.8	0.16							
140	5.2	0.16	0.8	0.16	0.8	2.3	0.51	1.49	11.96		
150	5.5	0.16	0.9	0.16							
160	5.8	0.16	0.9	0.16							
170	6.1	0.16	1.0	0.16	1.0	25	8.25	25.00	152.50		
TOTALS						52.3	24.96	44.91	184.90		

GEAR CK SCHEDULE CK BUDDY GEAR CK BUDDY SCHEDULE CK

DIVER SIGNATURE NAUI Trimix Diver BUDDY VERIFICATION NAUI Trimix Instructor or Partner

Trimix Section 4 Pg 25

This is an **RGBM schedule for a 170 fsw dive using TX 16/24** to the bottom and then back up to 100 fsw where a **switch to air** is made and then up to 20 fsw where a **switch to oxygen** is made. Partial minutes were rounded up in the calculations for Deco Run Time. This RGBM schedule is based on an actual 30 fpm descent and ascent rate, but for calculating gas requirements and oxygen exposures for problem 1, an instantaneous descent was used.

SECTION 5 TOPICS

- ✓ **Buoyancy Compensator**
- ✓ **Regulators**
- ✓ **Regulator Performance**
- ✓ **Cylinders**
- ✓ **Rigged Doubles**
- ✓ **Stage Cylinders**
- ✓ **Instruments**
- ✓ **Accessories**
- ✓ **Rigging Options**
- ✓ **Gear Checklist**
- ✓ **Pre-dive Checklist**

Trimix Section 5 Pg 1

Fifteen questions and their answers covering section 5 are on slide 92.

BUOYANCY COMPENSATOR

- | | |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> ☒ High Capacity BC ☒ Back-mounted Wings ☒ Redundant Bladder ☒ Retractable Bladders ☒ Deflator/Inflator Hose ☒ Dump Valves ☒ Power Inflator | <ul style="list-style-type: none"> ☒ Nylon Harness ☒ Backplate ☒ D-Rings ☒ Buckles ☒ Crotch Strap ☒ Pocket |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Trimix Section 5 Pg. 2

Select a **BC** with **sufficient lift capacity** (80-100 lbs/36-45 kg) for your outfitted weight. Back-mounted “wings” offer the least drag for lift capability and don’t cause a body squeeze when inflated. BC wings with a low profile at the top of the bladder are preferred by divers who dive dry because their dry suit provides added lift in this area. When not wearing a dry suit and/or weight belt or when wall diving, dual bladders is advised. Retractable dual bladders (bondage wings) allow a diver to adjust their center of buoyancy and trim, however the elastic bands must not be so tight that lift capacity is reduced. If a retractable bladder springs a leak, it will deflate rapidly, so don’t use a bondage system on a single bag BC. Install a split tire inner tube between the outer shell and the internal bladder if you want extra protection against punctures. Position the wings and backplate on the doubles so your **center of buoyancy is at chest level** and when the BC’s partially inflated you have **clear access to the manifold valves**. Connect the **primary LP hose to the primary BC inflator** and the **backup LP hose to the backup BC**. When wearing a dry suit inflated from back gas, connect the LP inflator hose from the left post to the dry suit and the one from the right post to the BC inflator. When using a wet suit and single bladder BC, hook the left LP inflator hose to the BC and tie or tape the right LP hose to it so they can be quickly switched. Hoses should be secured so they can’t float up or behind you. To keep deflator hoses stationed in the chest region, run an inflator hose through the shoulder D-ring before connecting it to the inflator valve, or loop bungee around them, or use a long LP hose routed under your arm to connect to the primary inflator. Inflator hoses should be the right length so they lay flat when connected. Use two 1/4 inch wide bands of large diameter bicycle inner tube around the deflator and inflator hose to keep them side-by-side or use a neoprene shoulder pad. If both hoses are the same length, wrap light colored electrical tape around the end of the primary to differentiate it from the backup. Turn their mouthpieces inward. Use a neoprene sleeve to protect the backup deflator hose routed over the BC. A **high-flow inflator and LP hose permit faster power inflation**. It only takes 5 seconds to fully inflate an 80-lb. bladder at the surface compared to 15 seconds with a factory installed (standard flow) inflator. **Over-expansion valves** are integral components to every BC. The **pull-dump cord** permits the diver to vent gas without having to maneuver into a vertical or a right-side down position. It’s important to learn how and when to use BC dump valves. If the dump cords are routed near each other, you may want to install differently shaped plastic ends on the primary and auxiliary or shorten one to better tell them apart. A basic **harness** is continuous 2-inch nylon webbing woven through 8 slots in an aluminum or stainless or plastic backplate. Some have a Q-R buckle on the left shoulder strap to make it easier to get on and off. It’s made of 3 sections of webbing that connect to a metal ring on each shoulder strap. The shoulder straps and belt should have at least one metal **D-ring** on each side. Align bottom D-rings at the hip so gear doesn’t hang lower than the body midline. D-rings are different sizes, are hinged or rigid at 45° or 90° and are straight or bent up slightly. A **crotch strap** keeps the BC from moving around on your back. It attaches to the bottom of the backplate and to a small buckle on the front of the belt. A **zippered pocket** on the belt carries items needed during the dive: slate, pencil, tables, compass, web/wire cutters. Open ocean divers use a **waterproof canister** to carry surface position signals: dye, mirror, VHF radio, EPIRB, etc.

REGULATORS

- ✓ **Class A Performance**
- ✓ **DIN Valve Connections**
- ✓ **Primary Second Stage**
- ✓ **Auxiliary Second Stage**
- ✓ **Spare O-rings and Parts**

Trimix Section 5 Pg.3

Select high performance scuba regulators that are known to have a good deep diving track record, preferably Class A. Each first stage needs a second stage, but one should have a 7 ft (2 m) long second stage hose. Use a **Q-R necklaces** on both second stages to keep them located in the upper chest region or attach a brass swivel snap to the long hose near the second stage with a breakaway connection so it can be clipped off to the right shoulder D-ring when not in use. Because the long hose needs to be immediately accessible since it's the one donated, some divers put a snap on the short hose and necklace on the long.

Using **identical regulator connections (DIN)** make it possible to switch a malfunctioning regulator underwater. (A first stage with a dry-bleed valve may lose its ability to compensate for depth when flooded.) Streamline each regulator hookup so that the hoses do not obstruct the manifold on/off knobs and the hoses from one regulator do not intertwine with those from the other.

Rigging the short hose on the left outlet and the long hose on the right is fairly standard, but which one to breathe from isn't. **To avoid donating the second stage in your mouth, breathe off the regulator with the short hose and pass the long hose.** To have the capability of short and full length long hose deployment, run a loop under two elastic bands around the right cylinder so it's situated behind the backplate, then pass a loop through a bungee on each cylinder neck so it lays in front of the manifold under the regulators, then bring it over your arm and cradle the second stage in an elastic Q-R necklace.

Passing the long hose you are breathing from is the best way to ensure an out-of-gas diver gets a good breathing regulator. One rigging option is to route it down the right side of your tanks and back toward the front under your light canister or knife (or over your arm and down across your chest with the loop tucked into your belt), then up across your chest and over your left shoulder and halfway around your neck. To donate it, simply dip your head forward while extending the second stage away from you - toward the buddy in need. No matter which hose you breathe from or how you route it, passing the long hose will avoid inadvertently giving away (or getting) a second stage delivering hot gas. The longest hose should always deliver bottom mix that can be consumed at maximum planned depth, but this distinction is obscured if a long hose is also used on a deco regulator. Always stow deco second stages after being used.

To know if the left on/off knob accidentally rolls closed from contact with a ceiling, either breathe off the second-stage on the left valve outlet or setup your primary inflation system off the left outlet.

Forward movement will rotate the left handwheel clockwise while it will rotate the right handwheel counterclockwise. But contact with a taut line can close either valve, so stay out from under lines and avoid contact with ceilings. **Connecting the SPG to the first stage with the long second stage hose allows you to monitor the gas supply to an out-of-gas buddy breathing from your long hose** because they can't. If the SPG is on the outlet with the short hose and the isolator is unknowingly closed, the buddy on the long hose could run out of gas in that cylinder without any warning. And whether you breathe from or inflate your BC or dry suit from the left regulator, you'll notice if the isolator is closed during descent because the pressure reading won't drop if the SPG is attached to the right outlet.

SCUBA REGULATOR PERFORMANCE CRITERIA

VO₂ (L/min)	RMV (L/min)	V_T (L)	BPM	DP (kPa)	kPa (J/L)
0.90	22.5	1.5	15	0.147	0.231
1.60	40.0	2.0	20	0.393	0.617
2.50	62.5	2.5	25	0.982	1.542
3.00	75.0	2.5	30	1.375	2.159

Trimix Section 5 Pg 4

The **normal respiratory rate** for an adult is about 12 to 16 breaths per minute (BPM) but it can go as high as 30 BPM when working hard. At sea level and a body temperature of 98.6 F °, respiratory minute volume (RMV) can range from 6 liters per minute (0.21 ft³/min) at rest to a maximum of 90 L/min (3.18 ft³/min) during heavy exercise. The average adult male RMV is about 9.8 L/min (0.35 ft³/min).

Scuba regulator performance criteria shown above are for air from 0 to 200 fsw (61 m) and for heliox from 0 to 1500 fsw (457 m). Optimum regulator function at MOD is an RMV of 75 L/min (2.65 ft³/min), but 62.5 L/min (2.2 ft³/min) is the limit for reasonable breathing work values. VO₂ is the oxygen consumption per minute at a particular workload, V_T is the tidal volume, delta P is the pressure change measured from no flow to maximum flow, and work-of-breathing (WOB) is the resistive effort measured in kPa (J/L).^{8/15} (NEDU Manual 6/94) It's very important to have all your regulators serviced annually and also whenever there is any change in performance.

Goals for a high performance regulator:

1. Function as an adequate gas delivery source at MOD
2. Minimize WOB, Peak Inhalation Pressure (PIP), Peak Exhalation Pressure (PEP) and static lung loading
3. Provide condensation of inspired gas
4. Minimal dead air space and adequate elimination of carbon dioxide
5. Lightweight hydrodynamic design and the second stage center-of-gravity matching its center-of-buoyancy to minimize jaw fatigue

DIN connections are preferable for deep diving, but there are some additional safety precautions to heed. The first stage DIN connector must be examined prior to each dive to be sure the threaded retainer is tight inside the body so that the internal O-rings seal properly. Some manufacturers call for the application of Loctite 271 on the last 3 threads. Also make sure the O-ring that seals inside the valve orifice is seated in its groove properly. When installing the regulator, align the first stage body and hoses before firmly tightening the handwheel and pressurizing the system.

CYLINDERS

- ☑ **Sufficient Capacity Cylinders**
- ☑ **Weight and Buoyancy Characteristics**
- ☑ **Dual Outlet Valve / Isolation Manifold**
- ☑ **DIN Valves**
- ☑ **Handwheels**

Trimix Section 5 Pg. 5

Doubles with a dual outlet manifold or a high capacity single cylinder with a dual outlet valve that has enough gas for the dive, including healthy reserves, is mandatory. Stage cylinders must have enough gas to meet dive requirements as well. When using steel cylinders for back gas, it's best to use aluminum stage cylinders to avoid being overweighted.

When the **isolator valve** is straight up it's easy to grab, but it stands a greater chance of hitting a ceiling or snaring a line. When it's rotated forward about 45 degrees or when its profile is lower than the valve outlets or first stage couplings there is less chance it will be banged, plus it's easier to grab by a diver who doesn't have full shoulder rotation, although, depending on its position, they may bump their head when tilting it backwards. Sometimes it's still necessary to raise or lower the doubles bands to be able to reach the center knob.

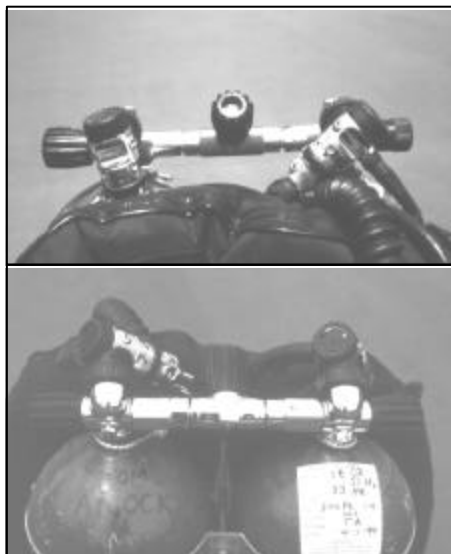
DIN connections are preferable to yoke because they employ a captured O-ring design, which is less likely to rupture and they flow about 150% more gas compared to yoke-type valves. When installing a regulator, align the first stage regulator body so that the attached hoses are oriented downward and are streamlined before firmly tightening the DIN handwheel.

After each scuba system is rigged, **check first-stage plugs and all LP and HP hose connections for leaks and be certain everything functions properly**. This is especially important if hoses have been moved around or replaced. Make a small mark on the first stage body with a grease pencil after checking a student's regulator or mark the appropriate box on the Trimix Diver Plan after all of the student's systems have been inspected. Be sure to **examine the cylinder-to-valve connections and the manifold connections** during setup. Listen for any leaks after pressurizing the system. If you suspect there is a problem, apply some soapy water or mask defog to the area. Expanding bubbles indicate a leak. Close all the valves and do not dive with the unit until it has been properly repaired by an authorized scuba technician.

Be sure **handwheels operate normally** and that the isolation valve is either fully open or is open a minimum of two full turns. The other valves should be opened all the way or opened and backed off slightly. Backing off 1/4 turn leaves a directional decision to be made during an emergency shutdown, which can cause confusion. But if a fully opened handwheel gets bumped, it can jam open so that it's extremely difficult to close and time wasted in shutting it down would add to an already serious gas loss situation. Rubber handwheels are easier to grab, absorb shock better than metal or plastic, do not break on impact and incidental contact is less likely to damage the valve stem.

Check each student's cylinder pressures and content's analyses. Verify this information matches the content's tags and be sure it's recorded on the Trimix Diver and Team Plans before the dive.

RIGGED DOUBLES



Trimix Section 5 Pg 6

The rig in the top photo shows a “clean” manifold. All the valves are accessible. But regardless of which way a rig is configured, **make certain you can reach the valves and operate them easily.** Bulky hose protectors can be removed or shortened to allow greater hose flexibility and access to valves. Some divers use different colored hose protectors to facilitate hose identification by a buddy. For instance, a blue protector on the primary second stage hose, green on the auxiliary second stage, black on the high pressure line and so on.

In these photos, all the handwheels are rubber. The handwheel on the isolator and the right valve outlet are ergonomic in that they feel “smooth” when rubbing your hand clockwise over the knob. This decreases the chance it will be bumped closed. They feel “knobby” when rubbing a hand counterclockwise over them and this makes it easier to open, especially with wet hands. The “low friction” knob on the left post is smooth to touch in either direction and is recommended when diving in any type of overhead environment, such as a wreck, cavern or cave. It’s altogether less likely to roll closed with accidental contact against a ceiling or a taut line. The rubber handwheel on the center post has about a 1/4 inch lip over the tension screw. This offers some protection against damaging the valve stem when it’s accidentally bumped. The extra height also makes this knob a tad easier to get hold of and turn. It’s important to position the isolation valve where it’s easiest to reach when wearing the rig. Keep all valve assemblies well lubricated.

The bottom photo shows the backside of a set of doubles. The **contents identification is on the right cylinder** because it’s the side the second stages are on and the **diver’s name is on the left cylinder** to identify the rig on land and the diver from behind in the water. In addition, the cylinders are numbered to differentiate similar sets of doubles. This is very helpful for a blender who must fill several twin sets at a time.

Divers who frequent sites with an overhead environment may want to install a **stainless steel cage or bracket over their manifold** to protect the valves and first stage regulators. The tradeoffs are their tendency to snare objects in a wreck environment and they can hinder valve access.

STAGE CYLINDERS



Trimix Section 5 Pg 7

- ☒ Soft mounted metal snaps and backup
- ☒ Carrying strap next to side
- ☒ Barrier under & over hose clamps
- ☒ Hot gas on left side, bagged second stage, system closed & pressurized, hose looped along top side - under arm
- ☒ Travel gas on right side, unhindered second stage, valve open 1/2 turn, hose looped along outside - away from body
- ☒ MOD labels on cylinder crown and horizontally along side

Stage cylinders need only provide **sufficient gas** to meet the dive requirements and reserves. Using cylinders with capacities far in excess of what is needed adds additional weight and drag and increases a diver's burden unnecessarily. They should hang in-line with your body as much as possible to minimize drag. Some divers attach a stage bottle to a separate belt worn around their waist and put the valve through a bungee around their shoulder strap to keep it in trim. Others use a combination of metal snaps and hose clamps to carry it from D-rings on their BC harness.

Use nylon line to **“soft” connect** a brass or stainless swivel snap to the cylinder neck so it can be cut away in an emergency if necessary. If the top snap is connected in the same loop as the carrying strap, back it up with line or silicone tubing, which won't quickly deteriorate like natural rubber. The line should be loose enough to get one finger between it and the valve so it can be cut away from the valve and so that the snap can move around the valve easily. Connect the bottom swivel snap to the SS hose clamp secured around the cylinder, but independently of the carrying strap. If the line holding the snap breaks, you can clip it onto the carrying strap and the harness D-ring to keep the bottom of the stage cylinder from floating around unhindered. Use a rubber barrier under the SS hose clamp to prevent galvanic action from the dissimilar metals. Rig it so the strap is up, between your body and the second stage hose and it doesn't impede second stage deployment or act as a snare. Use snaps that operate easily when wearing gloves. **Securing the oxygen second stage in a bag with a Q-R buckle is a training requirement** if the system is carried throughout the dive. A yellow second stage hose is highly recommended for visual identification from a distance. Stow the hose on top of the cylinder, under your arm next to your body, so it's not accessible without deliberate thought and action by you or a buddy without assistance. Additional steps are carrying it on the left and keeping the system pressurized and the valve closed until you're ready to use it. Stage the **travel gas** or bailout cylinder on the right with the valve open 1/4 to 1/2 turn so it can be quickly closed during a free-flow, but a diver can immediately breathe off the setup in an emergency. Don't clip or bag the second stage. Rig the hose along the outside of the cylinder under elastic bands so it's easily accessible by the diver and the buddy. Stow second stage hoses after their use to prevent making a wrong gas switch and entanglements.

Install a **MOD label at the top of the stage cylinder** so you can read it when geared up and a **large one horizontally along the outside** so that others can read it from a distance. Paint or inscribe the MOD in black permanent ink on wide yellow tape or laminate a computer generated label and stick it to the cylinder with transparent packing tape. The **large MOD numerals** should be at least 2 1/2 inches (6 cm) tall.

A small “pony” **submersible pressure gauge** (SPG) is suitable for the hot gas, but always obtain a precise pressure reading with a standard gauge before the dive. A 6-inch (15 cm) hose or standard length HP hose and an SPG are appropriate for travel and bailout cylinders.

INSTRUMENTS

- ≡ **Depth Gauges**
- ≡ **Pressure Gauges**
- ≡ **Timing Devices**
- ≡ **Dive Computers**

Reliability

Readability

Redundancy

Trimix Section 5 Pg 8

Use redundant **depth gauges** that are rated deeper than the maximum dive depth and that denote shallow depths precisely. Wear wrist-mounted depth monitors side-by-side.

Air or nitrox computers cannot provide decompression schedules for trimix, but diving with a computer that is downloadable to a personal computer that produces a graphic illustration of depth-time profiles, decompression stops, and descent and ascent times is a training asset. A **trimix computer** that does this and offers greater diving flexibility is surely needed, and is being developed by Abysmal Diving.¹ In any case, backup tables should be cut for a trimix computer until its track record is proven to be reliable and you can afford to dive with two.

Use reliable **waterproof timing devices** that track elapsed time in minutes. Digital watches with a chronograph or stop-watch function are ideal to time decompression stops. Select one that isn't likely to be accidentally stopped in mid function, is self-illuminating and whose digits are easy to read. The start-stop button should have a collar around it to prevent accidental activation. A watch with a split-timer that is easily inadvertently activated may cause mistakes in tracking stop-times. It's imperative to know how your timer works before relying on it to manage staged decompression. For redundancy, a watch and dive computer or watch and bottom timer will suffice, but two like devices are recommended.

When a **hoseless gas-integrated computer** is used to monitor back gas, its sending unit should be attached to the regulator on the same side that the wrist unit is worn to prevent a loss of signal. A redundant analog SPG would then connect to the opposite regulator. Using just an **SPG**, connect it to the redundant regulator so you can monitor your remaining gas supply when the primary regulator is isolated or when donating back gas to a buddy on your long hose. Install a metal snap on the SPG to clip it to a harness D-ring or weave it under your harness-through a small loop of tubing so its chest level so you can see it without picking it up.

The **6-inch hose for the SPG on a deco bottle** can be tied back on itself so it rests on top of the first stage so you can read it throughout the dive and it won't be damaged when the cylinder is laid down. Route a standard length HP hose in a loop under elastic cylinder bands and clip off the SPG. Its gauge face should also be in the correct orientation to be read without having to move it or pick it up.

3 Rs to guide instrument selection are:

Reliability- Instruments function properly!

Readability - Instruments are easily accessible and understood!

Redundancy - If it's crucial to the safety of the dive - back it up! If it isn't crucial, get rid of it - **Reduce!**

ACCESSORIES

- f **Mask**
- f **Fins**
- f **Thermal Protection**
- f **Lights**
- f **Lift Bags**
- f **Line Reels**
- f **Cutting Devices**
- f **Slate(s) and Pencil**
- f **Tools, O-rings, Parts**
- f **Line, Snaps, Cable Ties**



Trimix Section 5 Pg 9

A **mask** that seals properly and offers clear 20/20 vision is basic to every scuba package. (Have students clean the faceplate to prevent condensation.) Using **full-face masks with underwater communications during deep training dives is not advised** because potential problems may outweigh the benefits of talking underwater. Breathing efficiency decreases when speaking and divers typically hold their breath or skip breathe when listening because of ambient noise and the quality of communications is often extremely poor. This results in elevated CO₂, which in turn decreases the depth and time threshold for toxicity and narcosis. Furthermore, planned and emergency gas switches are complex without a gas switching block. Removal of a full-face mask to switch second stages will intensify a student's anxiety during an already stressful situation, especially in an out-of-gas situation.

Fins appropriate to the underwater activity and environment are equally important. A section of bicycle inner tube or duct tape wrapped around the buckles should prevent line entanglement. Dry suit divers may want to consider using fin straps that have a spring to keep them from coming off when inverted.

Adequate **thermal protection** is mandatory to ward off hypothermia. Thick wet suits are suitable for warm water dives, but a semi-dry or dry suit is appropriate for long or cold water dives, as are a hood, boots and gloves. A pony bottle of argon is recommended for suit inflation when diving dry and breathing helium-rich back gas. Attach it to the side, bottom or top of the doubles or on the side of the backplate.

Carry **2 high powered lights**, a 25-50 watt primary and a sufficient backup when diving in low-light conditions. Carry 3 if there is any chance natural light will be lost. Two small lights can be taped together for a backup. Use a rubber boot or tape around the outside of a clear plastic lens cover to keep refracted light from blinding you. Mount the battery canister on the backplate or harness. A Goodman grip on the light-head permits hands-free operation. Avoid helmet mounted headlamps which blind dive partners.

Open water divers should carry a **lift bag** for drift decompression and another differently colored one for an emergency signal. The **emergency signaling device** should be large and not accidentally able to dump when it hits the surface (one with a duck-valve). Review various methods of lift bag/reel deployment.

Students must carry one reel (instructors should carry 2) with enough line to reach the surface from maximum depth. The backup spool should have enough line to reach the surface from the first deco stop.

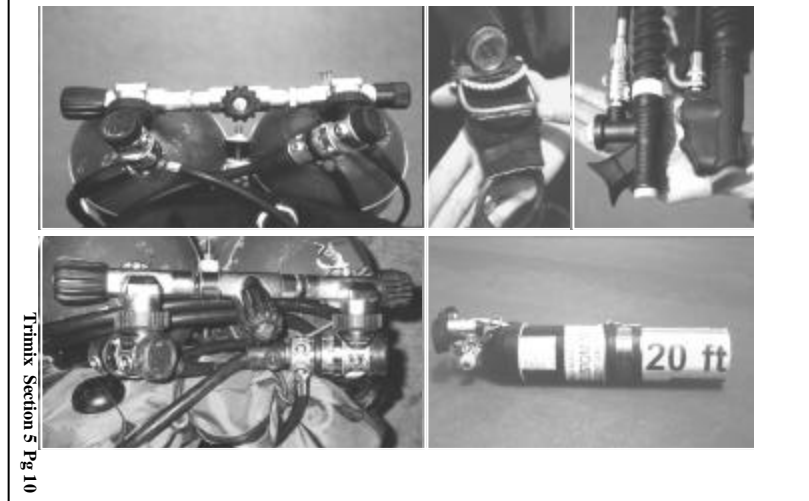
Carry a **slate** to write on and pass to a partner or send to the surface. You shouldn't have to relinquish the slate that your schedule is on to communicate with others. Attach a snap to clip it to a D-ring.

Carry **two stainless cutting devices**, something to cut heavy line as well as fishing leader wire and attach a metal snap to one so you can clip it to a D-ring while alleviating an entanglement.

Soft mount metal snaps to accessories to clip to the BC. Avoid gate snaps or boat snaps for items using just one snap because they are line traps and disconnect with a rotating twist.

Keep enough **O-rings, spare parts and tools** to perform minor repairs and move hoses around at the site.

RIGGING OPTIONS



Trimix Section 5 Pg. 10

The **top left photo** shows a rigged dual outlet (doubles) manifold with the valve handwheels unobstructed.

The **bottom left photo** shows a rig with the long hose run down the side of the cylinder and back up in front of the manifold. One pull frees up enough hose for short deployment, two pulls frees all of the hose.

The **top center photo** shows the right harness shoulder strap with a red gauge light slid under a neoprene shoulder pad and a SS shoulder harness D-ring with a slight bend to make removal of clips easier. The bungee on the strap is secured to the D-ring retainer for clipping a backup light to.

The **top right photo** shows two inflator/deflator mechanisms. The primary with the white electrical tape around it has a high-flow hose and power inflator mechanism and the back up has a low profile inflator. The mouthpieces are orientated toward the inside of the body to avoid being a line trap.

The **bottom right photo** shows an aluminum 40 ft³ cylinder rigged as an oxygen sling bottle. The large yellow MOD decal displaying the 20-foot MOD is affixed to the side of the cylinder with clear packing tape and is positioned so that others can read it right side up during a dive. Keep a stock of different laminated MODs for labeling cylinders at the dive site. The content's sticker is above the tank decal that says, "Warning Custom Mix." The diver cannot and does not rely on an "oxygen" label, but must verify the contents and MOD before using it. A cylinder with a "special mix label" and "O₂ service" designated on the current visual inspection sticker means it can be filled with nitrox or helitrox without having to change the decal for different mixtures, just the MOD. The SPG is on a 6-inch hose tied back on itself so the gauge rests on top of the first stage so the diver can read it. The valve knob is green, the second stage housing cover and hose are yellow and the second stage is secured in a green bag. Notice that the second stage is not within view or reach of other divers because it is rigged to go under the diver's arm, next to their body when carried as a sling bottle. This makes it nearly impossible for another diver to access it and it takes several deliberate steps for the diver to be able to breathe from this second stage. The more steps it takes to do this, the more opportunity for verification, the less likelihood for a fatal error. Remember, there is always enough time to verify a mix before using it! A small yellow MOD is on the top of the cylinder crown so it faces the diver and one is also on the second stage exhaust cover. The O₂ second stage has a white neck strap that is worn tight to prevent the second stage from falling out. If a seizure occurs the buddy can remove the first stage from the O₂ while the afflicted diver is not breathing and attach it to a cylinder of bottom mix or air so the diver will have a normoxic mix when they resume breathing. Labeling, rigging, positioning and a buddy verifying the depth and MOD whenever a gas switch is made are safety precautions against making a deadly gas switch.

GEAR CHECKLIST

- ☑ Valves open and unobstructed, isolator open at least 2 full turns
- ☑ Short hose regulator on left outlet and long hose on right outlet
- ☑ Long second stage hose routed for use and/or to extend quickly
- ☑ Hoses from each regulator are not intertwined
- ☑ Neck straps on second stage mouthpieces (brass snap on short hose)
- ☑ BC secured to backplate and inflated
- ☑ Primary inflator secured in front and backup secured for easy access
- ☑ SPG secured within view and/or to an accessible D-ring
- ☑ Primary light (with snap to clip to D-ring when not used)
- ☑ Red gauge light attached to mask strap or a BC shoulder strap
- ☑ Lift bag held in place by rubber bands on cylinder or backplate
- ☑ Line reels attached to hip D-ring
- ☑ Depth and time monitors and deco schedule on arm, slate in pocket

Trimix Section 5 Pg 11

Discuss different gear packages and rigging options. Go over each diver's setup and make appropriate adjustments for streamlining and safety. Students who are already diving technical rig should explain how and why their gear is configured, especially if different from others. Offer suggestions if there is a better way or point out potential problems. In any case, **it is highly recommended that everyone set their gear up the same during training.** This will make problem management underwater simpler. Seek a balanced configuration by wearing a stage bottle on each side or a sling on one side and battery pack for a light on the other. Ideally, stage bottles and accessories should hang inline with the body, within 10% of the body's vertical plane to minimize drag.

Check if the isolation valve is only open "two full turns" (check where open is) or is fully open. **Valve outlets** are customarily positioned "hard-on" in an overhead environment, while they are opened but "not hard-on" in open water.

Students should secure their **SPG** within their line of sight (and the instructor). Route it under an arm and clip or bungie it to a shoulder D-ring or more experienced divers they may opt to clip it to a hip D-ring.

Fully inflate the **BC** to check for leaks and proper inflator/deflator function. For a dual bladder BC, fully inflate the backup and check for leaks. Deflate it partially and then inflate the primary bladder while continuing to deflate the backup bag until all the gas is squeezed out. For a retractable BC, leave the primary bladder inflated to stretch the bands to weaken their tension. This is important for cold water dives and especially for wall dives where the bladder must react quickly because, for all practical purposes, there is no bottom to stop a diver's descent before reaching the MOD of their breathing gas.

A metal swivel snap installed on the **primary light** (light-head) enables a diver to clip it to a D-ring when not in use or when doing skills in close quarters with the instructor. Clip **backup lights** and accessories to D-rings stationed above your body midline. Use a small **gauge light** with a red lens (or translucent red plastic wrap under the lens) to permit instrument viewing without loss of night vision.

Carry a rolled up **lift bag** under cylinder tubing or put it through two loops of bungie at the bottom or on the side of the backplate. A backup can be carried in a pocket or in a stealth pack on the backplate.

Carry a **knife** and a backup cutting tool where they are accessible by either hand and won't be a line snare.

Double check that you have your **decompression tables, slate and pencil, depth and time monitors.**

PRE-DIVE CHECKLIST


- ☑ **Dirt dive (check placement-confirm access)**
- ☑ **Buoyancy check (weighting and trim)**
- ☑ **Equipment check (functioning & no leaks)**
- ☑ **Safety drill (gas sharing procedure)**
- ☑ **Turn pressure (gas management rule)**
- ☑ **Review signals, skills and dive plan**
- ☑ **Synchronize watches**
- ☑ **Mark time of descent**

Trimix Section 5 Pg 12

Have students perform a “**dirt dive**” on land while geared up to learn how to do specific skills and to be sure they can reach their valves before demonstrating skills during their first “wet dive.” They should conduct a **buoyancy check** in shallow water to determine if they are weighted properly and will be able to conduct the shallowest deco stop at low cylinder pressures without holding onto an anchored line. Their **center of gravity** should be along their vertical midline and their **center of buoyancy** should be no higher than chest level. Ideally, stage bottles should be worn within 10% of one’s vertical trim. Slings one under each arm is preferable to carrying two on one side, unless they are planning on dropping off the hot gas at its MOD. Diving with “piggy-backed” stage bottles has greater potential for confusion, misidentification and making a deadly gas switch and is not recommended for students. All hoses must be configured so they can be deployed without getting trapped or tangled with another piece of gear. If a (dry suit) diver must wear a **weight belt**, use of two “inline” Q-R buckles can prevent an accidental blowup caused by the belt being lost from a buckle unexpectedly opening or breaking. When donning the setup, be sure the BC crotch strap is under the weight belt before attaching it so that the weight belt can be released in an emergency. Also, to ensure a rolled up lift bag stowed at the bottom of a backplate can be pulled free when needed, route the crotch strap over the bag (between body and bag) before donning the rig. Under the instructor’s supervision each buddy team performs an **equipment check** for bubble trouble and **equipment function test**. Each partner examines their buddy’s rig while submerged (BC, tanks, valves, regulators, etc.) for inappropriate leaks and checks valves are open. Each diver checks breathing performance of each of their second stages when submerged, valves are opened correctly and cylinders are full, second stages are rigged for quick deployment and all lights work properly, and mask doesn’t leak. Next each team should conduct a **safety drill** just under the water surface where they perform a primary regulator shutdown and also simulate an out-of-gas situation and share gas with their dive buddy. The right hand removes the second stage from the mouth and the left hand inserts the backup. Use the recall slogan, “**right out - left in**” to help you remember which hand does what. When closing a valve with the right hand, rotate the knob toward your fingers, but when using the left hand, rotate the knob toward your thumb. The memory device is, “**right fingers - left thumbs**.” Simultaneously close the isolator valve with your left hand and close the right regulator outlet with your right hand. Last, **review the dive plan and signals**. To save time, ask each student to verbalize one section of the dive plan in sequence. Don’t forget to verify each student’s **turn pressure** and make a mental note who has the least gas volume and/or the highest consumption rate. Be sure everyone’s **watches are set and synchronized** and when everyone is ready, **mark the time** and initiate a controlled descent.

S-Drill Slogan: Sealed, Secured, Streamlined, Skills, Signals and Sequence.

SECTION 5 REVIEWED



- ✓ Buoyancy Compensator
- ✓ Regulators
- ✓ Regulator Performance
- ✓ Cylinders
- ✓ Rigged Doubles
- ✓ Stage Cylinders
- ✓ Instruments
- ✓ Accessories
- ✓ Rigging Options
- ✓ Gear Checklist
- ✓ Pre-dive Checklist

Trimix Section 5 Pg 13

1. Why should all your regulators have like DIN connections? A DIN valve flows 150% more gas compared to a yoke, has a captured o-ring that's less prone to rupture, and regulators can be switched underwater.
2. Explain being balanced and trimmed within 10%. Your center of gravity is aligned along your body's vertical midline, your center of buoyancy is at chest level, accessories are within 10% of your vertical plane.
3. For open ocean diving, why is it a good idea to carry two lift bags and two reels? Deploy one for drift decompression and have one as a backup or an emergency signal to surface personnel.
4. What is the normal adult respiratory rate and resting RMV? 12 to 16 BPM and 0.35 ft³/min (8.8 L/min)
5. The performance minimum for a scuba regulator for diving air to 200 fsw or heliox to 1500 fsw is a flow of 3.27 L/sec at an RMV of 62.5 L/min for 25 BPM, resulting in a WOB not greater than 1.542 J/L.
6. Describe a pre-dive in-water bubble check and safety drill. Each buddy examines their partner's submerged BC, cylinders, valves, regulators and lights for leaks and valves are opened correctly and cylinders are full. Each diver checks regulator performance, stage bottle valves are pressurized and closed, second stages are rigged properly, lights function normally, and they have reels, lift bags, gauges and tables.
7. What is the primary reason to breathe off the regulator connected to the left manifold outlet? You'll immediately know if it accidentally rolls closed during the dive and you won't unknowingly pass a "closed" second stage to an out-of-gas partner.
8. What is a "soft-mount" and what is its advantage for connecting metal snaps to accessories? Soft mount means the connection for a metal snap to an accessory is made of nylon line that can be cut. If the accessory gets entangled and it can't be unclipped from your BC harness, you can cut the snap off.
9. Describe safety measures for a diver carrying a sling bottle of O₂. Carry it on the left, bag the second stage, yellow hose and second stage rigged directly under your arm, system pressurized but valve closed.
10. Describe an MOD decal and where two should be located on a sling bottle. The MOD is the max operating (O₂) depth and units in at least 2 1/2 inch (6.35 cm) tall numerals (e.g. 20 fsw). A small decal on the cylinder crown so the diver can see it and a large decal down the outside so others can read it.
11. You must carry sufficient gas to meet the dive requirements, but using cylinders with capacities in excess of what is needed adds additional weight and drag and increases your burden unnecessarily.
12. What is the recommended lift capacity for a BC used for trimix diving? 80 - 100 pounds.
13. List four desirable features in a bottom timer? Waterproof, self-illuminating, readable, elapsed time.
14. Give 2 reasons to dive with a computer. Ascent alarms, PC downloaded record and graph of the dive.
15. What are the 3 Rs to guide instrument selection and what does reduce refer to? Reliability, Readability, and Redundancy. If it isn't crucial to the safety of the dive, get rid of it — Reduce.

SECTION 6 TOPICS

- ✓ **Team Members**
- ✓ **Players**
- ✓ **Surface Support Team**
- ✓ **Agency Protocols**
- ✓ **Accident Analysis**
- ✓ **Rescue Responses**
- ✓ **Emergency Responses**
- ✓ **Omitted Decompression**
- ✓ **DCS Signs & Symptoms**
- ✓ **Neurological DCS**
- ✓ **Desktop Decompression**
- ✓ **Skills and Techniques**
- ✓ **Technical Diving Symbols**

Trimix Section 6 Pg 1

Fifteen questions and their answers covering section 6 are on slide 108.

TEAM MEMBERS SHOULD HAVE SIMILAR...

- | | |
|---------------------|----------------|
| * Abilities | * Gas |
| * Experience | * Gear |
| * Objectives | * Getup |

Trimix Section 6 Pg 2

All dive team members should be essentially equal in their abilities, experience, objectives, gas, gear and equipment configuration to be better able to conduct the planned dive safely.

Abilities refers to fitness and includes medical soundness (physical and mental health) and physical fitness (aerobic conditioning and stamina). Metabolic oxygen consumption (VO_2) is one indication of a diver's fitness.

Experience refers to a diver's past scuba training (e.g. certification courses) and the type and amount of dives they have made. But their **recent condition or pre-dive activities**, such as a recent injury or illness (e.g. motion sickness) or recent strenuous physical exercise (e.g. running or weight lifting), may place them at a greater risk to DCS. Dr. Vann noted divers observed at Duke University and at DCIEM in Canada who performed strenuous exercise 24 hours within a dive resulted in high precordial Doppler bubble grades and in Type II DCS. It's postulated that pre-dive exercise may create additional nucleation sites leading to greater bubble formation than normal as well as the release of more than usual dissolved gas. It is known that exercising at depth increases the volume of inert gases absorbed and the time required for safe decompression. All team members need to honestly evaluate their pre-dive activities and physical condition for any additional risk factors before deciding to dive because a single diver falling short of the minimum requirements may jeopardize the safety of the entire team.

If abilities and experience are matched, but team members do not have the same **objectives** and are not able to work together - team safety will be compromised.

Gas mixtures should be the same for each diver. An exception is when two instructors are conducting training with a class. The backup instructor may dive air (or a light trimix, such as TX17/26) if the dive depth is within its MOD so that they can take an injured diver directly to the surface in a life threatening emergency. But they have the additional responsibility of making sure the deco requirements dictated by their table/meter fall within the planned schedule requirements of the other divers and that they can adhere to the longer deco schedule without any problems. Each instructor and each of the divers must have enough back gas to conduct the entire schedule on "their" back gas.

Each diver should have similar **gear and gear configurations**. Locating a piece of gear or a particular gas bottle on your dive partner should not be dependant on a visual search. Precious time spent hunting for gear dramatically increases the time pressure to solve a problem and pushes the stressed diver nearer to the brink of panic. Repetition based training is necessary to enable a diver to become completely familiar with their own gear and their partner's gear before conducting deep trimix dives.

THE PLAYERS

- | | |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> ♦ Boat Captain ♣ First Mate ♦ Team Leader ♠ Dive Leader | <ul style="list-style-type: none"> ♠ Crew Members ♦ Team Members ♣ Subordinates ♦ Observers ♦ Buddy System |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Trimix Section 6 Pg 3

Discuss the **traditional roles** and any special duties of each person engaged in training activities or the management of the dive site or the dive boat.

Typically the **boat captain** does not dive (USCG regulation), unless there are two captains on board. The first captain has the ultimate authority to do whatever is necessary for the safety of the boat and its passengers.

The **first mate** is a crewmember (sometimes a second captain) who communicates the wishes of the captain to other staff and the passengers in addition to various other duties. He or she is generally the first contact between customers and the captain.

The **team leader** is the person who organizes the gear and the divers and is responsible for the days activities.

The **dive leader** is the person who leads the dive, such as the instructor or dive master. They have control of the divers under their direct supervision and their safety is their guiding concern.

Boat crew members handle lines used to anchor or dock the vessel and they see to the needs of the captain and passengers.

Dive team members are those divers who are not leading or teaching, but who are a part of the dive team or who function as support divers. One example of a support diver's responsibilities is to dive down to check on the other divers once they reach their first deco stop.

Subordinates are those under the authority and supervision of the captain, team leader or dive leader.

Observers are passengers or crewmembers who are not part of the dive team, but who may or may not be diving.

Buddy system means each diver has an assigned partner whose personal dive plan and objectives are the same, their gases are matched, and their gear is alike and configured the same. A buddy team begins and ends the dive together. During the dive they're personally responsible to end the dive if a problem arises or if continuing it would be unsafe. The partner with a problem is assisted to the surface by their buddy.

SURFACE SUPPORT TEAM

- √ **Qualified Topside Personnel**
- √ **Qualified Rescue Divers**
- √ **Sufficient Gear and Gas**
- √ **Sufficient First Aid Supplies and Medical O₂**
- √ **Communications Equipment**
- √ **Written Emergency Plan**
- √ **Trimix Diver Plans**
- √ **Trimix Team Plan**

Trimix Section 6 Pg 4

Discuss individual responsibilities after the written dive plan and emergency plan are devised. When diving on a private vessel, review the correct use of communications equipment (marine VHF radio frequencies and call signs, etc.) and navigation instruments (e. g. compass, LORAN, GPS, etc.).

Establish and review audible and visual signals for in-water emergencies. Establish who is to respond and with what equipment and gas and who will dive down to check on the divers status quo once they reach their first deco stop.

Have 100% oxygen via a demand valve regulator immediately available at the surface, especially if each diver doesn't carry oxygen during the dive. If the distance to a recompression chamber is remote by distance or time, it is advisable for each student to keep in their possession a full cylinder of oxygen and an oxygen regulator. This is especially important when dive training will be conducted on subsequent days. A student will be able to begin oxygen breathing at the first sign of DCS, regardless of the time of day or night, while simultaneously seeking proper medical evaluation and treatment. Stress how critically important it is to not delay hyperbaric treatment for DCS. **Encourage students to report any unusual physiological or psychological symptoms that arise after a dive**, no matter how insignificant, even if the cause is believed to be unrelated to diving. **Diver's Alert Network** emergency hotline is (919) 684-4326. It and the phone number for the closest hospital should be with each student's belongings and by the nearest telephone, with the emergency O₂ and taped to the lid of a fully stocked first aid kit.

Perform a **5-minute neurologic exam** on each student, or have the students examine each other, prior to any in-water training to have a baseline to compare to in case a student develops a subtle case of CNS DCS. The idea is to gauge symmetry between the extremities and both sides of the body. Check muscle strength, sensation, coordination, hearing and vision and basic cognitive function. Be sure to note all "normal pre-dive asymmetries" that would be a false positive indication of DCS. Ultimately it's each diver's responsibility to personally evaluate their wellbeing and fitness to dive before entering the water. Peer pressure or fear of not getting certified should not be an inducement for someone to make a dive they do not feel comfortable or safe in making.

Check that each student's **Trimix Diver Plan** is filled out correctly, especially the deco schedules they will carry with them during the dive. Check that they have sufficient gases based on their SCR and that they match the deco schedule and all mixtures are labeled accurately. Complete a **Trimix Team Plan** and give it to the designated dive supervisor and/or station it with the medical O₂ at the entry/exit point.

AGENCY PROTOCOLS

- o **Boat**
- ∅ **Dive Site**
- H **Local**
- X **County**
- Σ **State**
- Γ **Federal**
- Certification Agency**

Trimix Section 6 Pg 5

There are many different agencies that have rules and standards or protocols that may affect divers and/or students directly or indirectly. Explain any and all information necessary for the safety and wellbeing of the divers, staff and the site.

Boating, diving and fishing activities are governed by local, county, state and federal laws that may apply to swimmers and divers. Examples of a typical rule enforced at state and federally owned parks is diver registration and specific diver entrance and exit areas. A signed waiver and a fee may be required before boarding a dive boat or gaining entrance to a particular landlocked dive site. An example of a training standard that needs to be explained before water training begins is the prohibition of students being in the water or exiting the water without supervision by their instructor or a certified assistant. In some places there are restrictions in what gases can be breathed underwater or what gases can be purchased without the proper certification or credentials (e.g. purchase of oxygen may require a doctor's prescription). Scuba certification agencies require waivers, medical histories, and prerequisite certifications before conducting trimix training. It is very important to **inform students of pertinent rules and standards before training activities begin.**

ACCIDENT ANALYSIS

- © **Accident Analysis**
- © **Common Crises**
- © **Potential Problems**
- © **Solution Scenarios**

Trimix Section 6 Pg. 6

Accident analyses helps us learn from the experiences of others. The purpose of studying **common crises** is to learn how to deal with similar circumstances and to be able to prevent them from happening. Provide articles about real-life diving fatalities and discuss survival options.

The most compelling question for mixed gas divers is, “**What is causing fatalities?**” Dr. Hamilton says for the majority of cases the answer is, “**Breathing the wrong gas.**” Half of the fatalities which occurred in the North Sea were caused by divers getting the wrong gas. This problem appears to be mirrored in the technical diving community as well. A disturbing number of deep divers have died from inappropriately switching to a deco gas at a depth where it is toxic to breathe. Certainly other problems are occurring, but for the most part, solutions are found or the result is decompression illness where survival is likely.

A secondary cause of North Sea fatalities was **lack of surface support** and this seems to be the case within the technical diving community as well. There are recorded accidents where the boat captain followed one surface signal, assuming all the divers were drift decompressing together, when in fact some of the divers became split off from the group and were lost at sea. This situation would be immediately obvious if a support diver went down to check on the divers when the lift bags are deployed and if divers simply deployed their personal lift bags to signal the support crew whenever they become separated.

Problems resulting from human error are often caused by **unfamiliarity with gear or its configuration**. Naturally, the least experienced diver is the one most likely to have problems. But it’s important to honestly evaluate each diver and the dive site to ascertain **potential problems** and review appropriate **solution scenarios**. Mental rehearsal is a valuable tactic to shorten the response time in dealing with an emergency. Obviously performance proficiency must be achieved before making deep mixed gas dives.

Ask students “**What if...?**” questions and time their responses. Make a point of how long it takes them to reply and then relate how the amount of time it takes them to think of the best solution would impact an actual emergency. Discuss the difference between real and imagined pressure (mental stress) as it relates to time and gas supply during problem management. Self-control is paramount. It depends on stopping all activity, breathing deeply, thinking about what to do and then acting in a calm but timely manner.

Before diving at any training site, brief students on potential problems and establish solution scenarios. Leave a written emergency plan with topside personnel. Employing proper pre-dive planning and safe diving techniques is the most important way to prevent avoidable problems from ever happening.

RESCUE RESPONSES

Anxiety	Fatigue
Buoyancy Problems	Fear
Confusion	Gas Depletion
Cramps	Gear Malfunction
DCS	Hypo-/Hyperthermia
Dehydration	Injury
Embolism	Lost
Endangerment	Narcosis
Entanglement	Missing Diver

Trimix Section 6 Pg 7

Anxiety - Rapid breathing or movements, inappropriate behavior. Ascend and/or terminate the dive.

Buoyancy - Poor descent/ascent rate or depth/trim control. Contact line, investigate and/or terminate dive.

Confusion- Disorientation, delayed responses, doesn't follow dive plan. Contact diver and terminate.

Cramps - Grabs leg, can't kick. Stop, hold onto stationary object or maintain depth and relieve cramp.

DCS - Activate EMS, lay down, breathe O₂ and seek immediate HBOT.

Dehydration - Contributes to DCS, sore throat, gag reflex. Hydrate before, during and after the dive.

Embolism - Activate EMS at the surface, provide CPR or deliver O₂ and seek immediate HBOT.

Endangerment - Be aware of life threatening danger. Stop, think, act calmly to get to safety.

Entanglement - Stop, signal buddy, untangle yourself or gear and/or use knife and cut away from body.

Fatigue - Inattentive and slowed thinking, setup time and reaction times. Don't dive fatigued.

Fear - Expressed or nonexpressed fear of environment or failure. May be rationalized, faulty self-awareness and critique. Leads to performance problems and panic. Terminate the dive at first signs of fear.

Gas Depletion - Equipment failure, rapid breathing, overexertion, poor buoyancy - failure to monitor SPG. Go to bailout gas or share gas with a buddy and terminate.

Gear Malfunction - Poor pre-dive check and/or operator error. Go to backup equipment and terminate.

Hyper/Hypothermia - Inadequate thermal protection or long exposure to heat/cold. Terminate dive when first cold and lightly exercise at deco stops. When hot, unzip suit, remove hood, drink water, stop activity.

Injury - Maintain airway, apply pressure to control blood loss, surface, activate EMS, breathe O₂.

Lost - Note time. Cover dive light to look for ambient light from buddy or the surface. Rap on tank, listen for buddy's response or breathing. Use a compass or reel to look for buddy's bubbles or silt trail or go to prearranged meeting place or ascent line. If still lost after 1 minute, deploy lift bag and terminate dive.

Narcosis - Gauge fixation, slow responses, poor judgement, failure to heed signals. The hand signal is a circular motion at the side of the head. Ascend to depth where symptoms are relieved and/or terminate dive.

Missing Diver - Search 1 minute, go to prearranged meeting point. If not reunited, deploy emergency lift bag for surface support to initiate missing diver protocol. Note time, location, depth, gas pressure, ascend and decompress accordingly.

EMERGENCY RESPONSES

- | | |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ⇄ BC Malfunction
⇄ Buddy Problems
⇄ Gas Loss
⇄ Lost Line
⇄ Lost Visibility
⇄ Marine Hazards
⇄ Panic | ⇄ Regulator Failure
⇄ Seizure
⇄ Stress
⇄ Unconsciousness
⇄ Wrong/Missed Gas Switch
⇄ Wrong/Missed Deco Stop |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Trimix Section 6 Pg 8

BC Malfunction - Bladder or dump valve or auto inflator problem that results in lost buoyancy or poor buoyancy control. **Lost lift:** Go to backup BC, dry suit, lift bag or ascent line and terminate. **Unintentional ascent:** Disconnect problem BC inflator and use redundant auto-inflator or orally inflate, signal & abort.

Buddy Problems - Get the diver under control and then deal with the problem. Terminate if necessary.

Gas Loss - Loud sounds or cloud of bubbles or gas escaping behind your head. Switch over to the redundant second stage if needed and shutdown the problem regulator or cylinder, signal buddy and terminate.

Lost Line - Use a reel to search for the ascent line. If it's not found, deploy a lift bag and reel and terminate.

Lost Visibility - Zero Visibility: Make contact with line and partner, abort. **Light Failure:** Shut a dim light off, employ backup, signal partner, terminate. Reserve power on long dives by turning the primary light on and off as needed, but this increases the risk of blowing a bulb.

Marine Life Hazards - Avoid rapid jerky movements or placing head/hands/feet in crevasses/holes.

Panic - Don't endanger yourself trying to control a combative diver. Stay behind them, hold their manifold, put their inflator behind their head, hold their second stage in place, ascend slowly and terminate.

Regulator Failure - Switch over and shutdown the offending regulator while swimming to your partner.

Seizure - Tonic phase: breathing stops, mouth opens, extremities extend and body goes rigid for 30 seconds.

Clonic phase: apnea persists, all the muscles repeatedly contract for 1 minute, followed by hyperventilation. If O₂ is discontinued, consciousness gradually returns within a few minutes and mental alertness within 30 minutes.

Ascending while breath-holding causes AGE, lost regulator can cause drowning and omitted decompression can cause DCS. Get the diver off O₂ without removing their full-face mask or second stage if possible. When breathing resumes take them to the surface. At the surface, provide CPR if needed or O₂ if they are breathing and immediately seek medical care. Show hand signal.

Stress - Results from task loading and unfamiliarity with gear, skills or the environment. Practice new skills in shallow water until proficient before moving to deep dives. Go slow, praise accomplishments.

Unconsciousness - Lack of responsiveness or arousal. Take the diver to the surface, activate EMS, provide CPR with supplemental O₂ if possible. The rescuer should breathe O₂ and watch for DCS.

Wrong Gas Switch - Immediately switch to proper gas and notify partner. Each diver and the instructor must positively identify the mix and depth when a switch is made to a different gas. **Missed Gas Switch:** Use contingency schedule. **Wrong/Missed Deco Stop:** Add the amount of missed time to the next stop and go to the schedule for the next longer bottom time and the next deeper dive depth.

OMITTED DECOMPRESSION

- ✓ **Omitted Decompression Procedure**
- ✓ **Surface-Decompression (Sur-D-O₂)**
- ✓ **In-Water-Recompression (IWR)**
- ✓ **Surface Oxygen**
- ✓ **Emergency Medical Response**
- ✓ **AAUS and DAN Recommendations**

Trimix Section 6 Page 9

Dr. Wienke states in the presence of asymptotic free phases, increasing the off-gassing gradient is prudent because the smaller the bubble the shorter the dissolution time. Immediate recompression in less than 5 minutes is adequate treatment for bubbles less than 100 mm in diameter. This supports the practice of in-water recompression (IWR) in general, although never without sufficient gas or proper support personnel.¹³

If a Navy diver surfaces from a scuba dive breathing compressed air and has omitted any mandatory decompression time and there is no hyperbaric chamber, the diving officer may send them back underwater to perform the omitted decompression procedure using a full-face mask with communications. A “tender” diver stays with them and both receive continuous support and supervision by a diving medical officer.

The USN Omitted Decompression Procedure for an Air dive for a blowup ascent (missed deco) from greater than 20 fsw (6 m) calls for the asymptomatic diver and a tender to descend to the depth of the first stop and follow the schedule for the omitted stops 40 feet (12 m) and deeper and then perform the following procedures: multiply the 30 fsw (9 m), 20 fsw (6 m), and 10 fsw (3 m) stop times by 1.5.

Ascent time between stops is one minute.²² The diver has the option of breathing nitrox and/or oxygen if a full-face mask is available with a switching block to permit air or back gas breaks.

Primarily for operational reasons, commercial divers perform **Sur-D-O₂** inside a deck decompression chamber (DDC). Upon leaving a water depth of 40 fsw (12 m), the diver has only 5 minutes to ascend to the surface and get inside the DDC and be recompressed to 40 fsw and begin breathing pure oxygen.³

The **Hawaiian IWR for omitted decompression** and **Australian IWR for treating DCS** have histories of success. With the Australian IWR, the afflicted diver and a tender (on air) is sent back down to 30 feet (9 m) for 30 minutes breathing O₂, 60 minutes if the case is severe, but longer if there is no improvement.⁶ The ascent rate is 1 meter every 12 minutes (4 ft./min). If symptoms reappear during the ascent, the depth is held for another 30 minutes before ascending, unless doing so will deplete the O₂ supply. At the surface the patient spends 1 hour breathing O₂ and then 1 hour off, repeating this for 12 hours. Administration of IWR is restricted to trained medical professionals and only when access to a chamber is extremely remote.

The American Academy of Underwater Sciences, **AAUS, and DAN advise against re-entering the water for omitted decompression.** Both organizations recommend breathing pure O₂ at the surface for at least 30 minutes, resting, drinking replenishment fluids, and watching for signs or symptoms of DCS for 24 hours and seeking treatment if they occur.¹⁷

If DCS is suspected, the priority is life support, breathing 100% O₂ and getting immediate HBO therapy. The importance of this cannot be over emphasized! Because helium desaturates so much faster than nitrogen, helium bends will progress more rapidly and is likely to be more serious. Treatment delays increase the likelihood of irreversible damage and permanent residuals.

DCS SIGNS AND SYMPTOMS

- | | |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> ✓ Difficulty Breathing ✓ Pain ✓ Extreme Fatigue ✓ Headache ✓ Nausea ✓ Itching ✓ Rash ✓ Restlessness ✓ Muscle Twitch ✓ Bloody Sputum | <ul style="list-style-type: none"> ✓ Hearing Loss ✓ Ringing in Ears ✓ Stiffness ✓ Hot/Cold Flashes ✓ Cramps ✓ Swelling ✓ Pressure Sensation ✓ Muscle Ache/Soreness ✓ Skin Discoloration ✓ Unequal/Nonreactive Pupils |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Trimix Section 6 Pg.10

This and the next slide identify **symptoms that divers have reported to DAN**.¹⁷ Symptoms in the left column are associated with chokes or respiratory DCS, pain and skin and those in the right column are nonspecific symptoms that can fall in any of the four categories of DCS. This is not exhaustive list. In fact, it doesn't include voice change, which may occur with subcutaneous emphysema, an expansion injury.

Evidence of **arterial gas embolism** (AGE) is typically obvious soon after surfacing. It usually causes stroke-like symptoms, where one side of the body is affected, unlike symptoms of DCS which usually involve the bottom half or top half of the body. AGE is generally due to a breath-hold ascent or because of trapped air pathways in the lungs. A **patent foramen ovale** (PFO) is an exception to this rule. It's a fetal valve, which permits interatrial blood flow between the right and left sides of the heart, which doesn't close completely after birth in about 25% of the population. AGE can occur in a scuba diver with a PFO when the venous return bypasses the lungs, where bubbles are normally filtered, and enters the left atrium and subsequently the arterial circulation to the brain. Increased pulmonary pressure from performing too forceful Valsalva maneuver or having a high bubble load or trapped passages in the lungs increases right side heart pressure over the left side, which can then cause a right-to-left shunt. Gas bubbles from the venous return are able to travel to the brain where they cause blood vessel blockages, which results in localized damage and ischemic encephalopathy. AGE is a very serious injury that has a high mortality rate.

Diagnosis of AGE is not as important as early recognition of any signs or symptoms and receiving immediate medical attention. It is inadvisable for someone with a PFO to dive because of the increased risk for AGE. Diagnosis of a PFO is made by a transesophageal echocardiogram or cardiac catheterization.

It's imperative to schedule instruction to include non-diving days, plan conservative training dives, and monitor students underwater and after surfacing for signs of bends and expansion injuries. A change in behavior or personality can be attributed to dissatisfaction with ones performance, peer pressure, physical discomfort, normal fatigue and so on, but it could be a sign of neurological DCS and necessitates immediate medical attention. As an instructor, it is your responsibility to be vigilant regarding the health, safety, and wellbeing of those under your supervision and those who simply dive with you.

Do not permit anyone to dive with you who appears to be :

1) under the influence of alcohol or drugs, 2) ill or injured, 3) dehydrated or fatigued, or 4) unsafe or who may pose a threat to themselves or others.

NEUROLOGICAL DCS

SEVERE

- ✓ **Convulsions**
- ✓ **Paralysis**
- ✓ **Unconsciousness**
- ✓ **Semi-consciousness**
- ✓ **Visual Disturbance**
- ✓ **Speech Disturbance**
- ✓ **Difficulty Walking**
- ✓ **Bladder Problem**
- ✓ **Bowel Problem**

MILD

- ✓ **Numbness**
- ✓ **Dizziness**
- ✓ **Burning Skin Sensation**
- ✓ **Decreased Skin Sensation**
- ✓ **Personality Change**
- ✓ **Reflex Changes**
- ✓ **Weakness**

Trimix Section 6 Pg 11

Long, relatively shallow exposures favor limb bends, respiratory DCS and bone necrosis. Short, relatively deep exposures favors CNS DCS. Just over 40% of DCS cases with neurological complications reported in Israel were to a maximum depth between 165 to 230 ft (50-70 m), over 30% were to 100 to 165 ft (30-50 m), and most of the balance were to 66 to 100 ft (20-30 m).⁹ Based on a 1983 DAN analysis, the incidence of DCS from dives deeper than 100 fsw resulted in about 80% Type II hits compared to less than 20% Type I bends. A decade later, in 1994 well over 50% of the total 566 cases reported to DAN had Type II DCS and 48% of 144 divers classified as having Type I DCS reported neurological symptoms.¹⁷ **In 1/2 of these cases, symptoms appeared within 30 minutes after surfacing.** Pain was the presenting symptom in 1/3 of the cases. The second most frequent presenting symptom was numbness. The incidence of Type II cases would probably be higher if divers were to recognize a numb foot or weak limb as neurological symptoms. Unfortunately, only 1/3 of all the cases reported to DAN used surface-supplied supplemental oxygen before seeking evaluation. Of those that did, 12% were symptom free before recompression therapy. Over half the divers treated with HBO were symptom free after treatment, but 28% of the divers who had residual symptoms had neurological problems compared to only 17% left with pain only residuals.

The success of HBO treatment is directly related to the delay time in getting into a recompression chamber and breathing oxygen. When the delay from symptom onset to treatment was less than 4 hours, post-treatment residuals were just over 20% for neurological and less than 10% for pain only, compared to over 30% and over 20% respectively when the delay was from 4-12 hours, and 40% to 75% respectively when the delay was over 12 hours. **The lesson is that it is vitally important to recognize symptoms early and to immediately seek recompression treatment.**

It may not be a bad idea for mixed gas students to answer a DAN type (diagnostic) questionnaire an hour or so after surfacing from a dive to ascertain if they have any symptoms which might indicate DCS.

DESKTOP DECO SOFTWARE

- √ **Select reliable commercially available programs**
- √ **Register and use licensed software**
- √ **Read written operating instructions**
- √ **Take advantage of learning tutorials**
- √ **Talk to technical support**
- √ **Input realistic personal parameters**
- √ **Choose conservative profiles**
- √ **Stay abreast of updated changes and versions**

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The availability of desktop and laptop decompression software capable of determining gas fractions to blend virtually any helium based mixture and to generate decompression schedules for virtually any dive has made it easy for any diver to expand their horizons into mixed gas diving without first getting proper training. Some PC savvy and some home brew and an “air” diver becomes a “mixed gas” diver. But being certified as an air diver or even a deep diver does not make someone a knowledgeable mixed gas diver. “It’s what you don’t know that gets you!” Qualified training is widely available, but the selection process must be improved to insure candidates are not just pursuing the next step in training because it is available and nor should they be pursued with the vigor open water students are sought.

The real and various risks must not ever be minimized or glossed over, because instructors and students alike need to understand and accept all the potential hazards before using mixed gases. The very nature of generating schedules from user input depths, times, gas switches, ascent and descent rates and personal conservatism factors, means the number of different schedules that can be created is endless, and thus, are impossible to validate. Furthermore, custom tables always carry risk for user input error. Beware of “number narcosis,” blindly relying on a deco schedule without heeding signals from your body or the environment or your common sense and conventional wisdom. Published air tables have a proven safety record but mixed gas tables have not garnered the same confidence as of yet. Accidents can and do occur because of inadequate decompression schedules, be it from a poor table or the faulty use of desktop decompression software.

It’s imperative that instructors and divers use reliable mixed gas tables and computer programs, read and follow their operating instructions, and implement conservative training profiles and procedures. Buy and license commercial programs so that you will have access to technical support, online updates and patches to correct “programming bugs.” Be advised that shareware or “bootleg software” doesn’t generally have an owners manual, operating instructions, technical support, regular updates and other relevant features. Their schedules may be dubious or the program may become outdated without your knowledge. It is vital to stay abreast of new information, particularly that which pertains to mixed gas usage and table developments.

The ultimate purpose is diver education. It’s aptly put in the timeless saying, “If you feed a person a fish, you feed them for a day, but if you teach them to fish, you feed them for a lifetime.” Trimix students need to learn how to use decompression software so they can produce deco tables after they’re certified, but they must understand that the freedom to “generate custom schedules” and to “improvise gas mixtures” carries greater responsibility than simply being given published tables to dive a bottle of air.

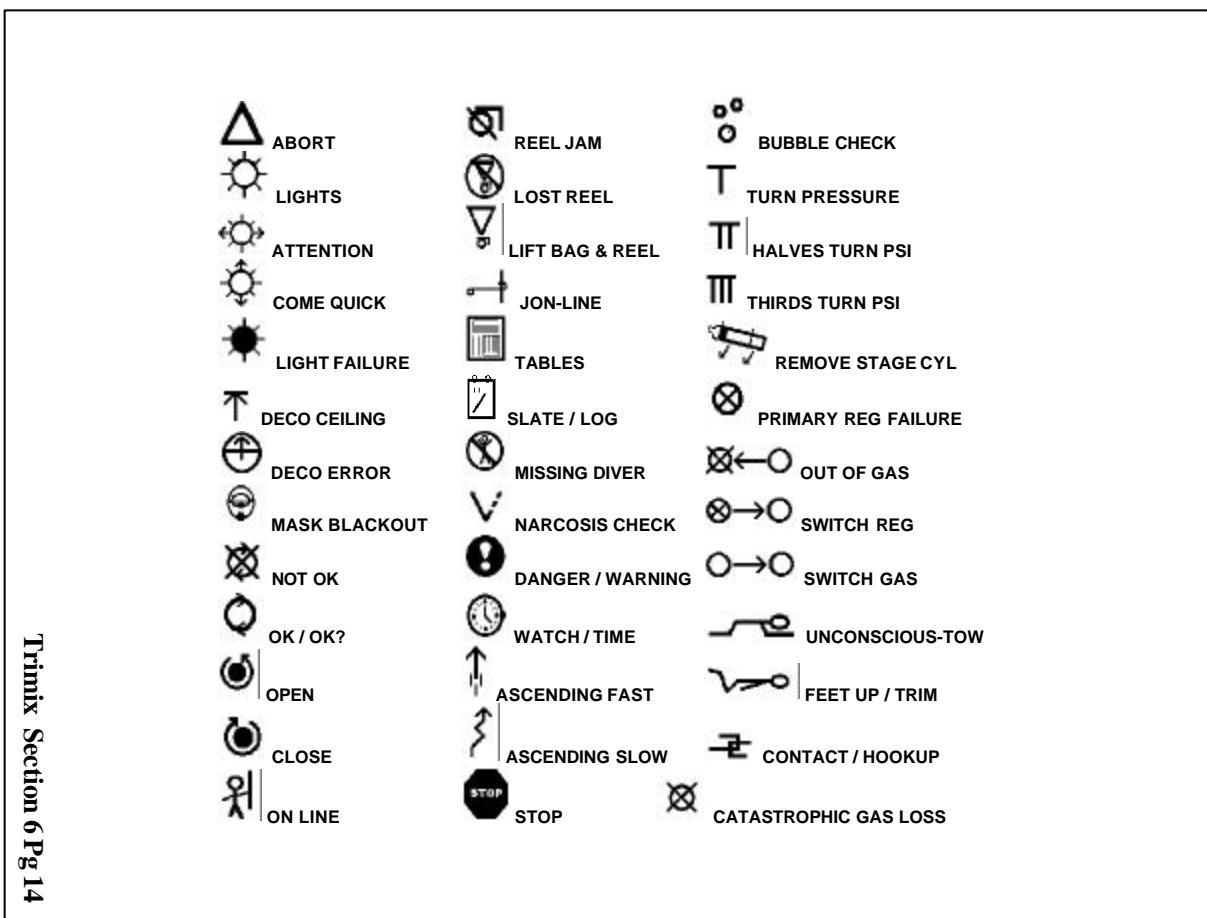
SKILLS & TECHNIQUES

Dive Planning	Buoyancy
Gas Analysis	Kicking
Gear Staging	Check-stop
Gear Check	Navigation
Streamlining/Trim	Light Management
Entries/Exits	Reel Use
Depth Control	Lift Bag Deployment
Descents/Ascents	Emergency Procedures
Don/Doff Gear	Drinking/Eating/Eliminating
Communications	

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TECHNICAL DIVER SKILLS

- χ Define oxygen limits based on $PO_2 \leq 1.4$ ata at max depth and ≤ 1.6 ata for decompression stops.
- χ Analyze all gas mixtures and label each accordingly with the mix and MOD.
- χ Complete the Trimix Diver Plan and the Trimix Team Plan.
- χ Set up personal scuba systems for each dive to satisfy training, environmental and physiological constraints.
- χ Establish safety and emergency procedures, contingency strategies, abort and bailout plans.
- χ Pre-dive safety check (BC, cylinders, regulators, gauges, lights, and review dive plan).
- χ Buoyancy control and trim (w/in 10% of midline) during dive and deco-stops.
- χ Turn around or begin the ascent at the predetermined back gas pressure or bottom time.
- χ Proper U/W communications (hand, light, tap and touch signals) and light usage.
- χ Shutdown failed regulator and isolate for catastrophic gas loss. (≤ 15 sec)
- χ Shutoff and switchover to redundant regulator. (≤ 100 fsw (30 m), off ≤ 15 sec, on ≤ 30 sec)
- χ Gas sharing, simulate out-of-gas scenario over a distance of 30 ft. (9 m).
- χ Remove and replace stage bottle. (off ≤ 5 sec, on ≤ 10 sec)
- χ Gas switches as planned and as necessary. (≤ 10 sec)
- χ Lost visibility: partially flood mask for up reference, maintain contact with buddy and continuous line to surface.
- χ Lost mask or light failure: deploy backups, signal buddy, contact line.
- χ Proximity and contact to buddy and and/or continuous line to surface and use of Jon-line.
- χ Missing diver search procedure.
- χ Tow a simulated unconscious diver 30 ft (9 m) and simulate a rescue ascent.
- χ Ascend with reel and lift bag and effect drift decompression. (hook-up ≤ 45 sec, full deployment ≤ 90 sec)
- χ Stage deco stops according to planned schedule or appropriate bail out plan.
- χ Activate abort plan, crisis strategy, omitted deco procedure or emergency aid for diving conditions and locale.
- χ Proper descent and ascent rate, and depth, time and gas management.
- χ Recall (and download and print computer output) the dive, discuss any problems or deficiencies and log it.
- χ *Optional: Student plans and executes final dive without assistance from instructor (except to prevent a life threatening problem) although under their in-water supervision.



These **technical diving symbols** are a **teaching aid for instructors to reference** underwater to be sure they teach all the required skills. Most of these symbols will **aid instructor-to-diver underwater communications** and are easily translated into hand or light signals. They can be printed and resized and then laminated or simply drawn on an underwater slate. Skills can be checked off with a pencil as they are performed. Student errors, such as ascending too fast or too slow, deco violations, improper light handling or underwater communications, and so forth can be recorded by writing the diver's initials or a check mark next to the appropriate symbol. Doing this provides a **recall device** for the instructor which will **facilitate post dive briefings and skills review with students and provides a means of tracking their performance.**

Review several methods of **lift bag deployment**, such as exhaling into the bag or by dumping gas from your BC deflator. If the line backlashes during deployment and starts pulling you up, let go of the reel. If a backlash occurs when reeling the line in, put a half-hitch around the line guide and then wrap the line around the outside of the spool as you take in the remaining line.

Explain how to make a **secure line hookup to a snap** (put the line eyelet through the snap swivel and then in the snap) and to a **natural or manmade "anchor"** (wrap the line around the "anchor" and use a couple of half-hitches to secure it or pull the reel through the line eyelet and encircle the anchor a couple of times). Students should **practice land drills to learn the mechanics** of how to do a skill and then **demonstrate skills in the water until proficient**. Unlike nontechnical scuba diver training, there is not enough time for the instructor to demonstrate skills to students during a deep trimix dive.

**IN CONCLUSION,
JUST DO IT RIGHT...**



Trimix Section 6 Pg 15

**CHECK
EVERYTHING
and DON'T
ASSUME
ANYTHING!**

Doing it right means having the right abilities, training, experience, equipment, plan and support for the particular mixed gas dive.

Instructor Notes:

IF YOU MUST ASSUME
ANYTHING, *ASSUME...*

Academic Achievement

Self-Sufficiency

Survival Skills

Unity Underwater

Mature Motivation

Experienced Expertise

Trimix Section 6 Pg 16

Academic Achievement means the diver is able to plan and handle all facets of a trimix dive and knows the physiological and practical limits and comprehends the risks involved.

Self-Sufficiency means the diver is proficient and totally self-reliant in abilities, equipment and gas.


Survival Skills means the diver is well versed in problem management and their solution scenarios and is capable of rescuing themselves as well as another team member.

Unity Underwater means the diver has a singleness of mind and is in harmony with the dive plan and their partners and the surrounding marine life.

Mature Motivation means the diver is motivated, not by ego or a new patch, but by genuine personal desire to never stop learning, and to have fun, but to do no harm.

Experienced Expertise means a diver is seasoned over time through varied experiences and has gained the intuition to deal with situations they have never encountered before, they can interpret environmental conditions and the impact on the dive plan and divers, and they can make in-field adjustments and repairs to their equipment.

SECTION 6 COVERED



- ✓ Team Members
- ✓ Players
- ✓ Surface Support Team
- ✓ Agency Protocols
- ✓ Accident Analysis
- ✓ Rescue Responses
- ✓ Emergency Responses
- ✓ Omitted Decompression
- ✓ DCS Signs & Symptoms
- ✓ Neurological DCS
- ✓ Desktop Decompression
- ✓ Skills and Techniques
- ✓ Technical Diving Symbols

Trimix Section 6 Pg 17

1. Team members should have the same abilities, experience, objectives, gas, gear, and getup.
2. Describe the rolls of the boat captain, team leader and dive leader. The boat captain has final authority for the safeguard of passengers and boat. The team leader is the group and activity organizer. The dive leader is the person who has direct control over divers under their supervision.
3. The surface support team should have a completed Trimix Team Plan and written emergency plan and consist of qualified personnel with sufficient gas and gear to perform a responsible rescue.
4. List the 7 authorities whose protocols or rules may affect divers either directly or indirectly? Boat, dive site, local, county, state, federal and certification agencies.
5. Accident analysis helps us learn from the experiences of others. The goal of identifying common crises is to learn how to deal with or prevent similar problems. It's also important to evaluate the dive site and divers to ascertain potential problems so that you can devise solution scenarios.
6. What is the rescue response for an injury? Maintain an open airway and breathing, control blood loss, abort. What is it for narcosis? Ascend or terminate. What is it for a missing diver? Search area for 1 minute then go to prearranged meeting place, look and listen for life signs (breathing/tapping/bubbles/light), but if the missing diver is not found, send up an emergency surface signal and terminate the dive.
7. Describe the emergency procedure for seizure. Get the diver off O₂, get them to the surface once they resume breathing, activate the EMS. What if they loose consciousness? Same thing and CPR if needed.
8. Describe the emergency procedure for regulator failure. Switch over and shut down the offending regulator and isolate the cylinder while moving toward your partner.
9. Identify 10 signs/symptoms of DCS and the typical onset time after a dive. Slide 102 & 103; 30 mins.
10. What should you do if you cannot find the ascent line? Do a compass search or a line sweep with a reel. If the ascent line isn't found, deploy a lift bag with your primary reel and decompress as needed.
11. What should you do if visibility drops to zero? Contact the line and your buddy and terminate the dive.
12. What does the AAUS recommend if a diver surfaces and has omitted decompression? Remain at the surface, breathe O₂ for at least 30 minutes, watch for DCS for 24 hours, seek HBOT if DCS develops.
13. Identify at least 5 underwater skills. See slide 105
14. What is the purpose of the technical diving symbols? A recall device for underwater skills.
15. What is the most common cause of fatalities among mixed gas divers? Breathing the wrong gas.