Counterdiffusion Diving: Using Isobaric Mix Switching To Reduce Decompression Time

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Abstract

Switching a diver's breathing mix from heliox to nitrox at a specified time during the bottom portion of the dive can reduce the total stop time for long dives in the deep nitrox range. Isobaric Mix Switching with oxygen decompression reduced calculated total stop times by an average of 38% compared to calculated total stop times using nitrox with oxygen decompression. The optimal mix-switch time was determined empirically using mixed-gas decompression software.

Introduction

This paper describes a diving procedure called Isobaric Mix Switching (IMX) that reduces the total stop time for long dives in the deep nitrox range. "Isobaric" means equal pressure, so Isobaric Mix Switching, as described in this paper, consists of changing a diver's breathing mix with no shift in depth, during the bottom portion of a dive. The mix switch is from heliox to nitrox with the oxygen percentage constant.

Switching the diver's breathing mix from heliox to nitrox takes advantage of differences in diffusion and saturation rates between the two inert gases. Helium is eliminated from body tissues faster than the nitrogen is taken up causing a transient reduction in total inert gas tissue tension. This results in a decrease in total stop time that will vary with the timing of the mix switch and can be optimized using mixed-gas decompression software.

Background

Experiments begun in 1959 by Keller and Bühlmann (Keller and Bühlmann, 1965; Keller, 1967 & 1968) first made use of the idea that different inert gases have different saturation speeds and that by switching mixes containing these inert gases, based on the rate at which these gases are taken up and eliminated by the body, a decompression advantage would result. Beginning in 1962, experiments sponsored by the U.S. Navy used multiple inert gases to optimize decompression from deep dives ranging from 130 fsw to 1,000 fsw (Keller and Bühlmann, 1965; Keller, 1967). Of the many experimental dives in this series, only one used an isobaric mix switch (Keller and Bühlmann, 1965). That dive was performed in a chamber to a depth of 130 fsw for 120 minutes, used seven human subjects, switched from oxygen /helium (40/60) to oxygen /argon (40/60) after seventy minutes, and used oxygen for the final portion of the decompression. In 1975, Bühlmann described the theoretical benefits of Isobaric Mix Switching in an identical dive profile that substituted nitrogen for argon in the second mix. These experimental and theoretical dive profiles demonstrated a major decompression advantage over conventional methods, but are impractical for open-water diving because they exceed oxygen exposure limits, such as those published by NOAA (Joiner, 2001).

Inert Gas Diffusion and Counterdiffusion

Gases typically diffuse from regions of higher concentration to regions of lower concentration (Wienke, 2001). Following an isobaric mix switch the inert component of the initial mix breathed by the diver will begin diffusing out of the tissues, and the inert component of the second mix will begin diffusing into the tissues. Since there is no change in pressure and the gases are moving in opposite directions, this is called “isobaric counterdiffusion” (Wienke, 2001; Lambertsen, 1978; Lambertsen and Idicula, 1975). Counterdiffusion can have favorable or unfavorable consequences, depending, in part, on the physical characteristics of each inert gas. Graham’s Law states that the volume of gas diffusing into a liquid is inversely proportional to the square root of the molecular weight of the gas (Keller, 1967). A “light” gas, such as helium, is taken up and eliminated faster than a “heavy” gas, such as nitrogen. For example, in the Bühlmann decompression model (Bühlmann, 1975), helium halftimes are 2.65 times faster than corresponding nitrogen halftimes for similar compartments.

The tissue tension for an inert gas is dependent on diffusion rate, perfusion, solubility, time, temperature, and other factors. When two or more inert gases are present in a dissolved state within the body, their tissue tensions are additive (Shilling et al., 1976). This means that the degree of tissue saturation is dependent on the combined tissue tensions of the inert gases and how their sum compares to ambient pressure.

“Good” Isobaric Counterdiffusion

Researchers studying isobaric counterdiffusion used the terms “subsaturation” (Lambertsen, 1978), “desaturation” (Wienke, 2001; Lambertsen and Idicula, 1975), and “undersaturation” (D’Aoust, 1983) to describe the theoretical decrease in total inert gas tissue tensions following an isobaric mix switch from heliox to nitrox. Yount (1982) used hypothetical tissue halftimes to illustrate that mix switching from one gas to another could reduce decompression below that of either mix used alone. Animal experiments (D’Aoust, 1983) supported the theory that specific mix switches, such as helium-to-nitrogen, could produce a decompression advantage.

Figure 1 illustrates the case where tissues are at or near saturation with an inert gas having a relatively fast diffusion rate, such as helium, and the diver’s breathing mix is switched to a mix with an inert gas with a slower diffusion rate, such as nitrogen. The total inert gas tissue tension will temporarily drop (Keller and Bühlmann, 1965; Wienke, 2001; Lambertsen, 1978; Lambertsen and Idicula, 1975, D’Aoust, 1983) because the helium is diffusing out faster than the nitrogen is diffusing in. This creates a decompression advantage that may be optimized by carefully timing the mix switch (Keller, 1967).

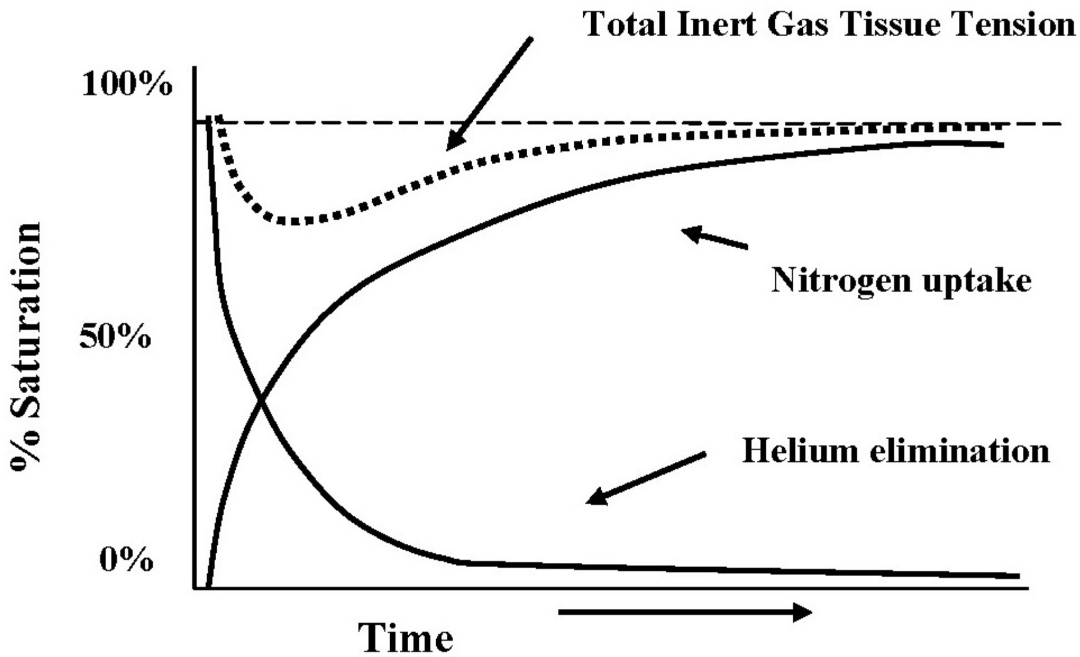

Figure 1. Showing the reduction of total inert gas tissue tension following an Isobaric Switch from heliox to nitrox.

"Bad" Isobaric Counterdiffusion

Nearly all the literature on isobaric counterdiffusion concerned the opposite case, where tissues at or near saturation with an inert gas having a slower diffusion rate, such as nitrogen, were exposed to an inert gas with a faster diffusion rate, such as helium (Lambertsen, 1978; Lambertsen and Idicula, 1975; D'Aoust, 1983; Blenkarn et al., 1971; D'Aoust et al., 1977; Hill, 1977a; Vann, 2004; Peterson et al, 1980; Strauss and Kunkle, 1974). These researchers found that tissue supersaturation and bubble formation could occur isobarically when the combined tissue tensions of the inert gases exceeded ambient pressure. "Counterdiffusion supersaturation" resulted because an inert gas with a fast diffusion rate, such as helium, diffused into the tissues faster than an inert gas with a slow diffusion rate, such as nitrogen, diffused out. This may occur most commonly in the following situations:

- A diver breathing a mix containing nitrogen, is surrounded by a mix containing helium. This could occur in a chamber or dry suit and lead to "superficial" (skin) lesions similar to "skin bends" (Lambertsen, 1978; Lambertsen and Idicula, 1975; Blenkarn et al., 1971; Vann, 2004; Peterson et al, 1980).

- A diver switches from a breathing mix containing nitrogen, to a mix containing helium, leading to "deep tissue supersaturation" and bubble formation (Lambertsen and Idicula, 1975, D'Aoust, 1983; D'Aoust et al, 1977; Vann, 2004). Since this phenomenon is well understood, both cases are easily avoided. A diagram of this situation is shown in Figure 2.

A third type of “bad” counterdiffusion may be involved in vestibular symptoms (Vann, 2004) seen isobarically in a deep (1,200 fsw) chamber dive (Lambertsen, 1978; Lambertsen and Idicula, 1975), in divers following a switch to air during decompression from deep heliox dives (Hill, 1977b; Doolette and Mitchell, 2003), and more commonly during helium saturation dives (Lambertsen and Idicula, 1975; Hill, 1977b). Researchers (Lambertsen and Idicula, 1975) suggest that the cause may be counterdiffusion of helium from the middle ear through the round window, but the mechanism and parameters are poorly understood (Vann, 2004).

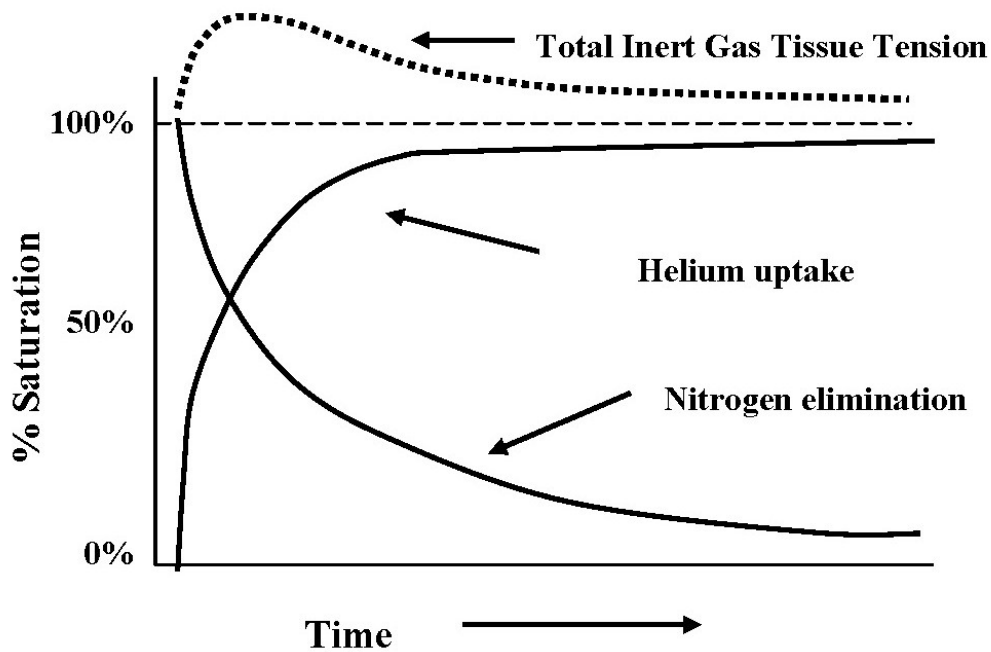

Figure 2. Showing a case of supersaturation caused by switching from nitrox to heliox (Bove and Wells, 1990).

Methods

Determine Mix: The first and most critical step in planning an Isobaric Mix Switch dive is to determine the oxygen percentage of the heliox and nitrox mixes. The author used Pro Planner™ Trimix v. 7.12C (Bushnell and Gurr 1997) decompression software to empirically determine the highest possible oxygen percentage (adjusted in 2% increments) that still allowed the dive and decompression to stay within oxygen exposure limits.

Determine Optimal Switch Time: The next step is to determine the Optimal Switch Time. The author used Pro Planner™ decompression software to calculate total stop times for a given dive profile with a fixed depth and bottom time, while systematically increasing the heliox portion of the dive in five-minute increments for each trial, until a minimum total stop time was found. For example, in planning a 60-minute dive for a given depth, the author calculated total stop time for 5 minutes of heliox and 55 minutes of nitrox; 10 minutes of heliox and 50 minutes of nitrox; 15 minutes of heliox and 45 minutes of nitrox, and so on. The author continued to increase the heliox and decrease the nitrox in five-minute increments until a minimum total stop time was found. This minimum total stop time provided the Optimal Switch Time. Using this technique, the author calculated total stop times for a matrix of depths and bottom times from 100 fsw to 150 fsw and from 50 minutes to 120 minutes both with and without oxygen decompression.

Using these Optimal Switch Times, the author then compared total stop times using four different decompression techniques: Nitrox Dive with Nitrox Decompression, Isobaric Mix Switch Dive with Nitrox Decompression, Nitrox Dive with Oxygen Decompression, and Isobaric Mix Switch Dive with Oxygen Decompression.

The author also compared selected profiles generated using Proplanner™ with those generated using Abyss™ 120 v. 2.30.17 software (Hemingway and Baker 2003), and V-Planner™ VPM-B software (Parrett, 2001).

Results

For a given depth and bottom time, the calculated total stop time decreased as the length of the heliox segment of the dive increased, reaching an optimal minimum value before increasing again. APPENDIX A contains a matrix of Total Stop Times for depths from 100 fsw to 150 fsw and bottom times from 50 minutes to 120 minutes for dives using Isobaric Mix Switching with Nitrox Decompression with the minimum stop times highlighted.

APPENDIX B contains a similar matrix of Total Stop Times for dives using Isobaric Mix Switching with Oxygen Decompression with the minimum stop times highlighted. These matrixes show how the timing of the mix switch affects total stop time for dives with and without oxygen decompression and gives the Optimal Switch Time for each dive profile. Tables 1 and 2 contain samples of the matrixes found in APPENDIX A and B for an 80-minute dive. Using Pro Planner™ the Optimal Switch Time generally increased with the bottom time and depth of the dive.

APPENDIX C contains a matrix of Total Stop Times for depths from 100 fsw to 150 fsw and bottom times from 50 minutes to 120 minutes for dives using four different decompression techniques: Nitrox Dive with Nitrox Decompression, Isobaric Mix Switch Dive with Nitrox Decompression, Nitrox Dive with Oxygen Decompression, and Isobaric Mix Switch Dive with Oxygen Decompression. The oxygen percentages of bottom and decompression mixes used in the decompression calculations for APPENDIX C were adjusted in 2% increments to optimize total stop times so that realistic comparisons could be shown. Table 3 contains a sample of APPENDIX C for an 80-minute dive.

Table 1 Sample profiles from the APPENDIX "A" Matrix used to determine Optimal Switch Time for dives using Isobaric Mix Switching with Nitrox Deco. Shaded boxes show shortest total stop times and therefore the Optimal Switch Time.

Depth	Time to Mix Switch from Heliox to Nitrox						Bottom
	20 min	25 min	30 min	35 min	40 min	45 min	Mix
	Total Stop Time for an 80 Minute Dive						
100 fsw	20	17	15	15	16		36%
110 fsw	30	27	24	25	27		36%
120 fsw	53	50	49	49	51		32%
130 fsw	79	74	71	71	72		30%
140 fsw	111	105	100	97	98		28%
150 fsw	133	125	119	116	116	117	28%

Table 2 Sample profiles from APPENDIX "B" Matrix used to determine Optimal Switch Time for dives using Isobaric Mix Switching with Oxygen Decompression. Shaded boxes show shortest total stop times and therefore the Optimal Switch Time.
Boxes marked N/A exceed ProPlanner oxygen exposure limits.

Depth	Time to Mix Switch from Heliox to Nitrox						Bottom
	20 min	25 min	30 min	35 min	40 min	45 min	Mix
	Total Stop Time for an 80 Minute Dive						
100 fsw	11	10	9	9	11		36%
110 fsw	18	17	17	18			34%
120 fsw	27	26	27				32%
130 fsw	40	38	37	37	40		30%
140 fsw	57	54	52	N/A	N/A		28%
150 fsw	77	73	70	N/A	N/A		26%

Table 3 Sample from APPENDIX "C" comparing total stop times using different techniques for an 80 minute dive

Depth	Nitrox Dive Nitrox Deco	IMX Dive Nitrox Deco	Nitrox Dive Oxygen Deco	IMX Dive Oxygen Deco
100 fsw	34	15	18	9
110 fsw	55	29	26	17
120 fsw	77	49	40	26
130 fsw	109	71	55	37
140 fsw	182	110	87	52
150 fsw	217	131	103	70

Using Pro Planner™, Nitrox with Oxygen Decompression reduced total stop times more than Isobaric Mix Switching with Nitrox Decompression for most dives shorter than 100 minutes. In the longer and deeper ranges, Isobaric Mix Switching with Nitrox Decompression reduced total stop times more than Nitrox with Oxygen Decompression. Some nitrox dives were not allowed by oxygen exposure limits, even when the oxygen percentage was reduced to that of air, while these same dives were permitted using Isobaric Mix Switching. In all cases, Isobaric Mix Switching Dives with Oxygen Decompression produced the greatest reduction in total stop time.

Reduction in Total Stop Time

Table 4 shows the reduction in Total Stop Time, in minutes, using Isobaric Mix Switching with Oxygen Decompression compared to Nitrox with Oxygen Decompression for dives from 100 fsw to 150 fsw and from 50 minutes to 120 minutes. Isobaric Mix Switching with Oxygen Decompression reduced total stop times within these ranges by an average of 38% compared to Nitrox with Oxygen Decompression.

Table 4 Reduction in total stop time in minutes using isobaric mix switching with oxygen decompression compared to nitrox with oxygen decompression.

Depth	Bottom Time							
	50	60	70	80	90	100	110	120
100 fsw	4	6	7	9	9	11	15	25
110 fsw	5	6	7	9	12	19	33	37
120 fsw	6	7	10	14	22	31	32	44
130 fsw	9	12	14	18	34	33	68	66
140 fsw	11	17	20	35	34	53	65	
150 fsw	18	20	27	33	60	54		

Comparisons Using Different Software Programs

Table 5 compares the optimal mix switching times of three different software programs for a 120-fsw dive for 80 minutes with a mix switch time from heliox to nitrox varying from 5 minutes to 50 minutes. This table was used to determine the optimal switch time for each software program's dive profile. The optimal switch time for the Abyss™ and V-Planner™ profiles occurred a few minutes later than that of the Pro Planner™ profiles.

Table 6 compares total stop times for three decompression programs using various decompression techniques. Isobaric Mix Switching with Nitrox Decompression reduced total stop times more than Nitrox with Oxygen Decompression in the Abyss and V-Planner programs. In all cases, Isobaric Mix Switching with Oxygen Decompression produced the greatest reduction in total stop time.

Table 5 Total Stop Times for 120-fsw for 80 minutes using Mix Switching Only. Shaded boxes show minimum total stop time used to determine optimal switch times.

	Time to mix switch from heliox to nitrox									
	5 min	10 min	15 min	20 min	25 min	30 min	35 min	40 min	45 min	50 min
	Total Stop Times for a 120-fsw Dive for 80 Minutes									
ProPlanner	71	65	59	53	50	49	49	51		
Abyss 120	70	63	56	51	45	40	35	35	37	
V-Planner	66	61	56	51	46	36	31	29	29	31

Table 6 compares total stop times for three decompression programs using various decompression techniques. Isobaric Mix Switching with Nitrox Decompression reduced total stop times more than Nitrox with Oxygen Decompression in the Abyss and V-Planner programs. In all cases, Isobaric Mix Switching with Oxygen Decompression produced the greatest reduction in total stop time.

Table 6. Comparison of Total Stop Times for a 120-fsw dive for 80 minutes.

	Nitrox Dive Nitrox Deco	IMX Dive Nitrox Deco	Nitrox Dive Oxygen Deco	IMX Dive Oxygen Deco
	Total Stop Times for a 120-fsw Dive for 80 Minutes			
ProPlanner	77	49	40	26
Abyss 120	88	35	43	24
V-Planner	71	29	38	18

Open Water Dives:

In December 2003, four NURC/UNCW staff divers performed eight square dives to an average maximum depth of 130 fsw off Key Largo, Florida using Isobaric Mix Switching and technical open-circuit scuba equipment. The divers breathed a 27/73 oxygen/helium mix, then switched to a 27/73 oxygen /nitrogen mix after 20 minutes. Since the heliox breathing time was relatively short, the divers carried a side-mount cylinder containing heliox and breathed it upon beginning the dive. Following the Isobaric Mix Switch, the divers breathed the nitrox from doubles for the balance of the bottom time and the ascent to 20 fsw. The divers carried a decompression cylinder containing 100% oxygen and breathed that gas at the 20-fsw and 15-fsw decompression stops. Each diver carried a VR-3 trimix dive computer (Delta P Technologies) with ProPlanner™ decompression software that provided primary decompression information. Bottom time for the eight dives totaled seven hours. The first four dives had a bottom time of 60 minutes and an average total decompression time of 27 minutes. The second four dives, performed the following day, had a bottom time of 45 minutes and an average total decompression time of 15.5 minutes. Decompression time included four minutes of deep stops. Three of the four divers reported elevated, transient narcosis immediately following the mix switch, and higher consumption rates for heliox than for nitrox. One diver reported a decrease in visual acuity following the mix switch.

In 2004, NURC divers used Isobaric Mix Switching in four operational dives (two square, two multilevel) at an average maximum depth of 135.5 fsw and for an average bottom time of 58.5 minutes. No DCS symptoms were reported on any IMX dive.

Discussion

Following a single chamber experiment by Keller and Bühlmann in 1962 (Bühlmann, 1975), Isobaric Mix Switching seems to have been forgotten. Perhaps this is because the military, commercial, and technical diving communities have focused on systems and techniques for deeper capabilities. Mix switching, although common in technical diving, is typically done during the decompression portion of the dive where mixes with increasingly higher oxygen percentages are used to shorten stop times.

Several factors now make Isobaric Mix Switching practical as a technique for reducing total stop times. Technical diving techniques and equipment have made mix switches routine. Dive planning software for mixed-gas diving is now widely available and easy to use. Newer dive computers can handle isobaric mix switches in real-time.

Operational Considerations:

Dive Planning: A good first step in dive planning is to compare the total stop time using Isobaric Mix Switching with the same profile using Nitrox to see if the reduction in decompression time is worth the additional operational complexity. Oxygen exposure is the single most important limiting factor on the deeper and longer dives and will drive the choice of both bottom and decompression mixes. As mentioned earlier, the author used ProPlanner™ decompression software and trial-and-error to determine the highest possible oxygen percentage that still allowed the dive and decompression to stay within oxygen exposure limits. As a practical matter, NURC has found it easier and more convenient to use 27% oxygen in both the heliox and nitrox, since these mixes are useful over a broad range of depths and times. The use of a single, reduced oxygen percentage mix also provided a margin of error and additional safety with regards to oxygen toxicity.

The exact time of the mix switch is not critical. Trials with mixed gas decompression software show that variations of +/- 10 minutes in mix switching times have little effect on the total stop time. Should it become necessary to leave bottom during the heliox portion of the dive, it is beneficial to switch to nitrox for the ascent. Water temperature, thermal protection and voiding should be considered. Divers using Isobaric Mix Switching must be qualified in mixed-gas diving for the equipment used.

Gas Management: Because of the longer bottom times available with this technique, gas management calculations must be performed to assure adequate supplies during each phase of the dive. Normal gas management rules, such as the rule of thirds, apply to the nitrox and the oxygen, but not to the heliox. This is because the diver can switch to the nitrox at any time during the dive, but should not switch back to the heliox. On the operational dives, the divers sent the used heliox cylinders to the surface on a "sausage" lift bag for recovery by the vessel. Normal technical diving gear can be used in many of the IMX dives, but for the long duration dives in the deeper range rebreathers or surface-supplied gear may be more appropriate.

Decompression Information: Tables or a mixed-gas dive computer may be used for decompression information. If computers are used, divers must carry contingency tables that allow them to leave the bottom at any time. Table 7 shows one of the contingency decompression tables used on the NURC dives.

Table 7. Sample Isobaric Mix Switching Contingency Tables.

138 fsw 27/73 Heliox → Nitrox IMX; 99% Oxy.							
Gas Used	**Bottom Time in Minutes**	**Micro-bubble Stops**		**Decompression Stops**			
		Nitrox 27/73				**Oxygen 99%**	
		2 min	**2 min**	**40'**	**30'**	**20'**	**15'**
Heliox 27/73	**5**	**69'**	**36'**				**1**
	10	**75'**	**46'**			**1**	**1**
	15	**82'**	**52'**		**1**	**1**	**5**
	20	**82'**	**56'**		**1**	**1**	**10**
Nitrox 27/73	**25**	**79'**	**46'**			**1**	**10**
	30	**75'**	**46'**			**1**	**11**
	35	**75'**	**46'**			**1**	**13**
	40	**79'**	**46'**			**1**	**15**
	45	**79'**	**49'**			**1**	**18**
	50	**79'**	**52'**		**1**	**2**	**19**
	55	**82'**	**52'**		**2**	**3**	**21**
	60	**82'**	**56'**		**4**	**4**	**23**
	65	**85'**	**59'**	**1**	**7**	**4**	**25**
	70	**85'**	**59'**	**1**	**10**	**4**	**28**
	75	**89'**	**62'**	**3**	**12**	**4**	**31**
	80	**89'**	**62'**	**4**	**14**	**5**	**33**

Conclusion

Calculations using decompression software as well as demonstration and operational dives conducted by divers from the NOAA Undersea Research Center confirm that Isobaric Mix Switching is a practical technique for reducing total stop times for long dives in the deep nitrox range. Isobaric Mix Switching with oxygen decompression reduced calculated total stop times by an average of 38% compared to calculated total stop times using nitrox with oxygen decompression. The optimal mix-switch time was determined empirically using mixed-gas decompression software. This technique should have scientific, commercial, and military applications using technical open-circuit scuba, rebreathers, and surface-supplied diving equipment.

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Appendix A – Page 1 of 2

Matrix of Total Stop Times Using Isobaric Mix Switching Only

(Shaded boxes show minimum total stop times used to determine optimal switch times.)

Depth	Time to mix switch from heliox to nitrox										Oxygen Percent in Mixes
	5 min	10 min	15 min	20 min	25 min	30 min	35 min	40 min	45 min	50 min	
	Total Stop Times for a 50 Minute Dive										
100 fsw	9	6	3	3	3	6	9	14			36%
110 fsw	15	12	9	8	9	11	15	19			36%
120 fsw	30	26	22	20	21	24	28	33			32%
130 fsw	38	33	29	27	28	30	36	46			32%
140 fsw	54	47	42	38	39	43	48	54			30%
150 fsw	74	64	56	53	55	57	63	69			28%
	Total Stop Times for a 60 Minute Dive										
100 fsw	16	12	9	7	6	7	10	13			36%
110 fsw	24	20	16	14	13	14	17	21			36%
120 fsw	43	37	33	30	28	29	33	37			32%
130 fsw	54	48	42	38	36	39	42	46			32%
140 fsw	74	65	58	54	53	54	57	62			30%
150 fsw	100	90	81	76	73	74	76	80			28%
	Total Stop Times for a 70 Minute Dive										
100 fsw	24	20	16	13	11	10	11	14			36%
110 fsw	33	28	24	21	19	18	20	23			36%
120 fsw	58	52	46	41	38	38	40	43			32%
130 fsw	79	72	64	59	57	56	57	60			30%
140 fsw	110	100	92	85	80	78	79	81			28%
150 fsw	133	122	111	102	97	94	93	96			28%
	Total Stop Times for an 80 Minute Dive										
100 fsw	31	27	24	20	17	15	15	16			36%
110 fsw	42	38	34	30	27	24	25	27			36%
120 fsw	71	65	59	53	50	49	49	51			32%
130 fsw	101	92	84	79	74	71	71	72			30%
140 fsw	143	132	121	111	105	100	97	98			28%
150 fsw	171	157	144	133	125	119	116	116	117		28%

NOTE 1: All times calculated using ProPlanner with 10% MicroBubble Factor.

NOTE 2: Oxygen percentage in mixes has been adjusted in 2% increments to minimize stop times while staying within ProPlanner oxygen exposure limits.

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Matrix of Total Stop Times Using Isobaric Mix Switching Only

(Shaded boxes show minimum total stop times used to determine optimal switch times.)

Depth	Time to mix switch from heliox to nitrox										Oxygen
	30 min	35 min	40 min	45 min	50 min	55 min	60 min	65 min	70 min	75 min	Percent
	Total Stop Times for a 90 Minute Dive										in Mixes
100 fsw	21	19	20	22							36%
110 fsw	38	38	39	40							34%
120 fsw	61	60	61	62							32%
130 fsw	89	87	85	86	88						30%
140 fsw	124	120	118	119	121						28%
150 fsw		166	161	159	158	159					26%
	Total Stop Times for a 100 Minute Dive										
100 fsw	28	25	25	27							36%
110 fsw	48	47	46	47							34%
120 fsw	76	73	72	72	73						32%
130 fsw		105	102	101	102						30%
140 fsw			144	142	142	142	144				28%
150 fsw				190	186	183	182	182	186		26%
	Total Stop Times for a 110 Minute Dive										
100 fsw	35	31	31	31	32						36%
110 fsw	59	57	55	56	56						34%
120 fsw	91	88	85	83	83	85					32%
130 fsw		125	122	120	120	121					30%
140 fsw			174	169	165	163	162	162	162	165	28%
150 fsw				225	217	210	206	205	206	208	26%
	Total Stop Times for a 120 Minute Dive										
100 fsw	43	40	38	37	38						36%
110 fsw		67	66	65	64	65					34%
120 fsw			99	98	97	98					32%
130 fsw				142	140	139	138	138	139		30%
140 fsw					192	187	183	180	179	181	28%
150 fsw						241	234	231	230	231	26%

NOTE 1: All times calculated using ProPlanner with 10% MicroBubble Factor.
NOTE 2: Oxygen percentage in mixes has been adjusted in 2% increments to minimize stop times while staying within ProPlanner oxygen exposure limits.

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Matrix of Total Stop Times Using Isobaric Mix Switching with Oxygen Decompression

(Shaded boxes show minimum total stop times used to determine optimal switch times.)

Depth	Time to mix switch from heliox to nitrox										Oxygen Percent In Mixes	Oxygen Percent in Deco Mix
	5 min	10 min	15 min	20 min	25 min	30 min	35 min	40 min	45 min	50 min		
	Total Stop Time for a 50 Minute Dive											
100 fsw	6	4	3	3	3	5					36%	99%
110 fsw	9	7	6	5	6						36%	99%
120 fsw	13	12	10	11							34%	99%
130 fsw	19	18	16	16	17						32%	99%
140 fsw	27	24	22	22	23						30%	99%
150 fsw	38	34	30	29	30						28%	99%
	Total Stop Time for a 60 Minute Dive											
100 fsw	9	7	6	5	4	5					36%	99%
110 fsw	13	11	9	8	9						36%	99%
120 fsw	21	19	17	16	16	18					32%	99%
130 fsw	31	28	25	23	23	25					30%	99%
140 fsw	44	39	35	32	32	34					28%	99%
150 fsw	58	53	49	45	44	45					26%	99%
	Total Stop Time for a 70 Minute Dive											
100 fsw	12	11	9	8	7	7	8				36%	99%
110 fsw	19	17	15	14	13	14					34%	99%
120 fsw		25	23	22	21	21	23				32%	99%
130 fsw		37	33	30	30	31					30%	99%
140 fsw			47	45	42	41	43				28%	99%
150 fsw			64	60	57	56	57				26%	99%
	Total Stop Time for an 80 Minute Dive											
100 fsw	16	14	13	11	10	9	9	11			36%	99%
110 fsw		21	20	18	17	17	18				34%	99%
120 fsw			29	27	26	27					32%	99%
130 fsw			43	40	38	37	37	40			30%	99%
140 fsw				57	54	52	N/A	N/A			28%	99%
150 fsw				77	73	70	N/A	N/A			26%	99%

NOTE 1: All stop times calculated using ProPlanner with 10% MicroBubble Factor.
NOTE 2: Oxygen percentage in mixes has been adjusted in 2% increments to Minimize stop times while staying within ProPlanner oxygen exposure limits.
NOTE 3: Boxes marked N/A exceed ProPlanner oxygen exposure limits.

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Matrix of Total Stop Times Using Isobaric Mix Switching with Oxygen Decompression

(Shaded boxes show minimum total stop times used to determine optimal switch times.)

Depth	Time to mix switch from heliox to nitrox										Oxygen Percent in Mixes	Oxygen Percent in Deco Mix
	25 min	30 min	35 min	40 min	45 min	50 min	55 min	60 min	65 min	70 min		
	Total Stop Time for a 90 Minute Dive											
100 fsw	13	12	12	12	14						36%	99%
110 fsw	21	20	21	22							34%	99%
120 fsw	32	31	32	33							32%	99%
130 fsw	54	52	52	51	51	54					28%	99%
140 fsw	75	72	69	69	N/A	N/A					26%	99%
150 fsw		110	107	105	103	105					21%	99%
	Total Stop Time for a 100 Minute Dive											
100 fsw	16	15	14	15							36%	99%
110 fsw	N/A	24	25								34%	99%
120 fsw	46	43	43	42	43						30%	99%
130 fsw	75	71	68	67	N/A						26%	99%
140 fsw		109	108	108	109						26%	50%
150 fsw			136	135	135	135	136				24%	50%
	Total Stop Time for a 110 Minute Dive											
100 fsw	20	18	17	18							36%	99%
110 fsw	N/A	N/A	33	34							32%	99%
120 fsw	71	68	64	63	62	62	N/A				26%	99%
130 fsw		94	91	88	N/A						24%	99%
140 fsw			127	125	125	125	126				26%	50%
150 fsw			173	170	167	165	164	166			21%	50%
	Total Stop Time for a 120 Minute Dive											
100 fsw	26	25	24	24	24	25					34%	99%
110 fsw	N/A	54	52	51	49	N/A					28%	99%
120 fsw		89	86	82	80	N/A					24%	99%
130 fsw			125	121	116	112	N/A				21%	99%
140 fsw				155	152	150	148	148	148	150	24%	50%
150 fsw				194	188	184	182	182	183		21%	50%

NOTE 1: All stop times calculated using ProPlanner with 10% MicroBubble Factor.
NOTE 2: Oxygen percentage in mixes has been adjusted in 2% increments to To minimize stop times while staying within ProPlanner oxygen exposure limits.
NOTE 3: Boxes marked N/A exceed ProPlanner oxygen exposure limits.

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Comparison of Total Stop Times Using Different Techniques
Calculated Using ProPlanner

Depth	Nitrox Dive Nitrox Deco	IMX Dive Nitrox Deco	Nitrox Dive Oxygen Deco	IMX Dive Oxygen Deco
	Total Stop Time for a 50 Minute Dive			
100 fsw	13	3	7	3
110 fsw	19	8	11	5
120 fsw	36	20	18	10
130 fsw	44	27	22	16
140 fsw	62	38	32	22
150 fsw	84	53	44	29
	Total Stop Time for a 60 Minute Dive			
100 fsw	19	6	10	4
110 fsw	28	13	15	8
120 fsw	49	28	23	16
130 fsw	70	42	35	23
140 fsw	94	60	49	32
150 fsw	128	82	64	44
	Total Stop Time for a 70 Minute Dive			
100 fsw	27	10	14	7
110 fsw	37	18	19	13
120 fsw	64	38	31	21
130 fsw	88	56	45	30
140 fsw	123	78	62	41
150 fsw	171	105	84	56
	Total Stop Time for an 80 Minute Dive			
100 fsw	34	15	18	9
110 fsw	55	29	26	17
120 fsw	77	49	40	26
130 fsw	109	71	55	37
140 fsw	182	110	87	52
150 fsw	217	131	103	70

NOTE 1: **All stop times calculated using ProPlanner with 10% MicroBubble Factor.**

NOTE 2: **Oxygen percentage in mixes has been adjusted in 2% increments to minimize stop times while staying within ProPlanner oxygen exposure limits.**

Appendix C – Page 2 of 2

Comparison of Total Stop Times Using Different Techniques
Calculated Using ProPlanner

Depth	Nitrox Dive Nitrox Deco	IMX Dive Nitrox Deco	Nitrox Dive Oxygen Deco	IMX Dive Oxygen Deco
	Total Stop Time for a 90 Minute Dive			
100 fsw	44	19	21	12
110 fsw	65	38	32	20
120 fsw	95	59	53	31
130 fsw	137	85	85	51
140 fsw	192	119	103	69
150 fsw	267	158	163	103
	Total Stop Time for a 100 Minute Dive			
100 fsw	52	25	25	14
110 fsw	78	46	43	24
120 fsw	115	72	73	42
130 fsw	164	101	100	67
140 fsw	228	142	161	108
150 fsw	334	182	189	135
	Total Stop Time for a 110 Minute Dive			
100 fsw	59	31	32	17
110 fsw	91	55	66	33
120 fsw	135	83	94	62
130 fsw	193	120	156	88
140 fsw	276	162	190	125
150 fsw	397	205	N/A	164
	Total Stop Time for a 120 Minute Dive			
100 fsw	69	37	49	24
110 fsw	108	64	86	49
120 fsw	184	97	124	80
130 fsw	268	138	178	112
140 fsw	390	179	N/A	148
150 fsw	600+	230	N/A	182

NOTE 1: **All stop times calculated using ProPlanner with 10% MicroBubble Factor.**

NOTE 2: **Oxygen percentage in mixes has been adjusted in 2% increments to minimize stop times while staying within ProPlanner oxygen exposure limits.**

NOTE 3: **Boxes marked N/A exceed ProPlanner oxygen exposure limits for air.**