Decompression in diving with gas mixtures

(Warning: this document may contain errors.)

Jaume Riba
jaume.riba@upc.edu

Updating of this document available in:
http://gps-tsc.upc.es/comm/jriba/personal.html
(ratiodeco_riba_en.pdf)

January 2009

V03-01

ÍNDICE

ACRONIMS

ATA	*Pressure unit*
CNS	*Central Nervous System*
END	*Equivalent Narcotic Depth*
GUE	*Global Underwater Explorer*
ICD	*Isobaric Counter Diffusion*
MOD	*Maximum Operation Depth*
NDL	*Non Decompression Limit*
OTU	*Oxygen Tolerance Unit*
ppO2	*Oxygen partial pressure*
RD	*Ratio Deco*
RGBM	*Reduced Gradient Bubble Model*
VPM	*Variable Permeability Model*
VPM-B	*Variable Permeability Model - Boyle*
WKPP	*Woodville Karst Plain Project*

1 INTRODUCTION

This document is a summary of some ideas of practical relevance about the way of performing decompression in open circuit diving by using several gas mixtures. It is based on several papers and notes available at internet, from which the most essential and important aspects for the diver have been extracted, removing theoretical stuff. Specially, the document deals with Trimix standard mixtures, ratio deco, and with some aspects related with the selection of bottom and decompression gas mixtures.

We also make comparisons between ratio deco profiles and ascent profiles obtained from computer models. For the comparison the VPM-B algorithm is selected, simply because it makes use of the oxygen window at the gas switches in such a manner that it closely resembles to the S curves suggested by ratio deco. Anyway (although omitted in the document) the ratio deco profiles are also very similar to those associated to Bulhman with gradient factors 30/85, as well as to this associated with V-planner with safe factor +2.

The document is mostly based on the following sources:
http://5thd-x.com/index.php?option=com_wrapper&Itemid=64
http://www.gue.com/
http://www.5thd-x.com/
http://www.geocities.com/vpm.open/contact.html
http://www.thedecostop.com/forums/showthread.php?t=3198
WIKIPEDIA http://en.wikipedia.org/wiki/Ratio_decompression

This list does not pretend to be complete, and the document also contains (unavoidably) information from other internet sources, books and persons, apart from being intentionally incomplete as all alive documents are.

1.1 HISTORY OF CHANGES

- V03-00 is the first translation of the document from Spanish (also available at http://gps-tsc.upc.es/comm/jriba/personal.html) to English, except one appendix that dealt with the preliminary motivations to writing this document initially in Spanish.

- V03-01. Some typos corrected. Warning added in the last example in section 3.5. about mix 15\55, thanks to http://www.h2o.org.il/Forum/viewtopic.php?t=144.
  Reference to WIKIPEDIA added.

2 STANDARD MIXTURES

GUE and WKPP propose specific bottom and deco mixtures. In the sequel we explain which they are as well as some criteria used for their design.

2.1 BOTTOM MIXTURES

2.1.1 General criteria

Bottom mixtures are calculated by imposing that:

- The ppO2 is less than 1.3 ATA at MOD.
- The ppO2 has an average of 1.2ATA at operating depths.
- The END is about 30m. This means that being at MOD the narcotic sensation is the one that would be experienced using air at 30m, and this is calculated assuming that oxygen is as much narcotic as nitrogen. Interestingly, having fixed the equivalent narcotic depth, the standard mixes have besides the property that they can be obtained by mixing helium with Nitrox 32%, because the MOD of Nitrox 32% is just 30m (for a ppO2 of 1.3ATA).

For instance, the standard mixture suitable to a depth of 52m is 21\35, meaning that it contains 21% oxygen and 35% helium. The nitrogen percentage in this mixture is 44% and the global percentage of nitrogen and oxygen is 65%. The maximum depth associated to a ppO2 of 1.3ATA is effectively 10*(1.3/0.21)-10=51.9m, and this depth is equivalent to an END of (51.9+10)*0.65-10=30.2m (approximately equal to 30m mentioned before).

With this criterion it is possible to establish a general, useful and simple relationship between oxygen (O2) and helium (He) percentages in the mixture, such that the END at MOD be always the same, that is END=30m. This general relation is (see appendix A):

$$He = 100 - 3O2$$

which is a pretty simple and easy to remember equation. For instance, if the oxygen content is 8%, the suitable helium content would be 76% (100-3*8) and the resulting mixture would be 8\76. This is not a standard mixture but it has the END of 30m associated to all them as well. Another possible mixture would be 5\85, and so on. A mixture that is indeed standard is, for instance, 10\70. If we restrict to the use of mixtures that fulfill an equation as the one described above, the process to prepare the mixtures becomes very simple, as described in appendix B.

2.1.2 Usual mixtures

The previous equation characterizes (approximately) all the standard mixtures. The most used ones verifying this equation are shown in the sequel:

	Depth at several ppO2:		
Mixture	1.2ATA	1.3ATA	1.4ATA
21\35	47m	52m	57m
18\45	57m	62m	67m
15\55	70m	77m	83m
12\65 (*)	90m	98m	106m
10\70	110m	120m	130m

(*) This mixture is not always considered as standardized.

2.1.3 Selection of the bottom mixture

The selection of the bottom mixtures is made as a function of the average ppO2 at the bottom, which should not be greater than 1.2ATA (and less than 1.3ATA at MOD) to properly control the effects of the oxygen toxicity, and should not be too much low to avoid the increase in the required decompression times.

2.2 DECOMPRESSION MIXTURES

2.2.1 General criteria

The mixtures to be used as decompression gas are calculated by imposing that:

- The ppO2 is 1.6ATA at MOD.

- The average ppO2 is 1.2ATA at operating depths of the mixture (except in the case of O2, in which case the ppO2 is constant and equal to 1.6ATA).

The diver will use them during the ascent at the moment of reaching the MOD of the mixture, assuming that the body is relaxed. Otherwise, in conditions of great physical effort, the utilization of the mixture will start some meters above of the MOD.

2.2.2 Usual mixtures

- O2 100% at 6m
- Nitrox 50% (from 21m to 9m)

- Triox (*) 35\25 (from 36m to 24m)
- Trimix 21\35 (from 57m to 39m)

(*) Triox (also named helitrox) is no more than a Trimix with an oxygen content greater than 21% (hyperoxic Trimix).

2.2.2.1 Considerations about the use of helium for decompression

In the definition of the standard mixtures, the helium percentage is considered as a minimum, which means that mixtures such as 50\25, 35\30, etc. may also be used, including Heliox (that is, a mixture consisting only on oxygen and helium). The use of helium in the decompression mixtures may improve (depending on the bottom depth and bottom time) the decompression efficiency and attenuates the possible impact of narcosis as well as (possibly) that of the isobaric counter-diffusion (ICD) at the moment of gas switches. In general, these effects are well avoided by forcing that the percentage of nitrogen does not increase in an abrupt manner at the moment of the switch. In this sense, some gas switches are not advised, such as Trimix to air at 57m or even Timix to Nitrox 50% when the Trimix has a high percentage of helium.

2.2.2.2 Considerations about the use of oxygen for decompression (gas breaks)

Concerning the oxygen, when the required decompression time with this gas is greater than 20min, stops using the bottom gas are mandatory (in general using the available gas with the minimum oxygen content) according with the following rule: 16min O2 followed with 6min stop with the other gas, and so on, up till covering the overall decompression time, taking into account that the time breathing the other gas is counted within the total time. It is accepted that this technique (known as gas breaks) significantly reduces the danger associated with oxygen toxicity. Moreover, the use of O2 at 6m during too much time produces vasoconstriction that makes gas elimination inefficient, and also produces lung irritation which reduces the lung efficiency as a filter. "Gas breaks" succeed in attenuating both effects and, as a consequence, breathing bottom gas turns out to be much more effective for the decompression than breathing O2 all the time. For that reason, the time breathing the other gas is indeed counted as time with O2. Once finishing with the O2 time at 6m, it is necessary to perform a very slow ascent to surface.

In this sense, it is worth mentioning that some technical divers propose spending one third of the total O2 decompression time at intermediate depths from 4.5m to 1.5m, appealing to the advantage in reducing the O2 charge at the nervous system (CNS), apart from assuring a slow enough ascent to surface in this way. Other divers, contrarily, claim that gas breaks are much more efficient and that it is better to control the CNS by reducing the O2 content of the bottom mixture and increasing the He percentage.

2.2.3 Selection of the decompression mixture

The selection of the mixture, as well as of the number of the required decompression bottles (basically one, two or three, and exceptionally four), depends on both desired decompression efficiency and desired redundancy/amount of gas, as well as overall drag. Nevertheless, it is well accepted that the used mixture to finish the decompression should be O2 at 6m, although there are some exceptions. This aspect is explained with examples in the last section.

3 RATIO DECO

The ratio deco is a simple procedure for calculating the suitable ascent profile using standardized mixtures, basically from the depth and bottom times of the dive. It is used for dive planning and for computing the decompression during the development of the dive (for that reason it is also named "deco on the fly"). It is useful for making dives without computer and also as a redundancy plan in the case of failure of the computer during the dive. Some divers use ratio deco as a basis, and they treat the computer as the redundancy element. Likewise, it gives general indications about the most suitable curves to follow during the ascent (an aspect ignored by most diving computers) which are in line with up to date research in decompression theory (VPM-B and RGBM). This includes the models that characterize important aspects of the gas behavior in its free phase (bubbles), apart from the behavior during its dissolved phase, the one considered by the classic algorithms (Bulhman with gradient factors).

It is worth mentioning that ratio deco is developed from identification of patterns and ascent profiles generated form decompression algorithms using computer simulations, and also from the observation and understanding of how the parameters associated to these patterns are modified when varying the dive profiles (depth, bottom time, stop enlargement, etc.). For identifying these patterns with more clarity, it is often useful (if the program allows for it) reducing to its minimum the separation between the decompression stops that it generates (3m or less between stops), as well as forcing that the last stop be shallower than 6m (for instance to understand whether the generated stop at 6m is of dissolved gas gradient-type or free gas gradient-type [oxygen window]) and be able in this manner to learn to better managing the CNS inside the water, if considered convenient. On the other hand, the selection of the model is on the diver hands, based on its own experience and perception of safety and comfort that the model gives to him. Therefore, the rules that follow in the sequel are basis rules that the diver itself can progressively modify, adapt and sophisticate according with his own experience, necessities and kind of dives.

3.1 RANGE OF APPLICATION

The ratio deco described in this document is valid for dives at a maximum depth of 120m with standardized mixtures and that require a decompression time with oxygen of a maximum of 70min. The method is not valid if extrapolated outside these ranges.

3.2 RATIO BETWEEN DECO_TIME_O2 AND BOTTOM_TIME

A fixed ratio is established (for a determined bottom depth) between the required decompression time with O2 at 6m and the bottom time of the dive. This ratio depends on the average bottom depth in the following manner:

Depth	[O2 time]
45m	0.5 * bottom time
60m	1 * bottom time
75m	1.2 * bottom time
90m	1.5 * bottom time
105m	2.2 * bottom time
120m	3 * bottom time

The previous rule can be interpolated to other depths. Thus, as an example, for a depth of 55m, it can be adequate to take the ratio 2/3 between the O2 time and the bottom time.

3.3 GLOBAL ASCENT PROFILE

Once the decompression time with O2 at 6m has been determined according with the previous table, ratio deco establishes a simple criterion to determine the overall profile to be followed during the ascent. To this end, several depth intervals are established and a time is assigned to each one of these intervals. The way of defining the intervals and the time assignation is as follows:

Interval 1: 6m (O2):	Total time = [O2 time]
Interval 2: 21m at 9m (Nitrox 50):	Total time = [O2 time]
Interval 3: 36m at 24m:	Total time = [O2 time] / 2
Interval 4: 57m at 39m:	Total time = [O2 time] / 4

where [O2 time] is determined in the previous section. At deeper depths, a maximum ascent rate of 9m/min will be respected starting from the bottom, and this rate will be reduced at the moment to reach the first decompression phase.

3.4 LOCAL ASCENT PROFILE

The way to perform the ascent inside of each one of the above mentioned intervals depends basically on the ppO2 of the mixture and on the depth.

3.4.1 Linear shape (deep stops)

For determining the profile to follow when the ascent starts, it is first necessary to define the concepts of start deco depth and maximum deco depth.

- Start deco depth. It is the depth where the body starts off-gassing at higher rate of on-gassing. It has no sense to perform deep stops at depths higher than the start deco depth. There exist several criteria for determining this depth, being the most used the following ones (which are pretty equivalent within the range of application):
    - It is the depth associated approximately with the 80% of the maximum depth.
    - It is the depth associated approximately with the one at 20m above the bottom (this is a reduction of 2ATA in ambient pressure).
- Maximum deco depth. It is the maximum depth at which a stop should be made. At that depth, it starts to be efficient performing a stop, and it is usually a little bit above the start deco depth. There exist several criteria for determining this depth, being the most used the following ones (which are pretty equivalent within the range of application):

- It is the depth associated approximately with a percentage of the maximum depth which varies from 75% to 50%, being 65% a very typical value.

- It is the depth associated approximately with the one at 30m above the bottom (this is a reduction of 3ATA in ambient pressure).

This initial decompression is controlled by the fast compartments and physically it is necessary to give enough time to the body for the blood to transport the bubbles to the lungs for its proper elimination. They should be short stops to be efficient, such that they do not make increase the remaining decompression time at shallower depths. Since the depth is high, the growing of bubbles is very linear with respect to the decrease of the depth, which implies that in these first decompression stops the diver should perform an ascent with a linear shape.

The first meters of ascent up to the start deco depth can be made at the maximum allowed ascent rate (for instance, 9m/min). When the start deco depth is reached, the ascent rate should be reduced significantly (for instance, 3m/min) until arriving to the maximum deco depth, where the first stop takes place. From this stop, a series of stops starts at each 3m, with equal stop times (linear shape).

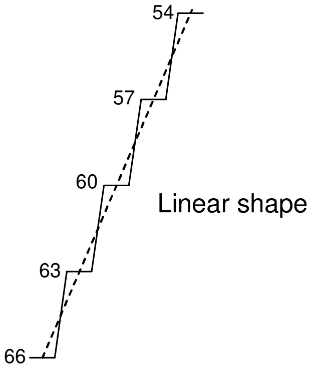
Depending on the percentage with respect to the maximum depth that has been used to set this first deep stop, the time of these first stops will differ, being short if the percentage 75% were selected and longer if 50% were instead chosen. The duration of these stops is shown in the following table:

Bottom time	Time of the stops associated to percentages 75% / 50%
< NDL	0min / 1min
30min	1min / 3min
60min	2min / 5min
90min	3min / 7min
120min	4min / 9min
150min	5min / 10min

In the case of short bottom times (less than 30min) the minimum stop time is 20seg (which is equivalent to an ascent rate of 9m/min) and in the case of very long bottom times (more than 150min) the dive can be taken as a saturation dive, and therefore the stop times continue to be the ones associated to the bottom time of 150min.

For example, a dive at 90m has the deepest stop at 66m (taking the criterion of 75%), and is the overall required decompression is within 30min and 60min, it will be adequate to perform the following initial profile:

Depth	T. Stop
90m-72m (80%)	Maximum ascent rate (9m/min)
72m-66m (75%)	Reduced ascent rate (3m/min)
66 m	1 min
63 m	1 min
60 m	1 min
57 m	1 min
54 m	1 min



where the resulting linear shape of these initial deep stops during the ascent can be clearly appreciated. Some divers perform the linear shape also as a very slow constant ascent rate equivalent in time.

Lastly, it is noted that these deep stops have only sense when standard mixtures are used, and they are not efficient when diving with air, where the useful decompressions always starts at depths significantly shallower than those using helium (typically at 18m or 15m).

3.4.2 Exponential shape (pushing gradient)

If there is no gas switch and, therefore, the oxygen partial pressure is low (intermediate depths), then an exponential type ascent is required, which means that, progressively, the stops should have an increased duration at each 3m.

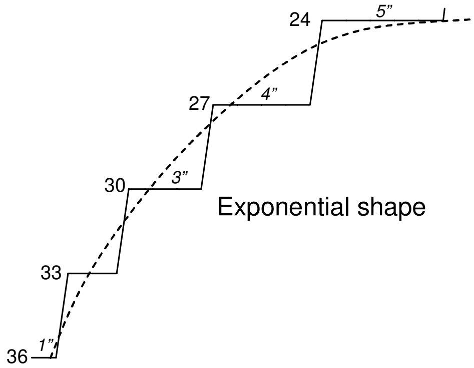
A simple way to obtain this profile consists in calculating the stop time at the central depth of the interval as the global time divided by the number of stops to make, that is, the mean time. Once this time is computed, the subsequent deeper stops are calculated by divining by two each 3m below (rounding up) and afterwards by calculating the duration of the shallower stops just adding to the mean time, the time that has been subtracted at deeper depths.

Let us see this with an example. Let us suppose that we are in the 36m to 24m interval, for which we have calculated a total time on it of 15min. In this interval, the number of stops is (36-24)/3+1=5, associated to depths 36m, 33m, 30m, 27m and 24m. The mean depth of the interval is 30m. For that depth, the stop time is calculated as 15min/5=3min, and the remaining times are:

Time at 33m = time at 30m / 2 = 3/2 < 2min (we have removed 1min from the mean time)
Time at 36m = time at 33m / 2 = 2/2 = 1min (we have removed 2mins from the mean time)
Time at 27m = time at 30m + time removed at 33m stop = 3+1 = 4min
Time at 24m = time at 30m + time removed at 36m stop = 3+2 = 5min

The overall ascent profile within the interval would be the following:

Depth	**T. Stop**
36 m	1 min
33 m	2 min
30 m	3 min
27 m	4 min
24 m	5 min



where the resulting exponential shape of the curve can be clearly appreciated.

Anyway, the exact calculus is not the essential thing, but it is following approximately a certain exponential profile what becomes essential, respecting the total time assigned to the interval as a whole. By forcing this exponential profile, one is acting in the most efficient way with the dissolved gas gradient that controls the tissue off-gassing. The more shallow we are, the more force exerts this gradient and the more time is to be given to allow enough off-gassing such that the own gradient be not excessively increased. In Bulhman models with gradient factors, the low gradient factor is the one that finally forces this exponential shape, as well as the first deep stop to be done, being the high gradient factor the one that controls the duration of the shallower depths.

When the oxygen partial pressure is low, the gradient of the dissolved gas is the unique mechanism controlling the off-gassing. This is not that way when the oxygen partial pressure is high, being convenient on that case to change the profile shape with the purpose of taking benefit of the so-called oxygen window thus better controlling the free gas gradient (bubbles). This is the topic explained in the sequel.

3.4.3 S shape (oxygen window)

During the ascent, at the moment of switching to a richer gas, the oxygen partial pressure rises to 1.6ATA with a big step, assuming that the switch has been done at the proper instant (although it is advised to arrive a that value with enough relaxed conditions of the body muscles). At this moment, the decompression is being produced in a very efficient manner because the excess of ppO2 plays now a good role in favor of the process. This is because the off-gassing mechanism of the gas in free phase (small bubbles already created within the diver) is different from the dissolved gas gradient mechanism that takes the control as the diver arrives to shallow depths, explained before. It is convenient to halt the ascent and hold this depth during an extended time to make enough pressure to the bubbles that, being still small, they are easier to shrink precisely at that moment, instead of continuing with the ascent and allowing bubbles to make them bigger and, therefore, more difficult to be eliminated at shallower depths.

The practical consequence for the diver is that, when the oxygen window is doing the work (elevated ppO2), he should stay at that depth during more time that the one required if he were ascending without any gas switch. Therefore, the ascent intervals that are initiated with a gas switch (for instance when switching to Nitrox 50% at 21m or to Triox 35\25 or 35\30 at 36m) should be initiated with an extended stop time and progressively continuing with the ascent afterwards. As the oxygen partial pressure is being again reduced with the ascent, the dissolved gas gradient mechanism is again acting solely, and therefore it becomes again necessary to perform an exponential ascent profile.

The consequence is that, as a whole, the way of ascending within the intervals that are initiated with a switch of the decompression mixture (ppO2=1.6ATA) should follow a shape similar to an S (instead of exponential) which translates to making first stops that are long, and that are being shorter in the middle of the interval, and they are made longer again at the moment of arriving to the shallowest depths of the interval.

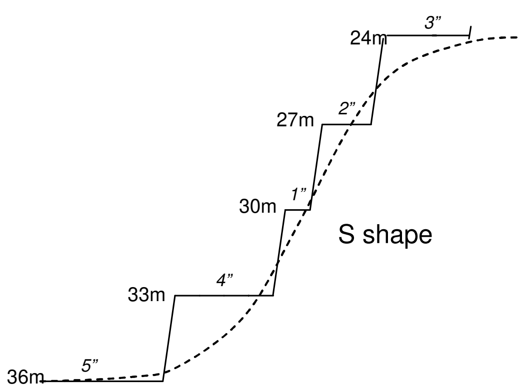
A simple way to obtain this profile consists in calculating the stop time at the minimum depth of the interval as the global time divided by the number of stops to make, that is, the mean time. Once this time is computed, the subsequent deeper stops are calculated by divining by two each 3m below (rounding up) until arriving at the middle of the interval, and afterwards by calculating the duration of the deeper stops just adding to the mean time, the time that has been subtracted at previous depths.

Let us see this with an example. Let us suppose that we are in the 36m to 24m interval, for which we have calculated a total time on it of 15min, and at the moment of arriving at 36m we start the use of a decompression mixture (such as, for instance, a Triox 35\25). In this interval, the number of stops is (36-24)/3+1=5, associated to depths 36m, 33m, 30m, 27m and 24m. The mean depth of the interval is 30m. For the minimum depth of 24m, the stop time is calculated as 15min/5=3min, and the remaining times are:

Time at 27m = time at 24m / 2 = 3/2 < 2min (we have removed 1min from the mean time)
Time at 30m = time at 27m / 2 = 2/2 = 1min (we have removed 2min from the mean time)
Time at 33m = time at 24m + time removed at 27m stop = 3+1 = 4min
Time at 36m = time at 24m + time removed at 30m stop = 3+2 = 5min

The overall ascent profile within the interval would be the following:

Depth	T. Stop
36 m	5 min
33 m	4 min
30 m	1 min
27 m	2 min
24 m	3 min



where the resulting S shape of the curve can be clearly appreciated.

However, it is not advisable to increase the ratio 1:4 between the minimum and maximum stop times, so a more convenient profiled would be:

Depth	T. Stop
36 m	4 min
33 m	4 min
30 m	2 min
27 m	2 min
24 m	3 min

Lastly, during the realization of the S shape with a Nitrox 50%, it is commonly accepted that, if for any cause the initial stops are extended more than the foreseen time during the development of the dive, the extra time on these first stops should also be added to the last stops, just as a mirror.

3.5 COMPARATIVE EXAMPLES WITH VPM-B

Let us see three examples at depths 45m, 66m and 90m, respectively. In each example, we will show the stops by applying ratio deco and, between parenthesis, the result given by the VPM-B algorithm with a conservative factor 1 (where 0 is the less conservative and 6 the most).

1) Let us suppose a dive at 45m with 40min bottom time. The decompression with ratio deco is started at 33m (75% from 45m). The O2 time is 20min (half the bottom time) and the time with Nitrox 50% is also 20min. Dividing these 20min in 5 stops at 21m, 18m, 15m 12m and 9m leads to a mean stop time of 20/5=4min. As at 21m there is a gas switch to Nitrox 50% and the ppO2 is high, it becomes convenient to distribute these 20min using a S shape, for example in the way 4min, 2min, 2min, 5min and 7min (from greater to less depth). Finally, from 33m to 24m, we perform 4 stops of 2min each with linear shape (perhaps slightly exponential), which nearly sums up to the 10min that would be associated to this range.

In summary, the ascent profile would be:

Depth	T. Stop (RD)	T. Stop (VPM-B)	Mixture
45 m	40 min	40 min	Tx21/35
33 m	1 min	*(9 m / min)*	Tx21/35
30 m	2 min	*(9 m / min)*	Tx21/35
27 m	2 min	*(9 m / min)*	Tx21/35
24 m	2 min	1 min	Tx21/35
21 m	4 min	3 min	Nx50
18 m	2 min	1 min	Nx50
15 m	2 min	2 min	Nx50
12 m	5 min	4 min	Nx50
9 m	7 min	6 min	Nx50
6 m	20 min	20 min	O2

2) Let us suppose a dive at 66m with 30min bottom time. The decompression with ratio deco is started at 48m (75% from 66m). The O2 time is 30min (the same one as the bottom time) and the time with Nitrox 50% is also 30min. Dividing these 30min in 5 stops at 21m, 18m, 15m, 12m and 9m leads to a mean stop of 30/5=6min. As at 21m there is a gas switch to Nitrox 50% and the ppO2 is high, it becomes convenient to distribute these 30min using a S shape, for example in the way 6min, 3min, 2min, 9min, 10min (from greater to less depth). From 36m to 24m we have a total time of 15min (half the time with Nitrox 50%) to distribute in 5 intervals using an exponential shape. The mean stop time is 15/5=3min and the profile would be 1min, 2min, 3min, 4min, 5min (from greater to less depth). Finally, from 48m to 39m a linear shape would be applicable with 1min each 3m.

In summary, the ascent profile would be:

Depth	**T. Stop (RD)**	**T. Stop (VPM-B)**	**Mixture**
66 m	30 min	30 min	Tx18/45
48 m	1 min	*(9 m / min)*	Tx18/45
45 m	1 min	*(9 m / min)*	Tx18/45
42 m	1 min	1 min	Tx18/45
39 m	1 min	1 min	Tx18/45
36 m	1 min	1 min	Tx18/45
33 m	2 min	2 min	Tx18/45
30 m	3 min	3 min	Tx18/45
27 m	4 min	3 min	Tx18/45
24 m	5 min	4 min	Tx18/45
21 m	6 min	3 min	Nx50
18 m	3 min	3 min	Nx50
15 m	2 min	4 min	Nx50
12 m	9 min	6 min	Nx50
9 m	10 min	8 min	Nx50
6 m	30 min	29 min	O2

3) Let us suppose a dive at 90m with 20min bottom time. The decompression with ratio deco is started at 66m (75% from 90m). The O2 time is 30min (1.5 times the the bottom time) and the time with Nitrox 50% is also 30min. Dividing these 30min in 5 stops at 21m, 18m, 15m, 12m and 9m leads to a mean stop of 30/5=6min. As at 21m there is a gas switch and the ppO2 is high it becomes convenient to distribute these 30min using an S shape, for example in the way 6min, 4min, 2min, 8min, 10min (from greater to less depth). From 36m to 24m we have a total time of 15m (half the time with Nitrox 50%) to distribute in 5 intervals, using also an S shape since at 36m a gas switch is done to Triox 35\30, with high O2 partial pressure. The mean stop time is 15/5=3min and the profile would be 3min, 2min, 1min, 4min, 5min (from greater to less depth). From 57m to 39m it corresponds a time of 7min (half the previous time) which leads to 1min each 3m applying a linear shape, which can be executed in a little exponential manner when arriving at the end of the interval (2min instead of 1min at 39m). Below that depth, we would have 1min each 3m up till 66m or 63m.

In summary, the ascent profile would be:

Depth	**T. Stop (RD)**	**T. Stop (VPM-B)**	**Mixture**	
90 m	20 min	20 min	Tx15/55	Warning:
66 m	*(9 m / min)*	*(9 m / min)*	Tx15/55	
63 m	1 min	*(9 m / min)*	Tx15/55	.
60 m	1 min	1 min	Tx15/55	
57 m	1 min	1 min	Tx15/55	
54 m	1 min	1 min	Tx15/55	

51 m	1 min	1 min	Tx15/55
48 m	1 min	1 min	Tx15/55
45 m	1 min	1 min	Tx15/55
42 m	1 min	2 min	Tx15/55
39 m	2 min	2 min	Tx15/55
36 m	3 min	3 min	Tx35/30
33 m	2 min	1 min	Tx35/30
30 m	1 min	1 min	Tx35/30
27 m	4 min	3 min	Tx35/30
24 m	5 min	3 min	Tx35/30
21 m	6 min	3 min	Nx50
18 m	4 min	3 min	Nx50
15 m	2 min	5 min	Nx50
12 m	8 min	6 min	Nx50
9 m	10 min	10 min	Nx50
6 m	30 min	31 min	O2

Warning: according to the rules explained, a better selection for this last example would have been Tx12\65 (instead of Tx15\55) as bottom mix, so this example should be taken only for illustration purposes.

4 OVERALL SELECTION OF MIXTURES

4.1 DIVES UP TO 30M

Short dives

If the bottom time requires less than 20min of decompression with the bottom mixture, it is not imperative to carry on decompression bottles.

- Bottom gas.
- Without deco bottles.

Long dives

If the bottom time requires 20min or more of decompression with the bottom gas, it is convenient to carry on one O2 bottle to be used at 6m.

- Bottom gas (from bottom to 9m)
- 1 deco bottle:
  - O2 (6m).

4.2 DIVES WITHIN THE RANGE FROM 30M TO 51M

Short dives

If the bottom time requires less than 30min of decompression with Nitrox 50%, it is enough to carrying on a single decompression bottle with Nitrox 50% to be used from 21m to surface. This occurs approximately in the following situations (assuming 21\35 and VPM-B):

Depth	Maximum bottom time
30m	55min
36m	41min
42m	30min
48m	27min
51m	24min

- Bottom gas (from bottom to 24m)
- 1 deco bottle:
  - Nitrox 50% (from 21m to 3m).

Example (VPM-B). Dive at 51m with 15min bottom time with Trimix 21\35, that requires a total decompression time with Nitrox 50% of 17min. It is compared with the necessary profile using O2 instead of Nitrox 50%, thus showing how the decompression time increases. It is also compared with the required profile with two deco bottles (Nitrox 50% and O2), where we can see how the small deco time saving does not justify having to carry on an additional bottle.

51 m	**15 min (Tx21/35)**	15 min (Tx21/35)	15 min (Tx21/35)
21 m	**3 min (Nx50)**	1 min (Tx21/35)	3 min (Nx50)
18 m	**1 min (Nx50)**	2 min (Tx21/35)	1 min (Nx50)
15 m	**1 min (Nx50)**	1 min (Tx21/35)	1 min (Nx50)
12 m	**1 min (Nx50)**	3 min (Tx21/35)	1 min (Nx50)
9 m	**1 min (Nx50)**	5 min (Tx21/35)	1 min (Nx50)
6 m	**3 min (Nx50)**	9 min (O2)	7 min (O2)
3 m	**7 min (Nx50)**	-	-
Total:	**35 min**	39 min	32 min

It is important to note that this configuration with bottom gas and Nitrox 50% as a unique decompression gas has no sense if air is used as a bottom gas (instead of Trimix). In these conditions, when switching to Nitrox 50%, the decompression is not efficient since there is still too much nitrogen (of the bottom gas) left to be eliminated, and this does not start to happen until reaching shallower depths. It is only when using Trimix as a bottom gas when the Nitrox 50% becomes an efficient unique decompression mixture.

Long dives

If the bottom time requires 30min or more of decompression if Nitrox 50% were used solely (bottom times longer than those of the previous table), then two deco bottles should be carried on, one with Nitrox 50% (to be used from 21m to 9m) and other with O2 (to be used at 6m). This additional O2 bottle gives higher decompression efficiency and besides it gives gas redundancy to the diver, who can deal with the eventual loss of any of the deco bottles.

- Bottom gas (from bottom to 24m)
- 2 deco bottles:
  - Nitrox 50% (from 21m to 9m).
  - O2 (6m)

Example (VPM-B). Dive at 51m with 45min bottom time with Trimix 21\35, that requires a total deco time with Nitrox 50% of 61min. It is compared with the necessary profile using O2 instead of Nitrox 50%, thus showing how the decompression time increases. It is also compared with the required profile with two deco bottles (Nitrox 50% and O2), where we can see now how the deco time saving is more significant, and carrying on an additional bottle compensates, apart from the fact that if provides more amount of total gas and the necessary redundancy.

51 m	45 min (Tx21/35)	45 min (Tx21/35)	**45 min (Tx21/35)**
30 m	1 min (Tx21/35)	1 min (Tx21/35)	**1 min (Tx21/35)**
27 m	2 min (Tx21/35)	2 min (Tx21/35)	**1 min (Tx21/35)**
24 m	3 min (Tx21/35)	3 min (Tx21/35)	**3 min (Tx21/35)**
21 m	3 min (Nx50)	4 min (Tx21/35)	**3 min (Nx50)**
18 m	2 min (Nx50)	5 min (Tx21/35)	**2 min (Nx50)**
15 m	4 min (Nx50)	8 min (Tx21/35)	**4 min (Nx50)**
12 m	5 min (Nx50)	11 min (Tx21/35)	**5 min (Nx50)**
9 m	9 min (Nx50)	18 min (Tx21/35)	**9 min (Nx50)**
6 m	13 min (Nx50)	33 min (O2)	**27 min (O2)**
3 m	25 min (Nx50)	-	-
Total:	114 min	132 min	**102 min**

4.3 DIVES WITHIN THE RANGE FROM 54M TO 72M

Short dives

If the bottom time requires less than 50min of overall decompression with Nitrox 50% and O2 (less than 25min with each of the bottles), then it is enough to carry in two decompression bottles, one with Nitrox 50% (to be used from 21m to 9m) and other with O2 (to be used at 6m).

- Bottom gas (from bottom to 24m)
- 2 deco bottles:
  - Nitrox 50% (from 21m to 9m).
  - O2 (6m)

Example (VPM-B). Dive at 72m with 15min bottom time with Trimix 15\55, that requires a total deco time with Nitrox 50% and O2 of 33min. It is compared with the necessary profile using an additional third Triox bottle, where we can see how the small deco time saving does not justify having to carry on an additional bottle.

72 m	**15 min (Tx15/55.0)**	15 min (Tx15/55.0)
42 m	**1 min (Tx15/55.0)**	1 min (Tx15/55.0)
39 m	**1 min (Tx15/55.0)**	1 min (Tx15/55.0)
36 m	**1 min (Tx15/55.0)**	3 min (Tx35/25)
33 m	**1 min (Tx15/55.0)**	1 min (Tx35/25)
30 m	**2 min (Tx15/55.0)**	1 min (Tx35/25)
27 m	**2 min (Tx15/55.0)**	1 min (Tx35/25)
24 m	**3 min (Tx15/55.0)**	1 min (Tx35/25)
21 m	**3 min (Nx50)**	3 min (Nx50)
18 m	**1 min (Nx50)**	1 min (Nx50)
15 m	**2 min (Nx50)**	1 min (Nx50)
12 m	**4 min (Nx50)**	3 min (Nx50)
9 m	**5 min (Nx50)**	5 min (Nx50)
6 m	**18 min (O2)**	17 min (O2)
Total:	**62 min**	57 min

Long dives

If the bottom time requires 50min or more of overall decompression with Nitrox 50% and O2, then three deco bottles will be carried on, one with Triox 35\25 (to be used from 36m to 24m), other with Nitrox 50% (to be used from 21m to 9m) and other with O2 (to be used at 6m). This additional Triox bottle will provide higher decompression efficiency at the deep stops and, besides, it provides with gas redundancy to the diver, who can deal with an eventual loss of any of the three deco bottles.

- Bottom gas (from bottom to 39m)
- 3 deco bottles:
    - Triox 35\25 (from 36m to 24m)
    - Nitrox 50% (from 21m to 9m).
    - O2 (6m)

Example (VPM-B). Dive at 72m with 30min bottom time with Trimix 15\55, that requires an overall decompression with Nitrox 50% and O2 of 73min. It is compared with the necessary profile using an additional Triox bottle, where we can see now how the saving in deco time is more significant, and carrying on an additional bottle compensates, apart from the fact that if provides more amount of total gas and the necessary redundancy.

72 m	30 min (Tx15/55)	**30 min (Tx15/55)**
51 m	1 min (Tx15/55)	**1 min (Tx15/55)**
48 m	1 min (Tx15/55)	**1 min (Tx15/55)**
45 m	1 min (Tx15/55)	**1 min (Tx15/55)**
42 m	1 min (Tx15/55)	**1 min (Tx15/55)**
39 m	2 min (Tx15/55)	**2 min (Tx15/55)**
36 m	3 min (Tx15/55)	**3 min (Tx35/25)**
33 m	3 min (Tx15/55)	**1 min (Tx35/25)**
30 m	4 min (Tx15/55)	**1 min (Tx35/25)**
27 m	5 min (Tx15/55)	**3 min (Tx35/25)**
24 m	6 min (Tx15/55)	**3 min (Tx35/25)**
21 m	3 min (Nx50)	**3 min (Nx50)**
18 m	5 min (Nx50)	**3 min (Nx50)**
15 m	5 min (Nx50)	**6 min (Nx50)**
12 m	8 min (Nx50)	**7 min (Nx50)**
9 m	11 min (Nx50)	**10 min (Nx50)**
6 m	41 min (O2)	**35 min (O2)**
Total:	132 min	**113 min**

4.4 DIVES WITHIN THE RANGE FROM 72M TO 90M

<u>Short dives</u>

If the bottom time requires less than 70min of overall decompression with Triox 35\-, Nitrox 50% and O2, then it is enough to carry on three decompression bottles, one with Triox 35\30 (to be used from 36m to 24m), other with Nitrox 50% (to be used from 21m to 9m) and other with O2 (to be used at 6m).

- Bottom gas (from bottom to 39m)
- 3 deco bottles:
    - Triox 35\30 (from 36m to 24m)
    - Nitrox 50% (from 21m to 9m).
    - O2 (6m)

Example (VPM-B. Dive at 90m with 15min bottom time with Trimix 21\65, that requires a total deco time with Triox 35\25, Nitrox 50% and O2 of 58min. It is compared with the necessary profile using a forth bottle with Trimix 21\35, where we can see how the small deco time saving does not justify having to carry on an additional bottle.

90 m	**15 min (Tx12/65)**	15 min (Tx12/65)
60 m	**1 min (Tx12/65)**	1 min (Tx12/65)
57 m	**1 min (Tx12/65)**	3 min (Tx12/65)
54 m	**1 min (Tx12/65)**	1 min (Tx12/65)
51 m	**1 min (Tx12/65)**	1 min (Tx21/35)
48 m	**1 min (Tx12/65)**	1 min (Tx21/35)
45 m	**1 min (Tx12/65)**	1 min (Tx21/35)
42 m	**2 min (Tx12/65)**	1 min (Tx21/35)
39 m	**2 min (Tx12/65)**	1 min (Tx21/35)
36 m	**3 min (Tx35/25)**	3 min (Tx35/25)
33 m	**1 min (Tx35/25)**	1 min (Tx35/25)
30 m	**1 min (Tx35/25)**	1 min (Tx35/25)
27 m	**1 min (Tx35/25)**	1 min (Tx35/25)
24 m	**3 min (Tx35/25)**	1 min (Tx35/25)
21 m	**3 min (Nx50)**	3 min (Nx50)
18 m	**3 min (Nx50)**	2 min (Nx50)
15 m	**3 min (Nx50)**	4 min (Nx50)
12 m	**6 min (Nx50)**	6 min (Nx50)
9 m	**8 min (Nx50)**	7 min (Nx50)
6 m	**26 min (O2)**	26 min (O2)
Total:	**86 min**	83 min

Long dives

If the bottom time requires 70min of more an overall decompression with Triox 35_, Nitrox 50% and O2, then four deco bottles will be carried on, one with Trimix 21\35 (to be used from 57m to 39m), other with Triox 35\30 (to be used from 36m to 24m), other with Nitrox 50% (to be used from 21m to 9m) and other with O2 (to be used at 6m).

- Bottom gas (from bottom to 60m)
- 4 deco bottles:
  - Trimix 21\35 (from 57m to 39m)
  - Triox 35\30 (from 36m to 24m)
  - Nitrox 50% (from 21m to 9m).
  - O2 (6m)

Example (VPM-B). Dive at 90m with 30min bottom tim with Trimix 12\65, that requires an overall decompression time with Triox 35\25, Nitrox 50% and O2 of 123min. It is compared with the necessary profile using an additional bottle with Trimix 21\35, where we can see now how the saving in deco time is more significant, and carrying on an additional bottle compensates, apart from the fact that if provides more amount of total gas and the necessary redundancy.

90 m	30 min (Tx12/65)	**30 min (Tx12/65)**
69 m	1 min (Tx12/65)	**1 min (Tx12/65)**
66 m	1 min (Tx12/65)	**1 min (Tx12/65)**
63 m	1 min (Tx12/65)	**1 min (Tx12/65)**
60 m	1 min (Tx12/65)	**1 min (Tx12/65)**
57 m	1 min (Tx12/65)	**3 min (Tx21/35)**
54 m	2 min (Tx12/65)	**1 min (Tx21/35)**
51 m	2 min (Tx12/65)	**1 min (Tx21/35)**
48 m	3 min (Tx12/65)	**1 min (Tx21/35)**
45 m	3 min (Tx12/65)	**1 min (Tx21/35)**
42 m	4 min (Tx12/65)	**1 min (Tx21/35)**
39 m	4 min (Tx12/65)	**3 min (Tx21/35)**
36 m	3 min (Tx35/25)	**3 min (Tx35/25)**
33 m	2 min (Tx35/25)	**2 min (Tx35/25)**
30 m	3 min (Tx35/25)	**3 min (Tx35/25)**
27 m	5 min (Tx35/25)	**3 min (Tx35/25)**
24 m	5 min (Tx35/25)	**5 min (Tx35/25)**
21 m	5 min (Nx50)	**5 min (Nx50)**
18 m	6 min (Nx50)	**5 min (Nx50)**
15 m	8 min (Nx50)	**8 min (Nx50)**
12 m	12 min (Nx50)	**10 min (Nx50)**
9 m	17 min (Nx50)	**15 min (Nx50)**
6 m	57 min (O2)	**50 min (O2)**
Total:	178 min	**156 min**

4.5 DECO BOTTLE LOSS PROTOCOL

If one of the deco bottles is lost, we will simply double the deco time associated with the lost bottle, using the available less rich mixtures or the bottom gas.

5 APPENDIXES

5.1 A: GENERAL STANDARD MIX EQUATION

In this appendix a general equation is derived for the Trimix mixtures having a particular END, and it is particularized to the case of END=30m.

END condition:

$$(MOD+10)\frac{100-He}{100}-10=END$$

MOD condition (for the case of maximum ppO2 of 1.3ATA):

$$MOD=10\frac{1.3}{O2/100}-10$$

Substituting on the other equation and isolating the He fraction, the following general equation results:

$$He=100-O2\frac{END+10}{13}$$

In particular, for END=30m, we obtain the equation of the standard mixes:

$$He=100-3O2$$

5.2 B: STANDARD MIXTURES PREPARATION MADE SIMPLE

In the sequel we describe a simple method for preparing standard mixtures by using only an oxygen analyzer and a very small set of equations. It is assumed that we have enough time to left the bottle to cool after each decanting operation and we do not care about gas compressibility issues, because the actual ratio between Helium and Nitrogen in the mixture is not critical.

Let P be the desired pressure of the final mixtures, typically $P=200bar$. Let O2\He the desired Trimix standard mixture, for example, 21\35, 10\70, etc. Let us start with the destination bottle completely empty and we start decanting Helium up to a pressure:

$$P_{He}=\frac{He}{100}P$$

From that point, it is enough to top-off the bottle with Nitrox 32% using a compressor with membrane. If this is not possible, then we should have our own Oxygen bottle. This allows us decanting certain amount of O2 after the Helium and top-off with an air compressor, more easily available. The O2 pressure to be decanted is:

$$P_{O2}=\frac{0,47O2}{100}P$$

which implies to left the bottle up to a final pressure of $P_{He}+P_{O2}$. These bar of O2 are usually not too much in comparison with the bar of Helium ($P_{O2} << P_{He}$), which means that the precision of the gauge affects more in that operation. For that reason, it is convenient to analyze the content of Oxygen in than moment, and to check that it is:

$$O2' = \frac{47}{\frac{100}{O2} - 2,53} \%$$

and better if we measure less now and correct later on. Note that in the case of a normoxic mixture in which O2=20.9, we obtain that O2' should also be equal to O2, that is, 20.9%. In the case of a Trimix such that O2<20.9, it happens that 0.47*O2<O2'<O2.

A trick to improve the gauge precision to put the correct amount of O2 is to use our smallest O2 deco tank for decanting (it is has enough pressure). Then, the desired pressure P_{O2} will be amplified by the ratio of volumes of back bottle to deco bottle and we can measure the decrease of the pressure at the deco bottle (instead of the increase of pressure at the destination bottle). For instance, if the volume of the back bottle is Lb=24L and deco bottle is Ld=5.5L, we should measure a decrease of pressure at the deco bottle of $P_{O2} L_b / L_d = 4,36 P_{O2}$, which improves the precision of the measure.

If we measure an oxygen percentage less than desired, we decant more Oxygen until we obtain the desired figure. Finally we take our Heliox bottle to an compressor, top-off with air up till a pressure equal to P, let it cool and mix, analyze oxygen and that's it.