Decotrainer - User Manual
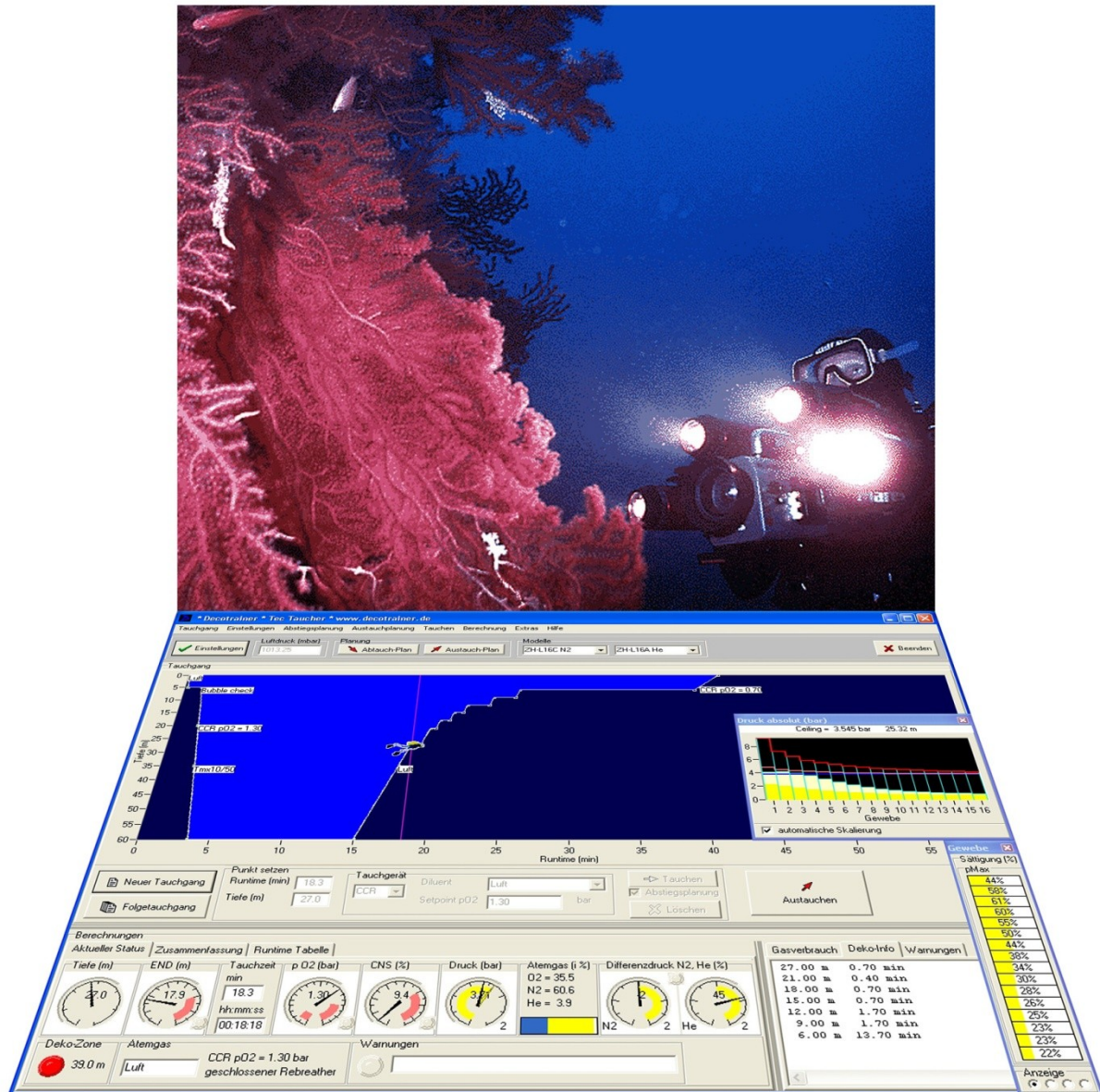
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Table of contents   page

0.   Intended Purpose and Limitations of the Program Decotrainer

This program was created to visualise saturation processes during diving. It was developed by the author as a tool for training purposes. It was not primarily developed to plan real dives. If you still want to dive the plans calculated by this program, you have to consider the following.

WARNING ADVICE

Diving is potentially very dangerous - especially to great depths and/or using different gas mixtures. Technical diving requires a good amount of sound knowledge as well as practical experience and thus professional training. Insufficient or even the lack of planning of a dive can cost someone's life. This program cannot replace this knowledge or experience, but it requires it. I have developed and tested this program with great care. As I am only human too, this program can - despite great diligence - contain errors. Moreover, this program can generate wrong results when used incorrectly.

DIRECTIONS FOR USE

The user has to verify that the calculated results are valid and conclusive. I recommend to re-calculate the dive using another independent computer program. The user has to monitor the dive with a suitable dive computer. This redundancy is essential for technical diving.

Your life depends on the correct decompression plan!

Only you are responsible for your dive!

1. Basic Principles

1.1. Units

The system of units that is used by Decotrainer is based on the standardised metric "International System of Units" (SI) [see Wikipedia].

Physical parameter	Unit	SI unit	Conversion to SI unit	Occurs as
Length	1 metre = 1 m	1 m		depth, length, height
Time	1 minute = 1 min	1 s	1 min = 60 s	runtime, time for descent, time for ascent, time of deco stops,...
Time	hh:mm:ss			time
Pressure	1 bar	$1 Pa = 1 N/m^2$	$1 bar = 10^5 Pa$	ambient pressure, air pressure, water pressure, water vapour pressure, partial pressure, pressure of inert gases on tissues, maximal recommended excess pressure on tissues,...
Volume	1 litre = 1 L	$1 m^3$	$1 L = 10^{-3} m^3$	size of the gas bottle, volume of the counter lung
Gas amount	1 bar*litre = 1 barL			Gas amount = gas volume calculated for surface pressure
Volume flow rate	1 litre/min = 1 L/min	$1 m^3/s$	$1 L/min = 1.67 * 10^{-5} m^3/s$	respiratory minute volume, supply performance, use of oxygen, SCR flow rate
Temperature	1 degree Celsius = 1°C	1 K	x/1°C + 273.15 K	water temperature
CNS	1 percent = 1 %			(short-term) oxygen toxicity
OTU	1			(long-term) oxygen toxicity
Proportion	1 percent = 1 % Sum = 100 %			mixture/ composition of breathing gases
Fraction	1 Sum = 1			mixture/ composition of breathing gases

1.2. Pressure

The physical parameter pressure is defined as the ratio of the force applied perpendicular to the surface of an object and the unit area over which that force is distributed.

$$p = F/a$$

where p =pressure, F = force and A = area. According to its definition the SI unit of pressure is:

$$1 \text{ N/m}^2 = 1 \text{ Pascal} = 1 \text{ Pa}$$

Since both air as well as water pressure can easily be calculated with the unit "bar", its use is quite common amongst divers. This unit is also generally favoured, as the standard air pressure is approximately 1 bar. For the conversion into different units the following applies [Wikipedia]:

1 bar	$= 10^5$	Pa	= 100'000 Pa
	= 1'000	hPa	= 1 hPa = 1 hecto-Pascal = 100 Pascal
			This unit is used by meteorologists
	= 1'000	mbar	= 1 mbar = 1 milli-bar = 1/1000 bar = 0.001 bar
	= 1.0197	kp/cm²	= 1 kp/cm² = 1 at = 1 technical atmosphere = the pressure that is exerted by a water column of 10 m (fresh water at 4°C)
	= 0.98692	atm	= 1 atm = 1 physical atmosphere = standard air pressure at sea level
	= 750.06	Torr	= 1 Torr = 1 mm Hg = 1 millimetre of mercury, historical unit now only used in medicine (blood pressure)
	= 14.504	lb/in²	= lb/in² = 1 pound per square-inch = 1 psi

Air pressure

The pressure that is exerted by Earth's atmosphere is called air pressure. It originates from the weight of the atmosphere. During a dive, air pressure is the pressure exerted on the water surface. Air pressure depends on different parameters, especially on the prevailing altitude, temperature and weather. The average air pressure of Earth's atmosphere at sea level (standardized value for air pressure [Wikipedia]) is:

$$p(\text{air pressure}_0) = 1.013 \text{ bar} = 1013 \text{ mbar} = 1 \text{ atm}$$

Due to the weather there can be fluctuations in the range of a couple of percent in air pressure (in Germany with a maximum of ca. ± 50 mbar [Wikipedia]). A much stronger influence shows the parameter altitude. Altitude-dependant air pressure can be calculated using the barometric formula (GERTHSEN *et al.* 1977):

$$p(h) = p(\text{air pressure}_0) * \exp^{(-h/H)}$$

where: p(h) = pressure depending on altitude in Pa, h = altitude in m, p(air pressure$_0$) = reference pressure = pressure at sea level in Pa, exp = exponential function to basis e, H = scale height = ca. 7989 m. The barometric formula provides an approximation of altitude-dependent air pressure. The approximation doesn't consider the decline in temperature with altitude. The table below shows a couple of examples for calculating average air pressure using the altitude formula.

Note: The air pressure for the altitude at Mount Everest equals 338 mbar using the altitude formula and thus - despite approximation - accords with a measured value of 326 mbar published on Wikipedia.

Location	Altitude (m above mean sea level)	Air pressure (mbar)
Dead Sea	- 400	1065
at Sea Level	0	1013
Attersee	469	956
Starnberger See	584	942
Walchensee	801	917
Lake Titicaca	3812	631
Mount Everest	8848	326 [Wikipedia]

Reduced air pressure while diving at altitude significantly influences decompression calculations. Reduced air pressure causes a greater relative decrease in pressure from a certain depth to another (e.g. from 10 m to the surface) than during a dive under normal air pressure conditions. Thus, decompression has to be slower when diving at altitude than when diving at sea level.

Decotrainer completely integrated both the barometric formula and all other characteristics for dives in mountain lakes (at altitude).

Water pressure and depth

During a dive the diver is exposed to an additional pressure exerted by the weight of the water column. The weight of the water column as well as the hydrostatic pressure created by this weight depend on both the depth of the water and its density. As water is almost incompressible, its density essentially depends on temperature and salt content. At depths that are accessible for divers, the water's density is thus not dependent on depth. Generally, at a depth of 10 m one is exposed to a pressure that corresponds to the normal pressure at the surface, i.e. 1 bar. This value is used by BÜHLMANN (2002) to calculate his decompression tables. Water pressure can easily be determined using the formula below:

p (water pressure) = depth / (10 m/bar)

More generally:

p (water pressure) = d / dCal

where d = depth in m, dCal = calibration for depth in m/bar. Decotrainer calculates with a calibrated linear depth-pressure function dCal, see the following examples:

10.000 m/bar   standard value

10.215 m/bar   fresh water at 20°C

9.804 m/bar   Red Sea (4.1 % salt content) at 15°C

Ambient pressure

Ambient pressure is the sum of air pressure, that weighs on the water surface, and water pressure.

p (ambient pressure) = p (air pressure) + p (water pressure)

with standard values this is effectively:

p (ambient pressure) = 1 bar + (depth / (10 m/bar))

Conversely, depth can be calculated from ambient pressure and air pressure:

d = (p (ambient pressure) - p (air pressure)) * dCal

where   d = depth in m, dCal = calibration for depth in m/bar

1.3. Ideal Gas Laws

The following gas laws are valid for "ideal" gases. In this context "ideal" means that the smallest components of the gases (molecules or atoms) show no interactions [see e.g. LETTNIN 2001]. Effectively, this precondition holds true for gases exposed to standard conditions, i.e. exposed to atmospheric pressure of 1 bar and room temperature. This condition cannot be fulfilled under higher pressure (e.g. 300 bar).

Dalton

Dalton's law states that the total pressure of a gas mixture equals the sum of all partial pressures that make up the mixture. Partial pressure is defined as the pressure that one single gas would exert on a certain volume. Partial pressure and volume fraction are thus directly related [Wikipedia], LETTNIN (2001)].

$$p = p(gas\ 1) + p(gas\ 2) + ... + p(gas\ n)$$

$$1 = f(gas\ 1) + f(gas\ 2) + ... + f(gas\ n)$$

$$p(gas\ i) = f(gas\ i) * p$$

where p = pressure, p(gas i) = partial pressure of gas number i, f(gas i) = volume fraction of gas number i (sum of all fractions = 1). The formulas are based on gas fractions that sum up to 1.

The relation between percentage and fraction is:

$$x(gas\ i) = f(gas\ i) * 100$$

$$100\ \% = x(gas\ 1) + x(gas\ 2) + ... + x(gas\ n)$$

where x(gas i) = percentage share of gas number i (sum of all shares = 100 %). Example:

Air under normal conditions (pressure = 1013 mbar, according to BÜHLMANN 2002):

Component	Volume fraction (%)	Partial pressure (mbar)
Oxygen O_2	20.95	212.2
Nitrogen N_2	78.08	791.0
Remainder (inert gases, CO_2)	0.97	9.8

At body temperature (37°C), the air we inhale through our lungs is saturated with water vapour. Water vapour has to be taken into account when calculating physiologically relevant partial pressures. Example: Inhaled air in our lungs under normal conditions (pressure = 1013 mbar, BÜHLMANN 2002):

Component	Volume fraction (%)	Partial pressure (mbar)
Oxygen O_2	19.68	199.4
Nitrogen N_2	73.25	742.0
Water vapour H_2O	6.19	62.7
Remainder (inert gases, CO_2)	0.91	9.2

Henry

Henry's law describes the processes that take place when gases are dissolved in liquids. It states that, at equilibrium, the concentration of a gas in a liquid equals the partial pressure of this gas (in the gas phase above the liquid) [Wikipedia, LETTNIN 2001].

$$c(gas\ i) = k * p(gas\ i)$$

where c(gas i) = concentration of gas i in a liquid, p(gas i) = partial pressure of gas i in the gas phase and k = proportionality constant ("Henry's constant").

In this context, one tends to use the simplified version "partial pressure of the gas in solution". The partial pressure of the dissolved gas at equilibrium then equals the partial pressure of the gas in the gas phase.

To explain decompression sickness, one has to remember the fact that gases show increased solubility in liquids when they are under pressure. The more the ambient pressure rises, the more the partial pressure of the inert gas nitrogen increases in the breathing air. Consequently, more nitrogen dissolves into all fluids that our body mainly consists of. During ascent pressure relief has to be as slow as necessary to enable dissolved nitrogen to leave the body, and to be released via exhalation through the lungs. This is called decompression. If decompression is too fast, gas bubbles can form within the body and cause decompression sickness.

Boyle-Mariotte

Boyle-Mariotte's law explains the relation between pressure and the volume of a confined amount of gas at a constant temperature. Pressure and volume are inversely proportional. Often the law is called Boyle's law [Wikipedia], Lettnin 2001].

> p * V = constant
>
> or
>
> $p_1 * V_1 = p_2 * V_2$

where p = pressure and V = volume, p_1 and V_1 = pressure and volume at point of time 1, p_2 and V_2 = pressure and volume at point of time 2.

This law is important for diving when there are changes in pressure. An increase in pressure decreases the volume of a gas and vice versa.

1.4.   Breathing Gases

1.4.1.   Oxygen O_2

Oxygen (O_2) is without colour or odour and has a density of 1.429 g/L under normal conditions. Breathing air contains roughly 21 % oxygen. Oxygen plays an essential role for all life on Earth. There would be no combustion - and thus no cellular combustion = respiration - without oxygen.

Although oxygen is essential for life, we can only tolerate it within certain margins. Is the content of oxygen too low, we suffer from suffocation, is it too high, oxygen damages our central nervous system and our breathing organs. The partial pressure of oxygen is used to quantify the gas. Under normal conditions, the partial pressure of oxygen in air equals approximately 0.21 bar (= normoxic).

Decreased O_2 partial pressure

The body shows first signs of an O_2 deficit below 0.16 bar. Common symptoms of an O_2 deficit (hypoxia) are shortness of breath (dyspnoea), bluish skin colour, clouding of consciousness and weakness [Wikipedia]. Hypoxia becomes life-threatening at concentrations below 0.12 bar (Aspacher 2000). Decotrainer uses 0.16 bar as the minimum limit value for pO_2.

Mixtures for breathing gases to dive to greater depths usually contain less O_2 than normoxic mixtures. These gas mixtures cannot be used under surface conditions as they might trigger hypoxia. To use such gases, one has to know about minimum operating depth (= MinOD). MinOD is the minimum depth where the partial pressure of O_2 in the breathing gas just reaches the minimum value.

> MinOD = (pO_2(min) / f O_2 - p(air pressure)) * dCal

where MinOD = minimum operating depth in m, pO_2(min) = minimum partial pressure of oxygen in bar, f O_2 = fraction of oxygen, p(air pressure) = air pressure at the surface, dCal = calibration at depth in m/bar.

Increased O_2 partial pressure

Partial pressures of oxygen of up to 0.5 bar can be tolerated by the body, even when breathed for a longer period of time (Bühlmann 2002). Partial pressures above 1.0 bar (100 % oxygen under normal conditions) bear the risk for oxygen intoxification (see Wikipedia Ú Oxygen toxicity). The symptoms of O_2 toxicity are muscle twitching, muscle cramps, discomfort, nausea, headache, irritation of the throat, pain behind the sternum, visual disturbances, dizziness, orientation disorders and states of confusion as far as

loss of consciousness. The higher the O_2 partial pressure, the shorter is the time to the onset of first symptoms. Short-term consequences of increased O_2 partial pressure affect the nervous system, long-term consequences affect all breathing organs.

Nowadays, the generally accepted maximum O_2 partial pressure for diving is 1.6 bar (ASPACHER 2000 and BÜHLMANN 2002). For many calculations 1.4 bar are recommended as the maximum value (ASPACHER 2000). Supervised treatments in decompression chambers commonly reach partial pressures of up to 2.8 bar (LETTNIN 2001). Decotrainer uses 1.6 bar as the maximum value for pO_2; if this value is exceeded, there will be a warning message (BÜHLMANN 2002).

The maximum operating depth (MOD), using a set breathing gas, is influenced by the maximum tolerable pO_2. MOD is the depth at which pO_2 rises to a maximum value due to an increased ambient pressure.

$$MOD = (pO_2(max) / f\,O_2 - p(air\ pressure)\,) * dCal$$

where MOD = maximum operating depth in m, $pO_2(max)$ = maximum O_2 partial pressure in bar, f O_2 = fraction of oxygen, p(air pressure) = air pressure at the surface, dCal = calibration at depth in m/bar.

In order to quantify medical consequences of breathing hyperbaric oxygen, the NOAA (National Oceanic and Atmospheric Administration of the USA) introduced decompression tables (BAUMGARTEN 1999, ASPACHER 2001, NOAA 2008). They differentiate between short- and long-term quantification.

CNS Clock

Short-term consequences mainly affect the central nervous system and can be quantified using the so-called "CNS clock". The diver is allowed a maximum of 100 % CNS oxygen exposure. The maximum value of 100 % is already regarded as critical (see e.g. ASPACHER 2001).

The original NOAA table (NOAA 2008, SALM 2013) shows the increase of CNS values in percent per minute as a function of pO_2 in atm. This table is cited incorrectly by many authors, as they use the unit bar instead of the original atm. The following applies: 1 atm = 1 physical atmosphere = 1.01325 bar (see chapter 1.2 and Wikipedia Ú atm).

Decotrainer calculates with BAUMGARTEN's (1999) values of pO_2 in a range between 0.5 atm to 1.82 atm, and re-calculates the original unit for pressure "bar" to "atm" internally for the use of the CNS table. There is linear interpolation between the grid points of the CNS table. Oxygen partial pressures below 0.5 atm will decrease CNS percentages. Oxygen under standard conditions (i.e. 0.21 bar) reduces CNS percentages by 50 % after 90 minutes (NOAA 2008). Oxygen partial pressure greater than the maximum value of the CNS table (1.82 atm) is linearly extrapolated.

The maximum value for CNS percentages that cause a warning message when exceeded is set on 100 % in Decotrainer.

OTU

Long-term effects of increased oxygen exposure mainly affect the breathing organs and are determined using the so-called OTU (Oxygen Tolerance Unit) method. OTU values correspond to UPTD (Unit Pulmonary Toxicity Dose) values (ASPACHER 2001). In Decotrainer OTUs are calculated using Bill Hamilton's so-called Repex Method (ASPACHER 2001).

$$OTU = t * (2 * pO_2 - 1)^{0.83}$$

where OTU = oxygen tolerance unit (without dimension), t = time in min, pO_2 = oxygen partial pressure in bar. The allowable number of OTUs for one day is OTU = 850 and it is the sum of OTUs of all dives that day. Due to accumulative oxygen exposure, the daily OTU limit is lower when diving over multiple days (or when treated in decompression chambers) (ASPACHER 2001). Decotrainer uses a maximum tolerable number of OTU = 850.

1.4.2. Carbon Dioxide CO_2

In its normal concentration under normal conditions, carbon dioxide (CO_2) is a colourless and odourless gas with a density of 1.977 g/L (LETTNIN 2001). It is thus more dense than air. CO_2 accounts for only around 0.04 % = 400 ppm of the atmosphere. Even though atmospheric CO_2 concentration is low, the measurable increase of CO_2 is held responsible for climate change (Wikipedia Ú Carbon dioxide).

CO_2 is one by-product of respiration:

$$C_6H_{12}O_6 + 6\ O_2 \ \ddot{E}\ 6\ CO_2 + 6\ H_2O$$
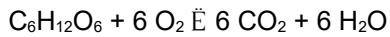
The chemical formula means that 1 molecule of glucose + 6 molecules of oxygen Ë 6 molecules of carbon dioxide + 6 molecules of water. Carbon dioxide is released with every breath. Expired air contains around 40 mbar of CO_2 - under standard conditions this equals 4 vol %. Our reflex respiratory centres are mainly stimulated by CO_2 partial pressure.

Normally, breathing gas does not contain CO_2. When diving with an open circuit, CO_2 is released to the environment via the exhaled air. In closed circuit dive systems, exhaled CO_2 is bound to soda lime and thus removed from the breathing circuit.

If soda lime is used, partial pressures of CO_2 in the breathing circuit can reach limits that have negative effects on the diver's health. The maximum allowable concentration (MAC) of CO_2 is 0.5 %. Concentrations above 5 % result in headaches and dizziness (vertigo), even higher concentrations can lead to an increased heart rate, increased blood pressure, difficulties in breathing and unconsciousness (Wikipedia > CO_2).

Decotrainer does not include CO_2 in the calculation.

1.4.3.   Nitrogen N_2

Nitrogen (N_2) is an odourless and colourless gas, and under standard conditions has a density of 1.2504 g/l (LETTNIN 2001). With around 78 %, nitrogen is the main component of air. Nitrogen belongs to the inert gases not taking part in respiration. Nevertheless, nitrogen shows an impact on dive conditions. Increased partial pressures of nitrogen have a narcotic effect on the central nervous system. This effect is also known as "rapture of the deep". Under standard conditions, early signs of inert gas narcosis can be observed from a depth of 30 m, which equals a pN_2 of 3.16 bar. Due to the narcotic effects of nitrogen, in most training guides diving on air is limited to a maximum depth of 50 m.

To avoid these unwanted and potentially dangerous effects, gas mixtures with reduced pN_2 are used for diving to greater depths. At a certain depth a certain breathing gas is assigned to an END (Equivalent Nitrogen Depth). END is the depth at which air, used as the breathing gas, potentially has the same pN_2 as under standard air pressure - and thus would result in a comparable narcotic effect. Decotrainer uses the formula:

$$END = [fN_2 / f\ N_2\ (air) * (d / dCal + p(air\ pressure)) - p(air\ pressure_0)] * dCal$$

where END = Equivalent Nitrogen Depth in m, fN_2 = fraction of nitrogen , fN_2 (air) = fraction of the nitrogen content of air, p(air pressure) = current air pressure in bar, p(air pressure0) = standard air pressure in bar = 1013 mbar, dCal = calibration for depth in m/bar. Decotrainer only associates nitrogen with narcotic effects, neither oxygen nor helium are narcotic to the program - a fact judged differently by other authors (LETTNIN 2001). Decotrainer uses an END of 50 m as a fixed limit.

1.4.4.   Water Vapor H_2O

Depending on the climate, normal atmospheric air contains gaseous water = water vapour, sometimes more sometimes less. BÜHLMANN (2002) assumes that human lungs are saturated with water vapour at body temperature (37°C). Under these conditions, the percentage of water vapour equals 6.19 % and the partial pressure of the water vapour equals 62.7 mbar. According to BÜHLMANN (2002), one should subtract this partial pressure (water vapour) of the ambient pressure when calculating partial pressures of breathing gases.

$$p(ambient) = p(gas\ 1) + p(gas\ 2) + p(gas\ 3) + ...\ p(water\ vapour)$$

Decotrainer offers this option as the selectable standard.

1.4.5.   Helium He

Helium (He) is a colourless and odourless gas showing a very low density of 0.179 g/L under standard conditions. Atmospheric air only contains traces of helium. When diving to great depths, helium is used in (partial) exchange for nitrogen to decrease nitrogen partial pressure, and thus its narcotic effects on the diver. In relation to narcosis, helium effects the body a lot less than does nitrogen. Decotrainer sets the narcotic effect of helium to zero (= 0). Rapid pressure increases, using a helium-rich gas mixture and with a high ambient pressure, can result in HPNS (High Pressure Nervous Syndrome, see LETTNIN 2001) - this is an effect that Decotrainer does not take into consideration.

Like nitrogen, helium is an inert gas which does not take part in gas exchange nor in respiration. Its characteristics in relation to saturation are different to those of nitrogen (see 1.5 Saturation and Desaturation of Inert Gases).

1.4.6. Air

Our atmosphere consists of air. Under standard conditions air has a density of 1.293 g/L (LETTNIN 2001). For diving, air is the standard gas. The composition of dry air is more or less constant, even when air pressure is very different - e.g. at -400 m NN (Death Sea, ca. 1065 mbar) or at +8848 m NN (Mount Everest, ca. 545 mbar). For the composition of air see 1.3 Ideal Gas Laws - Dalton. For air Decotrainer uses the following values (same as BÜHLMANN 2002):

xO_2 = 20.948 %

xN_2 = 79.020 % (equals the actual content of N_2 + rare gases)

xResidual gases = 0.032 %

1.4.7. Nitrox

Nitrox is an artificial breathing gas and consists of the components oxygen and nitrogen, but with an oxygen content different to normoxic conditions. The word is composed of

NITrogen + OXigen = NITROX

Commonly, NITROX mixtures with oxygen contents > 21 % are used. The advantage of using NITROX instead of air during a comparable dive, lies in the decreased ENDs and lower saturations in relation to the inert gas nitrogen. Usually, the mixtures are called EANx (Enriched Air Nitrox) where x stands for the percentage of O_2. The following mixtures of NITROX are integrated in Decotrainer by default:

EAN29, EAN32, EAN35, EAN36,EAN40, EAN60, EAN80, EAN100 = pure oxygen

1.4.8. HeliOx

HeliOx is an artificial breathing gas that consists of oxygen and helium without containing nitrogen. In recreational diving as well as technical diving HeliOx is not used in practice (it is used however for commercial diving when descending to greater depths). Not only is its production more expensive than the one of Trimix, but the missing nitrogen content also leads to the disadvantage that the diver can be affected stronger by HPNS than when diving on a comparable Trimix breathing gas. There is one exemplary HeliOx gas integrated to Decotrainer:

HeliOx 21/79

containing 21 % O_2 and 79 % He. It has the same oxygen content as air, but contains helium instead of nitrogen as the inert gas.

1.4.9. Trimix

Trimix is an artificial breathing gas composed of the three components: oxygen, helium and nitrogen. Trimix is used on deep dives, the composition of the breathing gas however has to be adapted to the operating depth. The choice of the oxygen content is based on an acceptable pO_2 range (e.g. 1.3 bar). The nitrogen content is determined in a way that the END of the mixture (as a result of pN_2) also falls into an acceptable range (e.g. 30.m). Normally, the nomenclature of Trimix gases is as follows:

Tmx xO_2/xHe

where Tmx = identifier for Trimix, xO_2 = O_2 content in %, xHe = He content in %. The following Trimix gases are integrated as examples in Decotrainer:

Tmx 20/40, Tmx 15/60, Tmx 9/66, Tmx 7/74, Tmx 5/80

2.   Saturation and Desaturation of Inert Gases

2.1.   Calculation of Saturation and Desaturation by BÜHLMANN

Recent research on decompression has been markedly influenced and developed by Prof. Dr. med. ALBERT A. BÜHLMANN. His book "Tauchmedizin" (Diving Medicine) (BÜHLMANN 2002) is the standard literature on this topic.

Prior to BÜHLMANN, the state of knowledge was summarised as follows: At the end of the 19th century decompression sickness was already known - mainly from people working under high pressure in caissons. The name "Caisson disease" for decompression sickness derived from this time. This sickness was researched systematically for the first time by PAUL BERT in 1878. SCOTT HALDANE then developed the first decompression tables in 1907, referring to the just discovered gas laws by Dalton and Henry. The concept of exponential saturation which is described by half-times can be traced back to Haldane. In 1958, the American marine published the first decompression tables. Subsequently, these U.S. Navy Tables became widespread even among recreational divers. For the development of the U.S. Navy Tables, solely marine soldiers were used as "lab rats".

In his research with medical background, BÜHLMANN concentrated on completely normal recreational divers of both sexes. The first issue of BÜHLMANN's book "Tauchmedizin" was published in 1983, the current issue is the 5th completely revised issue of 2002. Moreover, BÜHLMANN's calculation model ZH-16 is completely documented, and thus forms the basis of many decompression programs (for PCs and dive computers). The most important pillars:

- Saturation and desaturation are described by an exponential function
- 16 model-tissues with different saturation half-times and over-saturation tolerances
- Nitrogen saturation half-times between 4 min and 635 min
- Helium saturation half-times between 1.5 min and 240 min
- Lower over-saturation tolerances than in the calculation by the U.S. navy
- Lower velocity during ascent 10 m/min (compared to 18 m/min by U.S. navy)
- Additional definition of "risk divers" with higher risk of DCS
- Integration of diving at altitude (mountain lake) and repetition dives
- Calculations with inert gases other than nitrogen (hydrogen, helium)

Mathematical expression of saturation and desaturation as an exponential function:

$$p_G(t) = p_G(t_0) + [p_A - p_G(t_0)] * [1 - 2^{(-t / T)}]$$

where $p_G(t)$ = pressure of the inert gas in the tissues at the point of time t, $p_G(t_0)$ = pressure of the inert gas in the tissue at the point of time t_0 (at the beginning of the calculation), p_A = pressure of the inert gas in the breathing gas, t = time, T = half time. Half-time is described as the time that is needed for a tissue to be saturated exactly halfway following pressure changes.
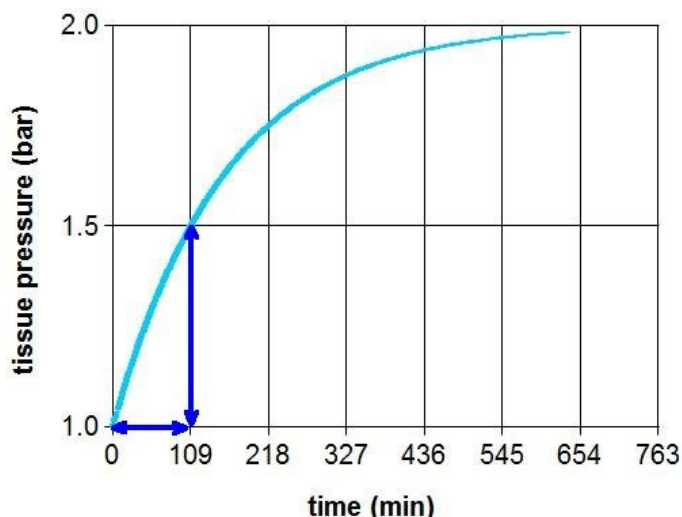

This example shows an increase in pressure from 1 bar to 2 bar. When the saturation half-time is over, in this example after 109 min, exactly half of the pressure difference is established (1.5 bar). This happens once again after another saturation half-time (109 min + 109 min = 218 min) and again after another etc.

The following figure shows the pressure curve of all 16 tissues during the same theoretical pressure increase from 1 bar to 2 bar.
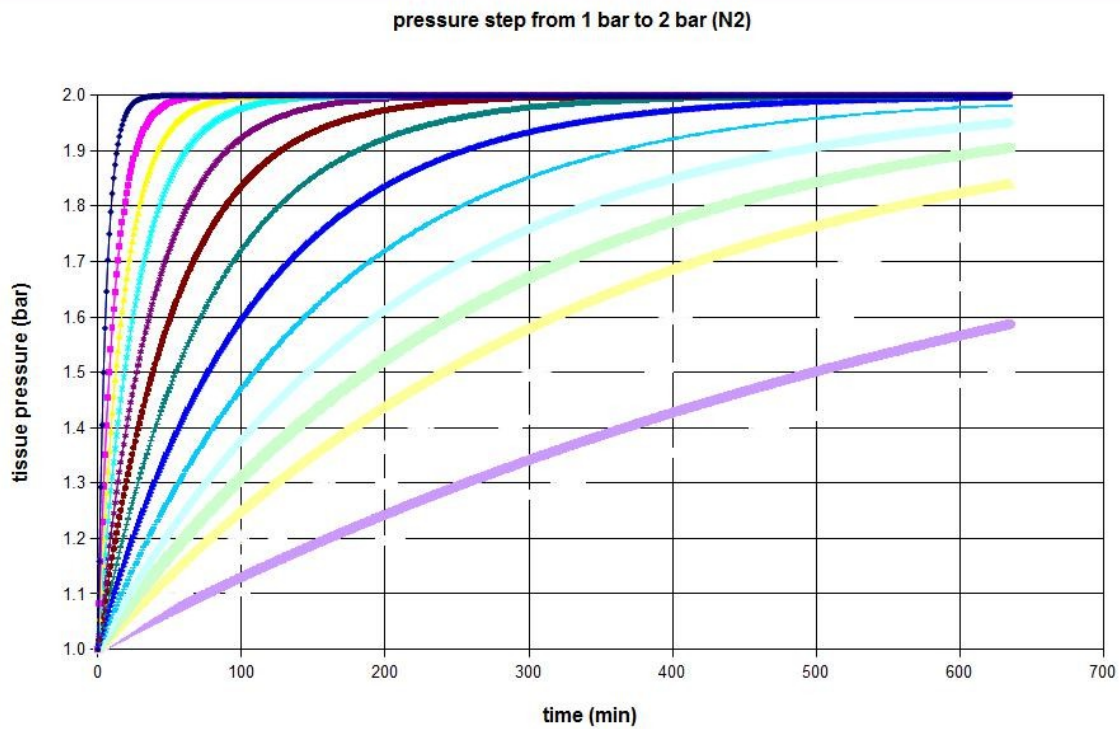
Pressure curves of the inert gas nitrogen in 16 tissues following a pressure change from 1 bar to 2 bar.

Differences in the rate of increase are dependent on different saturation half-times. Referring to the inert gas helium, pressure curves of the same tissues look as follows.
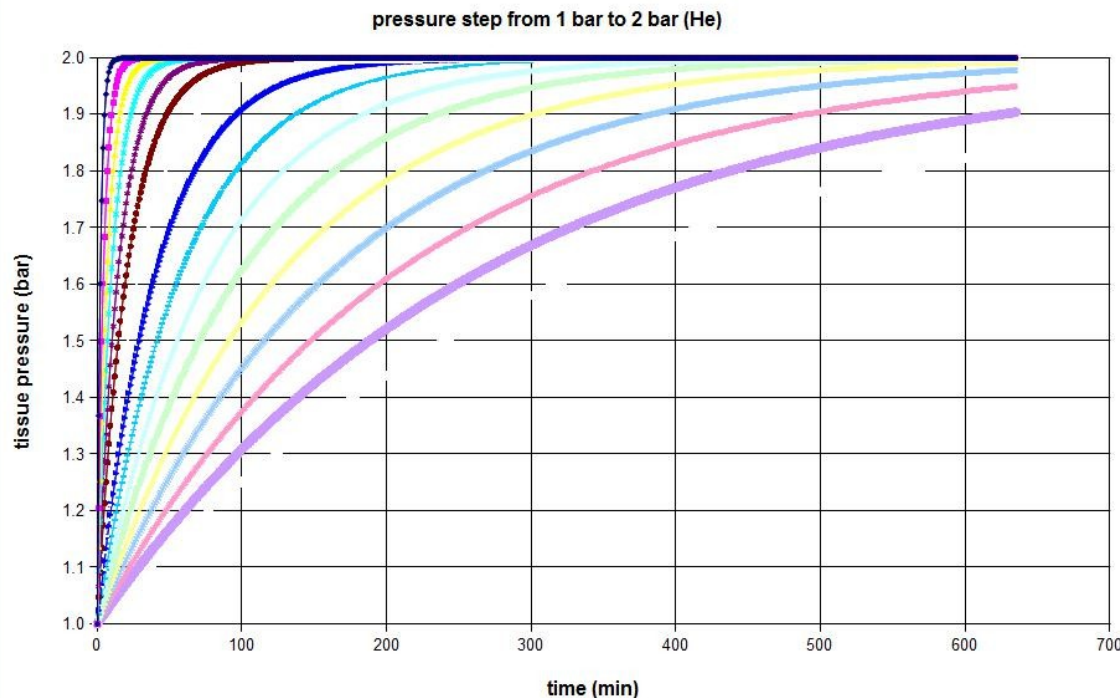
Pressure curves of the inert gas helium in 16 tissues following a pressure change from 1 bar to 2 bar.

Underlying half-times for saturation of the inert gases nitrogen and helium of the 16 tissues are (models ZH-L16C and ZH-L16A He according to BÜHLMANN 2002):

Tissue "Compartment"	Half-time Nitrogen (min)	Half-time Helium (min)
1	4.00	1.51
2	8.00	3.02
3	12.50	4.72
4	18.50	6.99
5	27.00	10.21
6	38.30	14.48
7	54.30	20.53
8	77.00	29.11
9	109.00	41.20
10	146.00	55.19
11	187.00	70.69
12	239.00	90.34
13	305.00	115.29
14	390.00	147.42
15	498.00	188.24
16	635.00	240.03

Maximum tolerated excess pressure of tissues

Body tissues can tolerate a certain excess pressure. Excess pressure in this context describes the partial pressure of an inert gas that exceeds the prevailing ambient pressure. Maximum tolerated excess pressure can be described as a linear function of ambient pressure.

$$p_G(max) = p(ambience) / b + a$$

where: $p_G(max)$ = maximum tolerated pressure of inert gases in tissues, $p(ambience)$ = ambient pressure, b = coefficient b, a = coefficient a. Lower values for b and higher values for a result in an increase of the maximum tolerated excess pressure.

maximum tissue overpressure (N2)
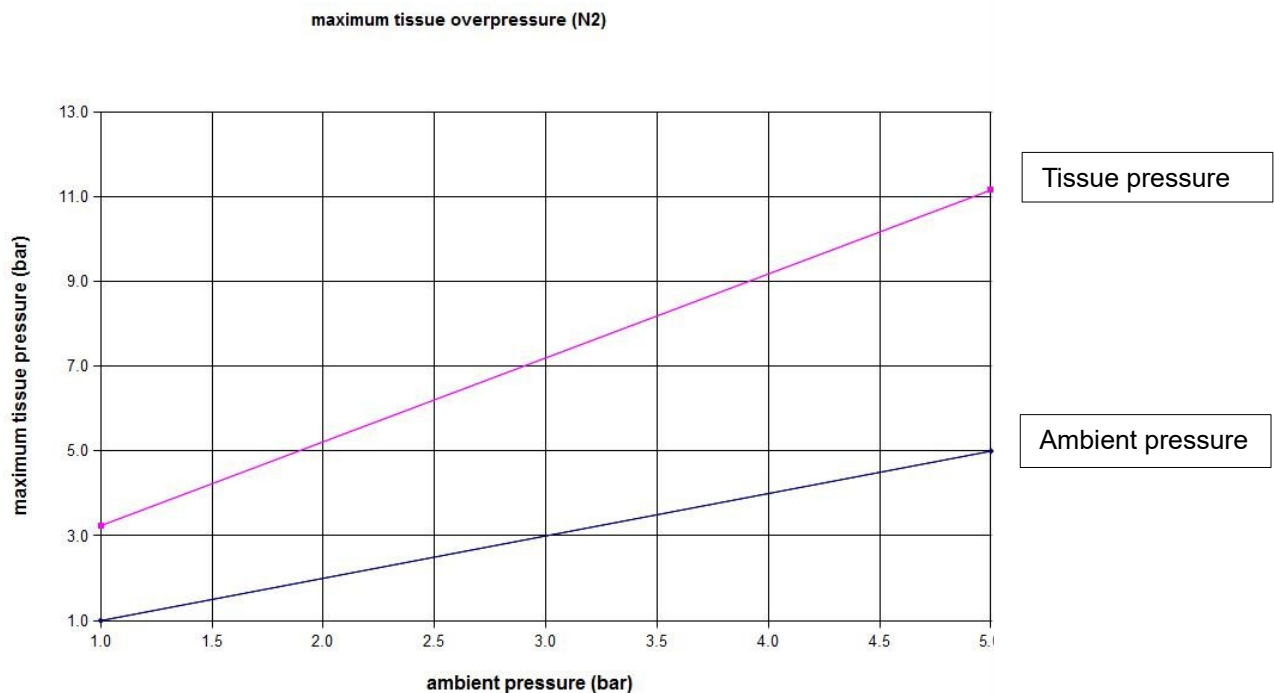
Exemplary graph of maximum tolerated excess pressure as a function of ambient pressure.

Coefficients a and b differ for the two inert gases nitrogen and helium.

Gewebedruck

maximum tissue overpressure (N2)
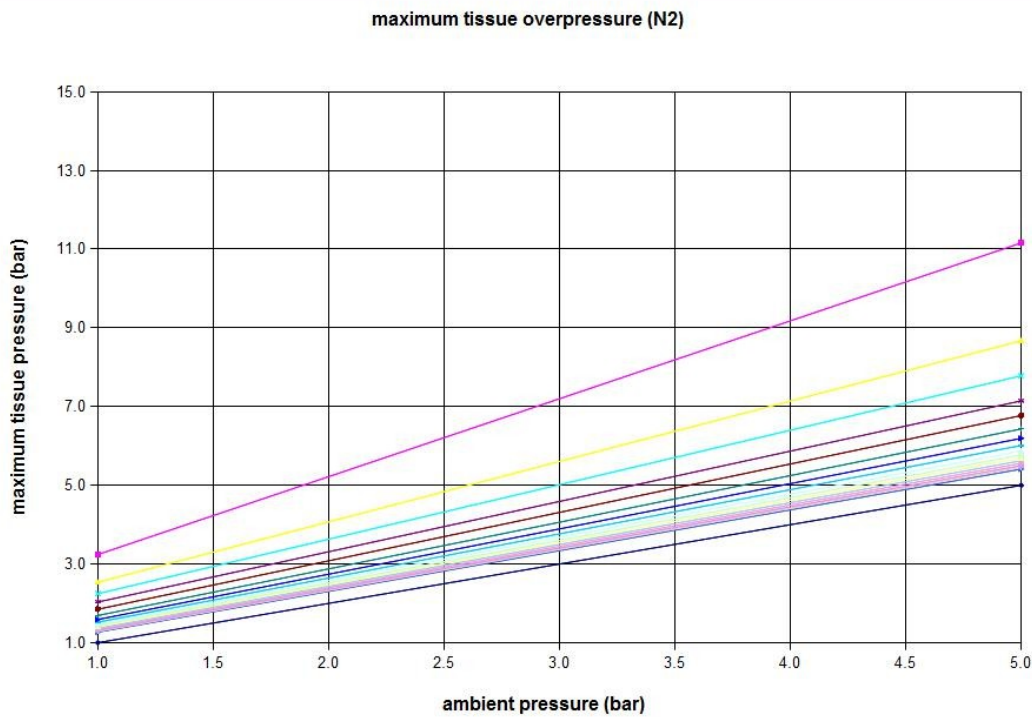
Maximum excess pressure of the tissues for the inert gas nitrogen depicted as a function of ambient pressure.

maximum tissue overpressure (He)
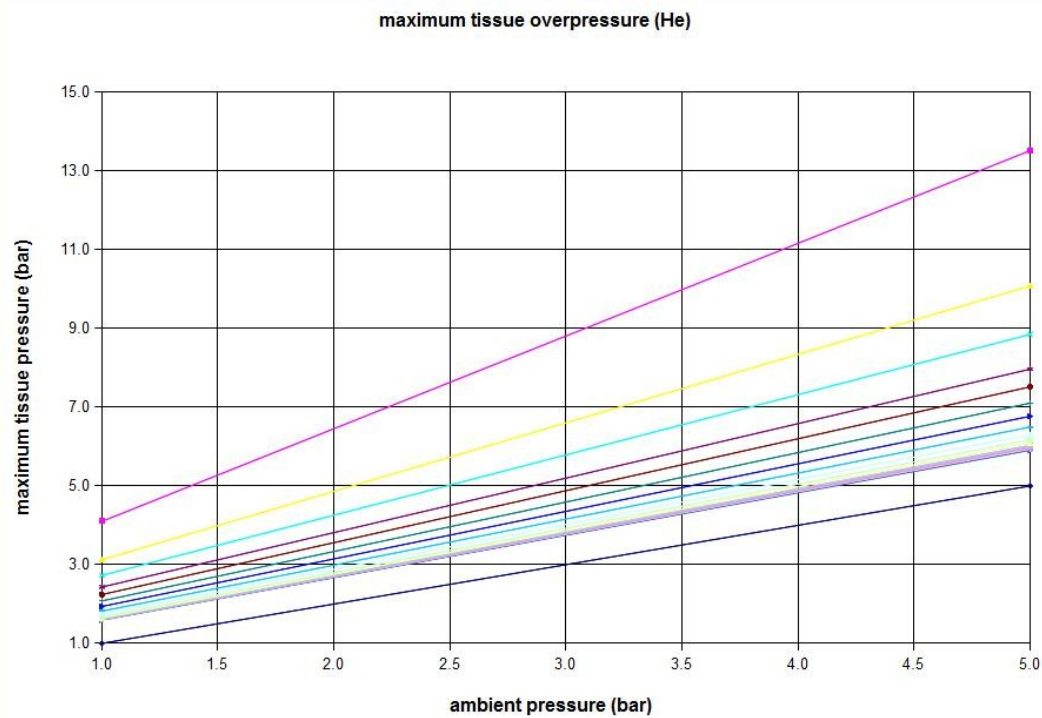
Maximum excess pressure of the tissues for the inert gas helium depicted as a function of ambient pressure.

Even though both nitrogen and helium are inert gases, they have different characteristics. Helium diffuses into and out of the tissue much quicker (shorter saturation half-times). Nonetheless, helium has higher tolerances when it comes to over-saturation (coefficient a is greater and coefficient b is smaller).

BÜHLMANN describes different models for the calculation with inert gases. For calculations with Decotrainer, all of those models published by BÜHLMANN are offered and can be used.

According to BÜHLMANN, the analysis of symptoms following decompression accidents allows to relate physiological tissues to mathematical tissues (so-called compartments). These relations are not unique and overlapping exists.

1 4
Brain
Spinal cord

9 12
Muscles

13 16
Joints
(Ligaments,
cartilage,
bones)

5 11
Skin
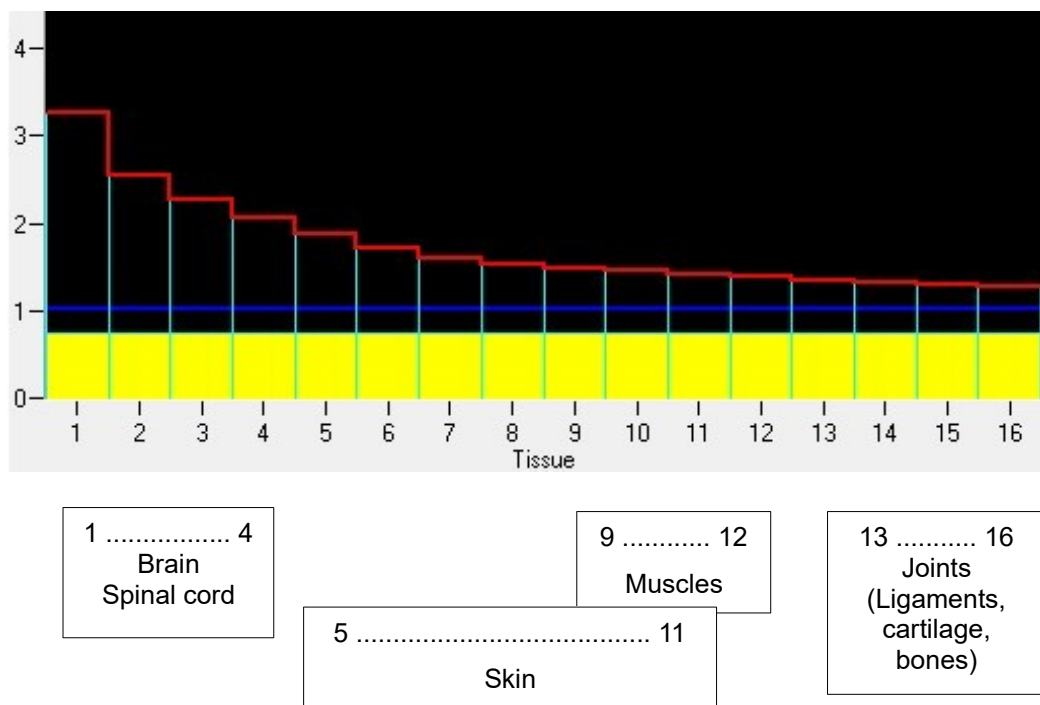
BÜHLMANN describes procedures of how to include additional safety reserves into the calculations.

- An extra of 3 % + 1 m is added to the actual depth. This addition assures that saturation is calculated at a higher than prevailing ambient pressure. Desaturation during decompression stops is performed with correct ambient pressure without an addition for depth.
- As a sensible guideline for risk divers, BÜHLMANN suggests to double the time of the last deco-stop to a minimum of 5 min. Factors to classify as a risk diver in this context are: open Foramen Ovale, dehydration, prevailing illness, obesity/overweight, nicotine addiction, female sex.
- For calculations on the computer, it is recommended to use the model "Bühlmann ZH-L16C" with slightly adjusted coefficients.

The program Decotrainer offers all of the above mentioned options for calculation, including all saturation models published by BÜHLMANN.

2.2. Gradient Factors - Modifications by BAKER

BÜHLMANN's formulas and models were and are the basis of many dives and are thus statistically very safe. Nonetheless, there can be decompression accidents, even if all requirements for the ascent (calculated according to BÜHLMANN) were adhered to. Especially since the use of dive computers is more widely spread, many divers tend to dive "the limit". As a result, it was reflected about how to include an additional safety reserve to BÜHLMANN's calculations.

ERIK C. BAKER developed a concept that has an additional safety reserve to BÜHLMANN's maximal over-saturation tolerances (BAKER 1998a, BAKER 1998b). For this purpose he defines a "gradient factor".
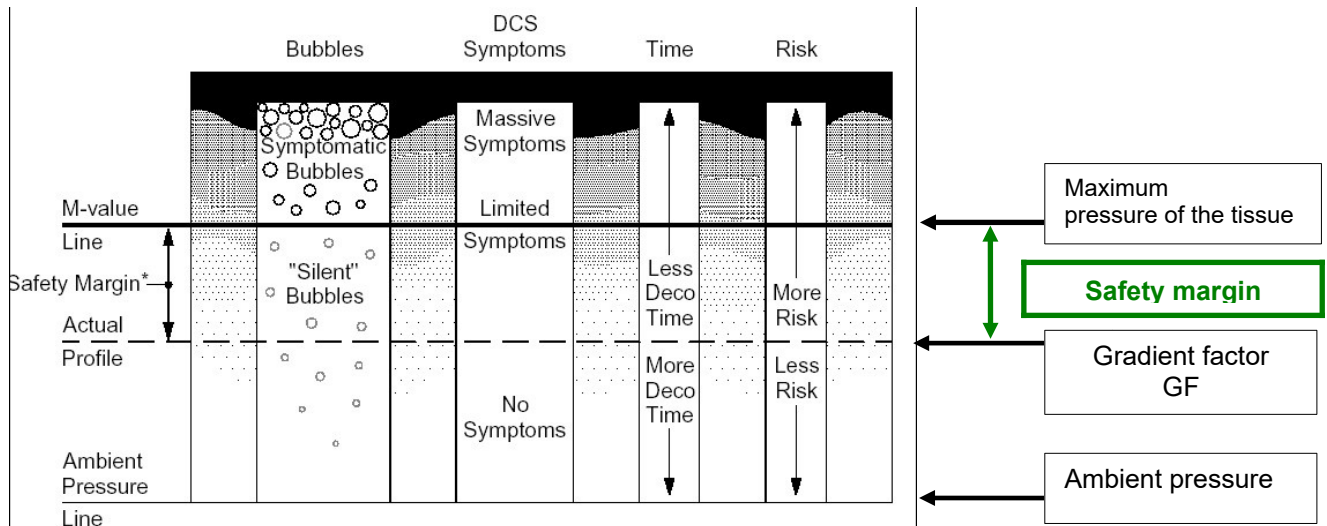
The gradient factor describes to which extent the maximum tolerated excess pressure of the tissues is made use of. Thus, the maximum tolerated excess pressure of the tissues equals (according to BAKER):

$$p_G(max, BAKER) = p(ambience) + GF * [p_G(max, BÜHLMANN) - p(ambience)]$$

where p_G(max, BAKER) = maximum tolerated excess pressure of the tissues according to BAKER, p_G(max, BÜHLMANN) = maximum tolerated excess pressure of the tissues according to BÜHLMANN (see 1.5.1), p(ambience) = ambient pressure. The gradient factor is mainly expressed in %. In this context, GF = 0 % indicates that the ambient pressure must not be exceeded, and GF = 100 % stands for BÜHLMANN's maximum over-saturation pressure. Furthermore, he defines another depth-dependent gradient factor which is calculated by linear interpolation of the actual depth and two preset gradient factors ("gradient factor Lo" = GF Lo and "gradient factor Hi" = GF Hi):

- GF Lo determines the maximum over-saturation and thus mainly the depth of the deepest deco stop. The GF Lo is valid between the start of ascent and first (deepest) deco stop.
- During ascent, between the first (deepest) and the last (shallowest) deco stop, the actual GF is calculated by linear interpolation between GF Lo and GF Hi.
- GF Hi determines the maximum over-saturation at the lowest ambient pressure and thus mainly the duration of the shallowest deco stop. The GF Hi is valid for the last (shallowest) deco stop. At this point, Erik C Baker is not as precise in his papers (BAKER 1998a, BAKER 1998b). His formulas use the last (shallowest) deco stop as a reference, his figures show the surface (depth = 0) as the reference. Decotrainer uses "last deco stop) as the default, as most probably other saturation calculaters do also. Decotrainer offers the option for "surface" from version 4.10. Using standard settings (GF Lo < GF Hi), the option "surface" calculates a little longer decompression times, because the actual GF at the last deco stop is < GF Hi.

The following figure illustrates the calculation of the current gradient factor.
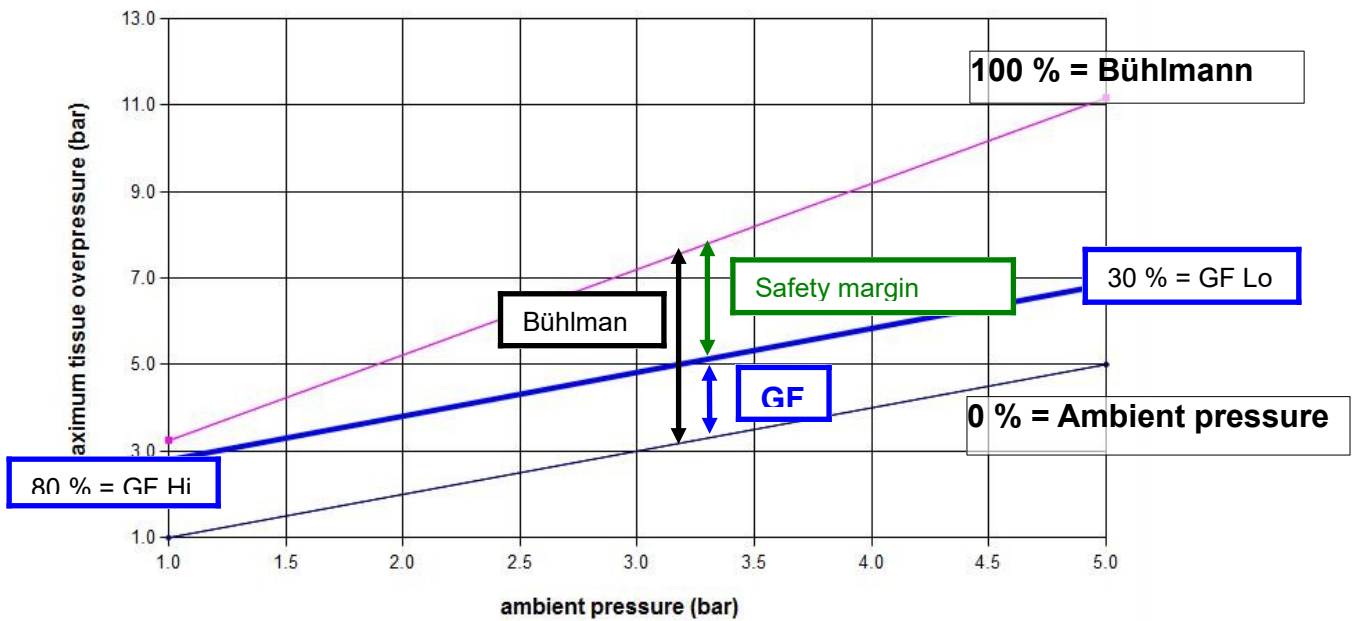
Current gradient factor (central blue line) as a function of prevailing ambient pressure, and both gradient factor Hi and gradient factor Lo. Upper line = BÜHLMANN's maximum tolerated excess pressure of the tissues. Bottom line = ambient pressure. The safety margin is the difference between BÜHLMANN's maximum tolerated over-saturation and a reduced over-saturation including the gradient factor.

The concept of gradient factors has been completely integrated into the program Decotrainer.

2.3. Deep Stops According to PYLE

The names Deep Stop and Pyle Stop both mean the same, namely a deep decompression stop that is set deeper than the first "normal" decompression stop. The first "normal" decompression stop is the deepest stop that is calculated in accord with BÜHLMANN.

RICHARD PYLE is an American biologist who developed his theory on "Deep Stops" when diving to catch fish in Hawaii (PYLE 1996). He dived relatively deep (around 70 m) on air. On these dives, he caught fish and sedated them. To prevent the swim bladders of the fish from blasting, he punctured them during ascent.

He realised that he often felt very tired after these deep dives. He guessed that this was one effect of being saturated with the inert gas nitrogen, and wondered why he felt the effect to different extents on dives with a similar profile. At some point, he saw a relation. He realised that his fatigue was more profound when he didn't catch a fish, and that is was less strong when he had hunted successfully. He correlated his varying condition to the stop at great depth which he took when puncturing the fish. This stop was usually cancelled when he didn't catch anything.

He guessed that the deep stop was better for his health because consequently pressure changes were more gradual on ascent. He created a simple rule for the calculation of deep stops:

- calculate decompression profiles using the adequate software.
- set a deep stop at a depth between seabed and first deco stop. Stay there 2 min to 3 min.
- calculate new decompression profile.
- if the distance between the deep stop and the next normal deco stop is greater than 10 m, add another stop of 2 min to 3 min at half-distance.
- repeat this procedure until the distance to the deepest normal stop is less than 10 m.

Decotrainer allows to integrate an automatically created deep stop.

2.4. Counter Diffusion

The phenomenon that at a constant pressure (= isobaric) one inert gas can diffuse from the breathing air into the tissue, and simultaneously another inert gas can diffuse in the opposite direction out the tissue to the breathing gas is called (isobaric) counter diffusion. Under certain conditions, counter diffusion can become a serious problem when diving (see LAMBERTSEN 1989).

- Surface counter diffusion: A diver takes up the light inert gas helium via her/his skin while she/he breathes a mixture rich in nitrogen. This effect can result in decompression injuries of the skin. When doing a standard technical dive, this should not affect the diver because, as far as heat insulation is concerned, no helium-rich gas is commonly used for the suit. This effect cannot easily be calculated with BÜHLMANN's formulas.
- Depth counter diffusion: A change of the breathing gas can result in counter diffusion between the breathing gas and gas that is dissolved in the tissue. In principle, this effect can be calculated using BÜHLMANN's formulas. Although the saturation of the tissue calculated with counter diffusion generally doesn't enter the range of over-saturation, there are divers suffering of decompression sickness in the field. Especially, there are reports of isolated forms of decompression sickness affecting only the inner ear and the vestibular system (balance). It is called "inner ear decompression sickness" = IEDCS (see e.g. DOOLETTE & MITCHELL 2003).

Gas switch $N_2 \rightarrow$ He
Principally, changing from a nitrogen-rich to a helium-rich breathing gas can result in an isobaric increase of tissue tension. Helium diffuses more quickly into the tissue than nitrogen exits it. However, such a gas switch is fairly uncommon amongst technical divers as deco time goes up.

Gas switch He $\rightarrow N_2$
A gas switch from helium-rich to nitrogen-rich gases is quite common amongst technical divers to shorten decompression time. Due to the "inert gas" characteristics of nitrogen and helium, this gas switch should not trigger any problems with over-saturation. Helium diffuses out of the tissue more quickly than nitrogen enters it. Nonetheless, this type of gas switch can be associated with inner ear decompression sickness. Inner ear decompression sickness seemed to be common for these gas switches at high partial pressures (DOOLETTE & MITCHELL 2003).

To judge and quantify potentially dangerous counter diffusion, Decotrainer offers the following pathway.

- Decotrainer calculates differences in the partial pressure of the tissues and of the breathing gas for the two inert gases helium and nitrogen. If these differences show an unlike sign, there is counter diffusion. The inert gas with the negative difference will diffuse from the breathing gas into the tissue. The inert gas with the positive difference will diffuse out of the tissue to the breathing gas.
- Decotrainer relates the differences in partial pressure to the current maximum tolerated excess pressure of the tissue. A negative difference in partial pressures has to fall below a safety limit value to be judged to be critical.
- The tissue with maximum saturation of inert gases has to resemble the physiological structures of the inner ear. The inner ear is a membranous labyrinth filled with perilymph fluid [Wikipedia]. This definition allows to conclude that the tissue critical to saturation has to be a "membrane" tissue of the numbers 5 to 11 (Ú 1.5.1 Calculation of Saturation and Desaturation by BÜHLMANN).

3.   The Program Decotrainer

3.1.   Overview

Decotrainer is a computer program designed for the calculation and visualisation of saturation and de-saturation processes during different dives. Decotrainer was developed in 2003 based on a simple program that allowed to calculate inert gas saturation according to the BÜHLMANN algorithm. By now, Decotrainer has evolved to become a complex program for the calculation and simulation of technical dives with the following main characteristics:

Versions of the program
- Demo: an exemplary dive, allows for all analyses, free of charge
- Recreational diver: dives on air, no gas switch
- Tec divers: no restrictions

Calculation of saturation and concepts of safety
- Calculation of the saturation with inert gases (N_2 and He) according to BÜHLMANN: All of the 8 BÜHLMANN models, all additional safety margins introduced by BÜHLMANN, also suitable for risk divers
- Gradient factors: GF Lo and GF Hi according to ERIK BAKER
- Deep stops: according to RICHARD PYLE
- Dive analysis: There is an option to analyse dives transferred from dive computers, e.g. by calculating oxygen toxicity using both CNS and OTU models

Supported dive systems
- Open-circuit dive systems (OC, SCUBA)
  - Respiratory minute volume (RMV) during the dive and RMV during deco can be set separately
- Closed-circuit dive systems (CCR = Closed Circuit Rebreather)
  - Calculation of partial pressures based on a simulated breathing cycle
  - Exact calculation of consumption based on a simulated breathing cycle
  - Consideration of changes in p(O2) due to descent on unsuitable diluents and/or due to emergency ascents, e.g. oxygen-off situation
  - Change of oxygen partial pressure set points
  - Automatic change of set points on descent and on ascent
  - Bail out
- Semi-Closed Constant-Flow dive systems (SCR = Semi Closed Circuit Rebreather) of the type "Dräger Dolphin"
  - Calculation of partial pressures based on simulated breathing cycles
  - Exact calculation of consumption
- Semi-Closed dive systems with passive addition (pSCR = passive addition Semi Closed Circuit Rebreather) of the type "Halcyon RB80″
  - Calculation of partial pressures based on simulated breathing cycles
  - Exact calculation of consumption
- Dive system interchangeable during the dive

Gases and gas switches
- Air, Nitrox, Trimix, Heliox, Oxygen.
  User editable gas switches during descent, bottom time and ascent
- Gasmixer with calculation of END (Equivalent Nitrogen Depth), MOD (Maximum Operation Depth) and MinOD (Minimum Operation Depth)
- Best Mix für certain depth
- Gas consumption for each gas, also for CCR, SCR and pSCR systems
- Gas consumption for ascent (e.g. Bail-Out)

Descent and ascent plan
- variable velocities of descent

- variable velocities of ascent
- adjustable depth for deco
- bubble check
- gas switch (maximum of 6)
- proposal for optimal gas switches
- set point for the change of $p(O_2)$

Mountain lake etc.
- Mountain lake: free choice of air pressure, also to be calculated based on altitude above mean sea level
- Depths can be calibrated for fresh and salt water. Consideration of temperature and salt content
- Calculation of no-flight time
- Calculation of repetition dives

Graphic data output
- all relevant parameters are depicted at all times:
  time (runtime), depth, END (equivalent Nitrogen depth), partial pressure of oxygen, Oxygen exposure in CNS % and OTU, GF, absolute pressure, composition of the breathing gas, absolute saturation and relative saturation in relation to the surface, parameters of counter diffusion
- saturation can be viewed and analysed for every single point of the dive
- animated display of calculation processes for the dive
- regarding saturation with helium and nitrogen all tissues coefficients can be depicted
- runtime table, can be adjusted by the user
- report output with print preview, even with a graph of the dive

Input and output of data
- Input and output with all settings and dive data in Decotrainers own data format
- Import and export of data in the UDDF format
- Import of data in the Shearwater CSV format
- Export of data in decotrainer CSV data format

The program...
- exists in two language versions: English and German
- comes with a comprehensive and detailed manual
- is free of viruses, spyware or other types of malware. This I can guarantee as I have written the code to the program myself and I know what is "in it".
- guaranties unlimited updates free of charge for licensed users

3.2. Installation, Un-locking and Program Start

System Requirements

Operating System:	Windows Operating System from Win95 (recommended Windows 10), also 64 bit operating systems.
User:	has to have administrator rights.
Screen Size:	1280 Pixel x 1024 Pixel or more recommended. Runs on smaller screens, e.g. 10" notebooks, with restrictions in the display of all windows.
Processor:	"fast" processor recommended.
Hard drive space:	not critical.

Installation and Activation

The program Decotrainer is only to be used with an acquired licence, and it has been coded with protection against copying. This protection prevents that the program can be used without having paid the licence fee. The protection is based on a "key" that is related to a certain user. Decotrainer allows for two different types of keys.

- **Software key:** This key resembles a password that only fits to a certain computer ID. The computer ID is determined by Decotrainer, once the program is installed on the user's computer. The user informs me about her/his computer ID and I supply the correct software key. Every software key is linked to a licence fee that has to be paid.

- **Hardware key:** This is a USB dongle, a small gadget that looks like a USB stick. I post the USB dongle to the user in the mail. The user connects the dongle to one of the USB ports of her/his computer. Decotrainer recognises the connection to the dongle and activates automatically. In this way, Decotrainer runs unrestrictedly on all computers. The USB dongle has to continuously stay connected to a USB port, as queries during the program sequence are made in several places and at different points in time. The hardware key only exists for the Tec version of Decotrainer. Minimum condition for the use of the dongle is a valid Decotrainer licence.

Download

You can download the latest version of Decotrainer from the website www.decotrainer.de.

Installation

Decotrainer_Setup   Open the installation program. It is recommended to accept the original standard settings (e.g. for the program folder).

Activation using a software key

⭐   Decotrainer has to be installed.

⭐   Start Decotrainer.

⭐   There will be a pop-up window "Safety and warning note / application instruction". The user **has to** accept otherwise the program will not run. Thus, click "I accept". Subsequently, another window will appear with the remark that Deotrainer only runs as a Demo version. The Demo version only allows to calculate a pre-determined dive. Close the window by clicking "OK". *(You can now calculate the Demo dive. First choose "New dive", then accept the dive by clicking "Dive" and finally press "Ascent".)*

⭐   Main menu "Extras" and "Activation".

⭐ The following window shows an exemplary "Computer ID". I need this number to calculate the corresponding unlocking key. The easiest way to transfer this number is via eMail by pressing the bottom "Ask by eMail for username and key". The pre-installed mailing program will open automatically. Of course, you can also give me a call.

⭐ I calculate the unlocking key and will send a return eMail containing both the key and the corresponding user name.

⭐ The user has to enter both received unlocking key and user name. For this purpose, start Decotrainer once again. Main menu Ú "Extras" and "Activation". Fill in the empty fields for "User name" and "Unlocking key". Or copy and paste the key and user name from the eMail to the fields. Finally, press "OK" and close the window.

⭐ Now the program is activated and fully operational. Activation has to be performed for every computer on which the program is installed. In case of an up-date there doesn't have to be another activation on the same computer.

⭐ I recommend to record and save all activation data.

Activation using a hardware key

⭐ Decotrainer has to be installed. Decotrainer doesn't have to be activated via a software key.

⭐ Connect the hardware key (= USB dongle) to a free USB port.

⭐ Start Decotrainer. The hardware key has to stay continuously connected while the program is running.

Program Start

After starting the program the following form will appear.

Safety and warning note / application instruction

This computer program was written for visualization of saturation processes during diving. It was written as a tool for teaching and understanding saturation. This program was not primarliy written for planning of real dives. If you want to do real dives using profiles calculated with this program, you must keep in mind the following.

WARNING ADVICE

Dives, especially dives into great depths and/or dives using multiple gas mixes, are potentially very dangerous. Technical diving requires profound knowledge and practical experiences and therefore a good training. Wrong planning of the dive may cost your life. This program cannot substitute your own knowledge and experience. The program requires your own knowledge and experience.

This program was written and tested by me very carefully. Because I am only a human beeing, the program may contain errors. And the program may produce erroneous data by erroneous handling.

APPLICATION INSTRUCTION

The user has to check the validity and conclusiveness of the calculated data. My suggestion is to check the calculated data using another separate computer program. The user has to wear a suitable dive computer during the dive to counter check. This REDUNDANCY is of of vital significance in technical diving.

Your life depends on the correct decompression plan.
Only you are responsible for your dive !

○ deutsch   ● english

✔ I accept   ✖ I do not accept

The user has to accept warning advice and application instructions, otherwise the program Decotrainer will not run.

Both advice and instructions are supposed to remind the user every time again that Decotrainer is a program for the visualisation of inert gas saturation processes when calculating dives. As soon as the user wants to put the calculated dives into action (dive the plan), she/he has to be aware of the risks. The author of Decotrainer cannot take the risk assessment off the user's hands.

3.3. Main Screen and Operation

After the safety advice has been closed, the main screen of Decotrainer appears. See the following figure for an exemplary screen display during the calculation of a dive.
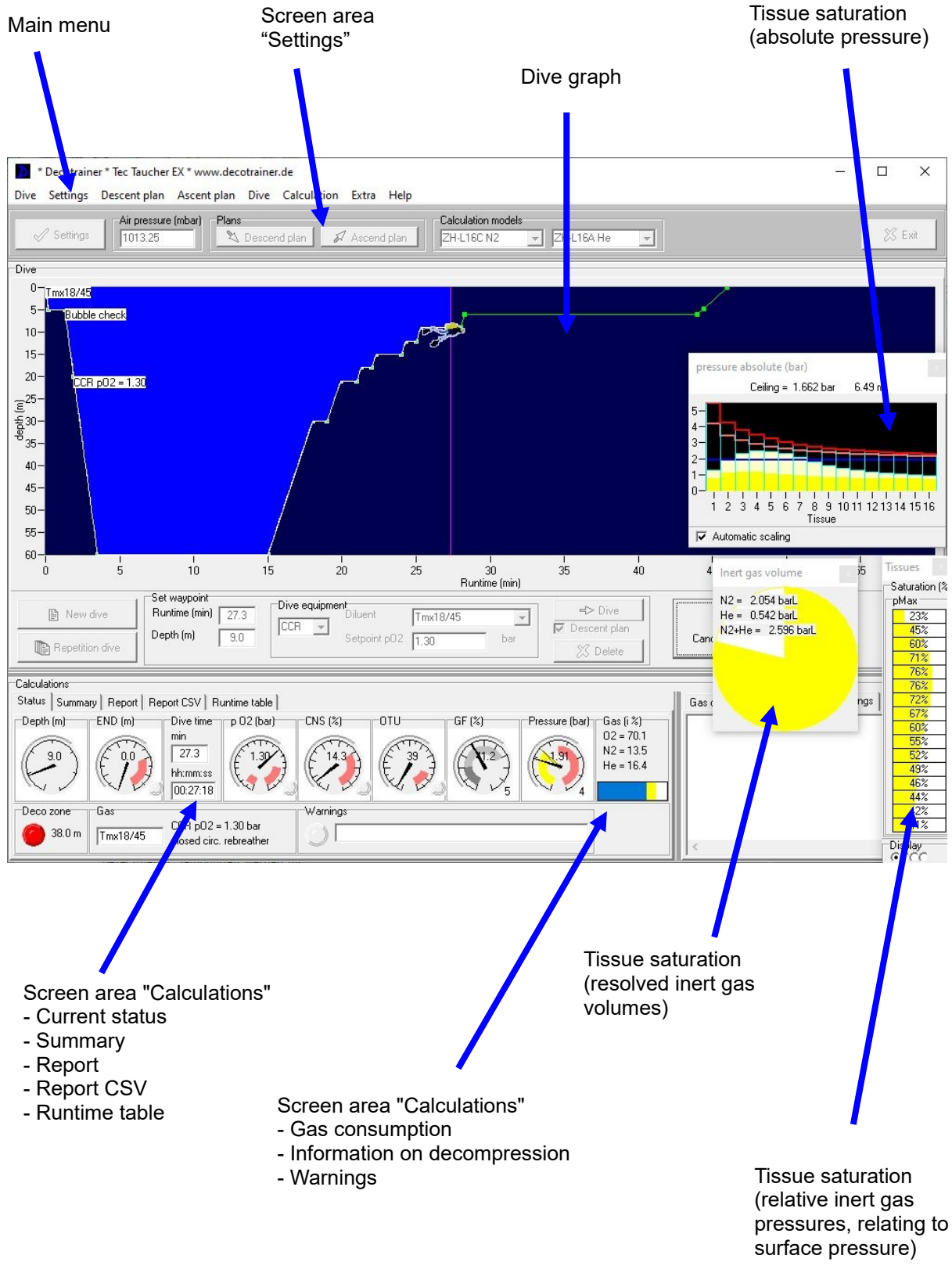
Main menu

Screen area "Settings"

Dive graph

Tissue saturation (absolute pressure)

Screen area "Calculations"
- Current status
- Summary
- Report
- Report CSV
- Runtime table

Screen area "Calculations"
- Gas consumption
- Information on decompression
- Warnings

Tissue saturation (resolved inert gas volumes)

Tissue saturation (relative inert gas pressures, relating to surface pressure)

3.4. Main Menu

3.4.1. Dive
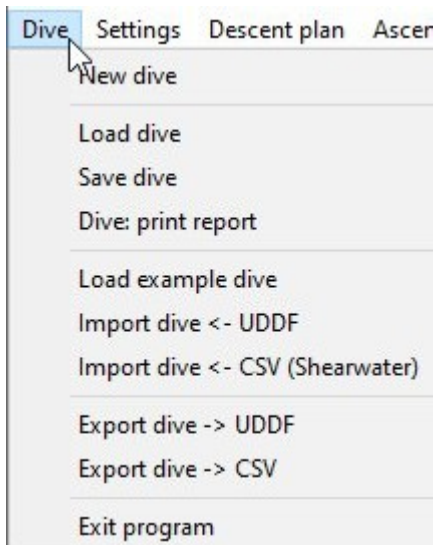
New Dive: Decotrainer initialises all data according to the settings for a new dive. Saturation is reset to a saturation with nitrogen as the single inert gas under the chosen air pressure. When initialising a mountain lake dive this allows for a complete adaption to the elevation of the mountain lake. You can access the same procedure when pressing the button "New dive" in the area of the screen that reads "Set waypoint".
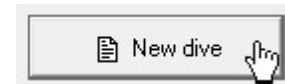
Load dive: A dive in the data format of Decotrainer is loaded. If there is a comment, it will appear as well. The following form "Analyse dive" enables the user to choose between three possible actions

(1) No further action. The dive can be viewed, e.g. in the format of a runtime table.

(2) Analyse dive. The end of the bottom time can be extracted from the window. This time can be adjusted (and reset) by the user. All safety settings are set back (no BÜHLMANN safety reserves, no gradient factors). The loaded dive is calculated from the beginning to the end. Gradient factors are determined using both dive data and calculated saturations.

(3) Re-calculate dive using actual ascent plan. The dive is accepted and calculated from the beginning to the end of the bottom time without any changes. Starting from the end of the bottom time, the dive is recalculated according to the current ascent plan.

Save dive: The current dive is saved in the Decotrainer data format. This contains all settings and dive data (waypoints). All of Decotrainer's data files come with their own text-based ascii data format and have the extension ".DEC".

Print: dive report: The program creates a printable report including a visualisation of the dive as well as a summary. The same procedure can be initiated by choosing "Runtime table" in the screen area of "Calculations" and pressing "Print".
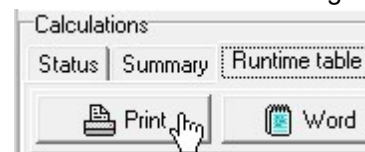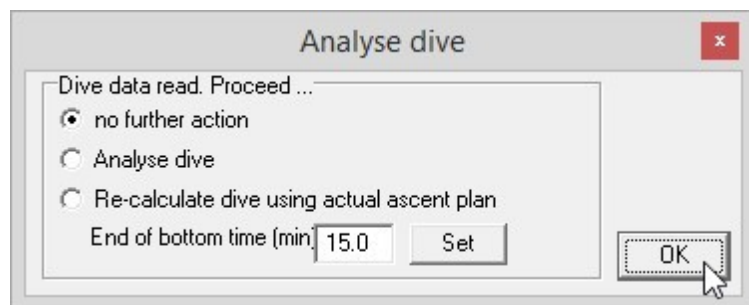
Load example dive: One of several example dives is load. The example dives are stored in a sub folder of the decotrainer program folder.

Import dive <- UDDF: A dive is imported in the UDDF data format. UDDF (Universal Dive Data Format) is a universal text-based ascii data format for the exchange of dive data between different software products. The current version is UDDF 3.1.0 (REITH 2010 and SCHRÖDER & REITH 2012). See chapter ➔ 3.4.6. Calculation" and ➔ 3.10.3. Import Dive.
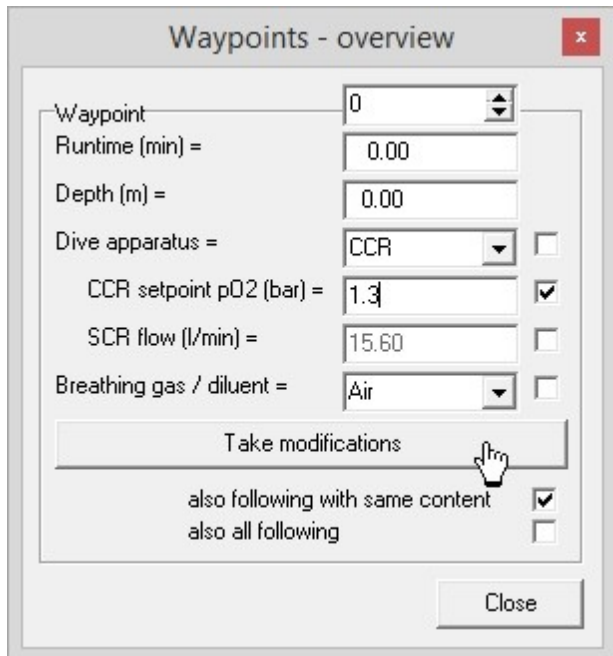
When the import is complete, a window showing an overview on all waypoints will appear. Here, the user can make changes to the waypoints (➔ 3.10.3. Import Dive).

Import dive <- CSV (Shearwater): A dive is imported in the Shearwater CSV data format. CSV (Comma Separated Value) is a text-based ascii data format using commas as a separation between columns. In the same way as by Shearwater (SHEARWATER 2011), the producer of dive computers, all columns are pre-determined. The new window containing both an overview of the waypoints and all options for changes will appear for the user at this point as well.

```
Time,Depth,FirstStopDepth,TTS Mins,Average PPO2,Fraction O2,Fraction He,First Stop Time,Current NDL,System
Byte,Current Circuit,Water Temp,Error Acks,Error Flags
10,8.4,0,1,0.78,0.05,0.75,0,99,0,0,26,0,0
20,11.7,0,1,0.84,0.05,0.75,0,99,0,0,26,0,0
```

Here one example where 1st and 2nd row = text with explanations, 3rd and 4th row = first two rows of data.

Export dive Ú UDDF: The current dive is exported in the UDDF data format (REITH 2010 and SCHRÖDER & REITH 2012).

Export dive Ú CSV: The current dive is exported as a comma-separated text file (CSV = comma separated value). The available data colums are:

```
" Runtime(min),Tiefe(m),Druck(bar),Gas,System,pO2(bar),CNS(%),O2(%),N2(%),He(%),rel. Sättigung Gewebe[1,..,16]

  0.0, 0.00, 1.013,Luft,CCR,0.95, 0.0,100.00, 0.00,
0.00,0.230,0.294,0.332,0.366,0.402,0.440,0.468,0.489,0.504,0.518,0.530,0.543,0.555,0.568,0.576,0.586
```

Exit program: The program Decotrainer will be closed. If an unsaved dive should still be open, the user will be advised to save the current dive.

3.4.2. Settings
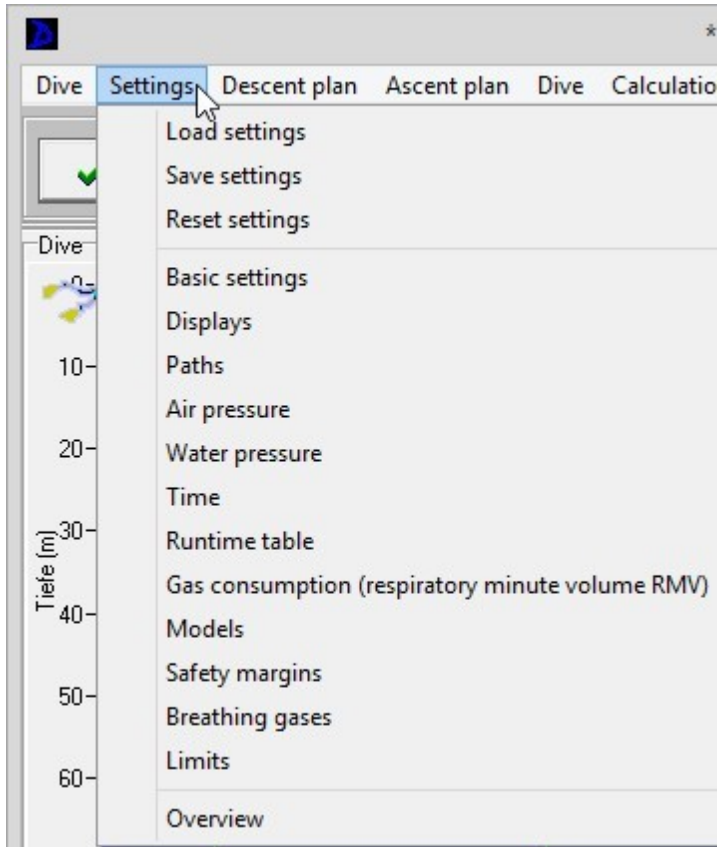
All settings can be accessed both via the main menu and via the button "Settings" in the screen area "Settings".

Load settings: All settings contained in the file "Decotrainer.INI" of the Decotrainer program folder are loaded and thus will over-write any current setting.

Save settings: All current settings are saved to the file "Decotrainer.INI" of the Decotrainer program folder. As soon as the user saves a dive in the Decotrainer data format, all settings are automatically saved. In this case, all current settings are contained both in the Decotrainer dive data file and in the file "Decotrainer.INI".

Reset settings: All current settings are reset to standard values.

Basic Settings
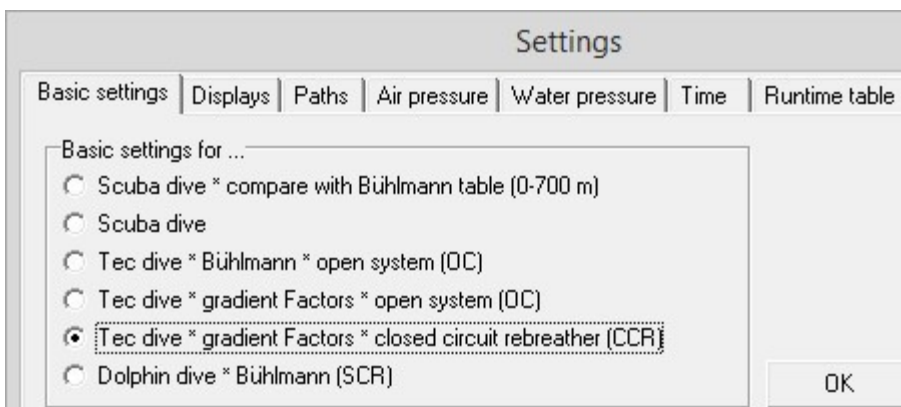
Decotrainer allows for different basic settings. Depending on the choice of the user, plans for descent and ascent, safety settings, time management, choice of model, preset dive system or displays (to mention some examples) are set to the corresponding pre-settings.

Displays
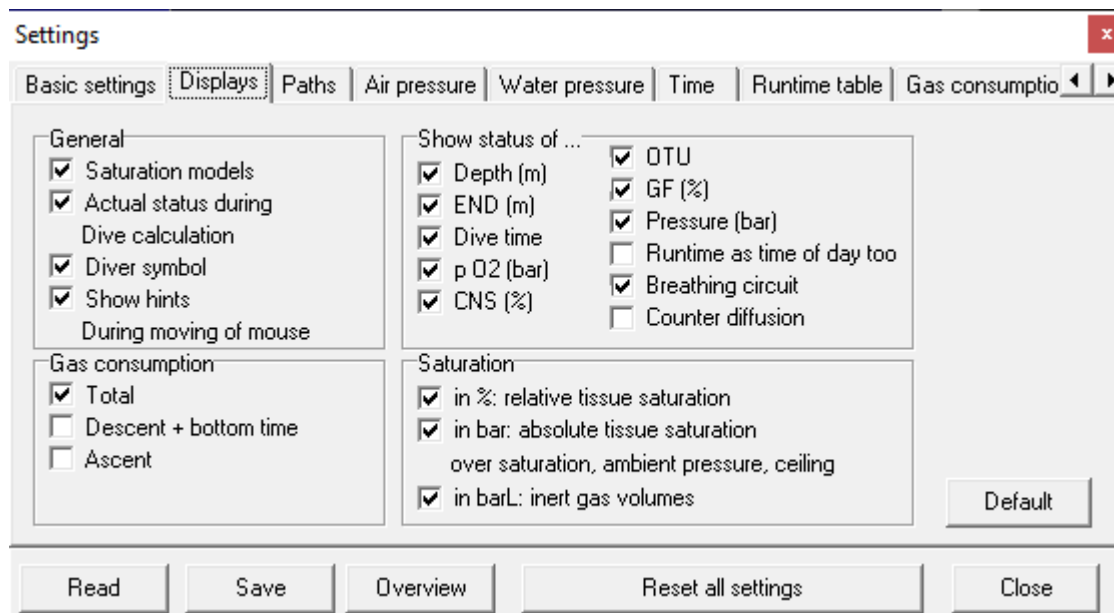
Here the user can choose which displays she/he prefers and wishes to select. Some of the displays are predefined and cannot be "de-selected".

Paths
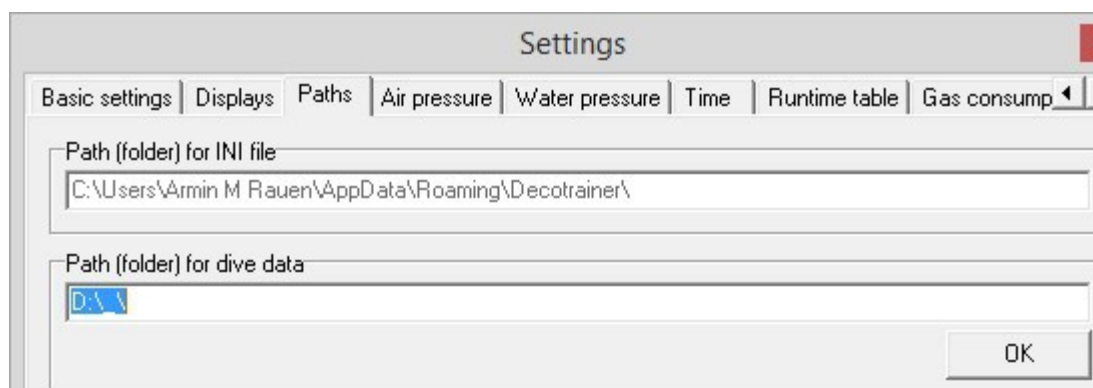
The INI file contains all settings specific to Decotrainer. The file is saved to Window's "User Application" folder (folder = "path").

The folder to which the user saves her/his dives can be customised by the user. After loading a Decotrainer dive, the folder will automatically be set to the current folder.

Air Pressure

Here, the air pressure at the surface can be set. By changing the settings for "Height above S.L.", the user can have the air pressure calculated according to topographic height. Decotrainer uses the barometric altitude formula for this calculation (see ➔ 1.2. Pressure). The button "Standard atmosphere" sets the air pressure to the standard value of 1013.25 mbar.

Water Pressure

This form serves to set the calibration function dCal (= pressure as a function of depth, ➔ 1.2. Pressure). The standard value equals 10.000 m per bar. The user can enter a different value and confirm with "OK". In the area "Water depth from calibrated pressure measurement" the user can have the current density of water calculated for different temperatures and salt contents. For more information on temperature-dependant density see GERTHSEN *et al.* (1977). Salt content is included via the weight portion in %. Decotrainer derives the new calibration constant in m per bar from the water's density.

Time
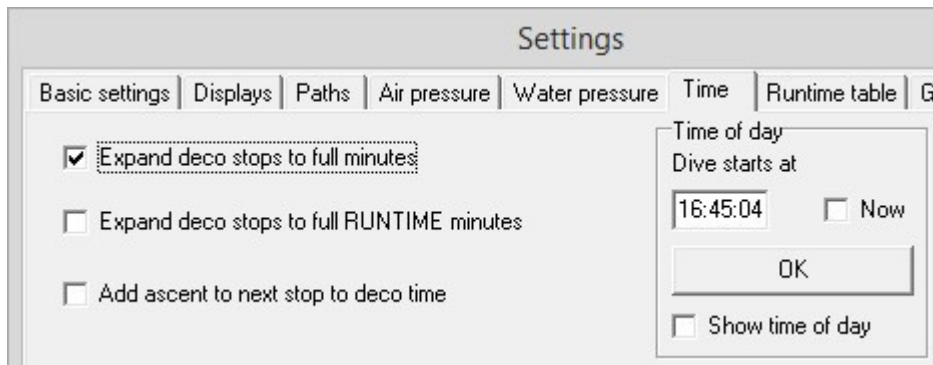
Expand deco stops to full minutes: Decotrainer bases its calculations of the time to be spend at a deco stop on the current state of saturation and on current maximum allowed over-saturation tolerances. As soon as the calculated minimum depth (= Ceiling) equals the depth of the following deco stop, the conditions for the current deco stop are fulfilled. If this box is ticked, the deco stop is extended to the <u>next full minute</u>. This complies with the standard setting for the calculation of decompression tables based on air according to BÜHLMANN (2002).

Expand deco stops to full RUNTIME minutes: To fulfil the conditions for finishing ones "duty of decompression", generally, the same as described in the paragraph above holds true. If this box is ticked, the deco stop is extended to the <u>next higher full runtime minute</u>. This complies with the standard setting for the different "Tec dives" settings.

Add ascent to next stop to deco time: This box is ticked for the standard setting "Recreational diver - comparison with BÜHLMANN table", as BÜHLMANN (2002) used this way to calculate his deco tables.

Time of day: Option to set a start time in the time format "hh:mm:ss". The current time is calculated from start time + current runtime and can be displayed in the screen area "Status" if requested.

Runtime Table
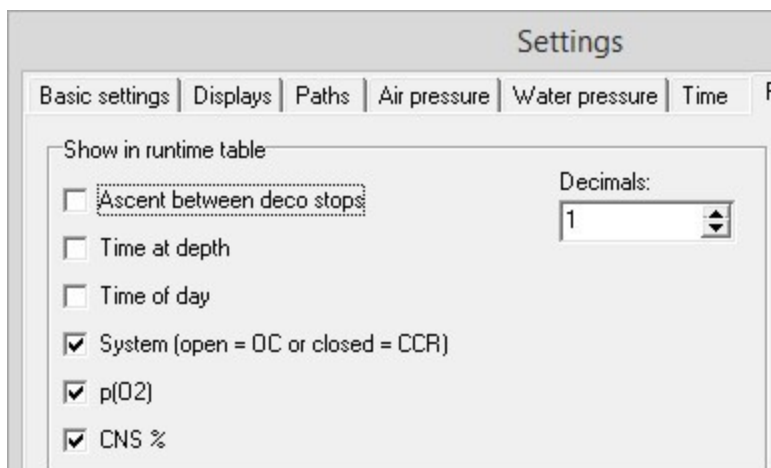
The display of the runtime table can be adjusted by the user. The runtime table is accessible via the tabulator "Runtime table" in the screen area "Calculations". There, adjustments can be activated as well.
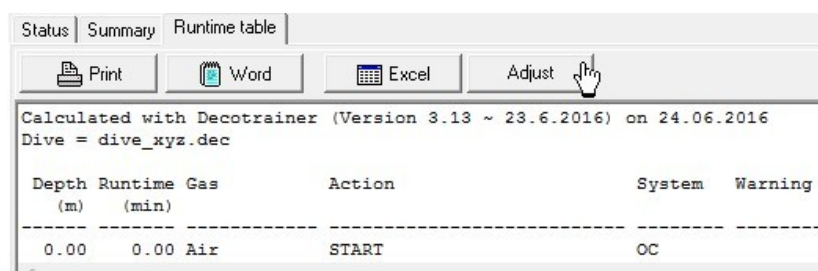
Gas Consumption

All settings that influence gas consumption are summarised here.

In the **modus "OC"** (diving with an open circuit system) the respiratory minute volume (RMV) can be displayed separately - for the dive and for the decompression phase.

In the **modus "CCR"** (systems with a closed breathing circuit) parameters are set which Decotrainer utilises to simulate the breathing circuit. Thus, calculations can be simulated realistically, e.g. "Oxygen Off" situations during ascent.

In the **modus "SCR"** (system with a semi-open breathing circuit of the type Dolphin) parameters are set to simulate the breathing circuit as close to reality as possible.

The **modus "pSCR"** (system with a semi-open breathing circuit with passive addition of gas of the type Halcyon RB80) also parameters simulate the breathing circuit.

For the diving system Halcyon RB80 see:
https://en.wikipedia.org/wiki/Halcyon_RB80

When calculating partial pressures of breathing gases, the pressure of the water vapour in the alveoli of the lungs (= partial pressure of water vapour of surrounding air) can also be taken into account. When choosing this option, ambient pressure is reduced by the partial pressure of the water vapour, and only then partial pressures of all breathing gases are calculated. This option is recommended by BÜHLMANN (2002), and it was used to calculate his tables.

If this option is activated, Decotrainer automatically calculates a stop of an adequate and corresponding duration at a constant depth, following an automatic gas switch (descent and ascent).

Models

The user can choose a model from the list for the calculation of inert gas saturation. The list contains all models published by BÜHLMANN (2002). The two models that were chosen in the example, are the two models recommended for computer calculations (BÜHLMANN 2002).

Safety Margins

Here, one can access all options that concern settings with a safety context. This includes all calculation options that increase safety when calculating saturation. Decotrainer allows for three different concepts, these can be used alone or in combination.

BÜHLMANN: All settings that were published by BÜHLMANN (2002) are realised (see ➔ 1.5.1 Calculation of Saturation and Desaturation by BÜHLMANN)

BAKER GF: Gradient factors according to ERIK C. BAKER (1998a, 1998b). See ➔ 2.2. All changes have to be confirmed by clicking "OK".
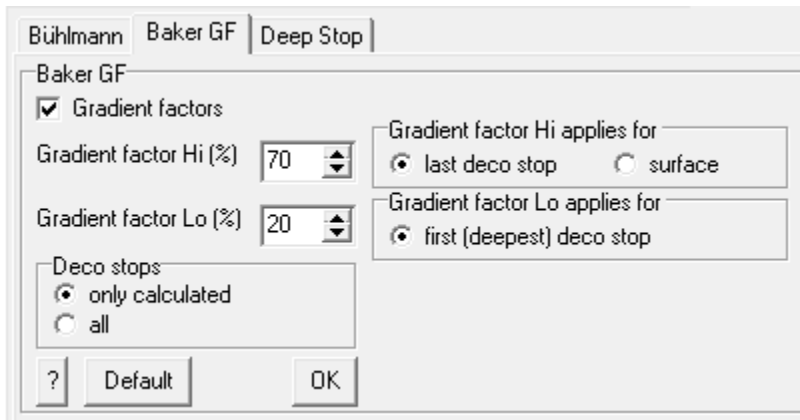
The GF Lo is valid for the first (deepest) deco stop. The GF Hi applies as default for the last (shallowest) deco stop.

Erik C. Baker uses the first (deepest) and last (shallowest) deco stops as the references for calculation the actual GF by linear interopolation (see the original papers ERIK C. BAKER (1998a, 1998b)). However, the figures and formulas in these papers are not as precise. The figures indicate also the surface (depth = 0) as a reference for the GF Hi.

The user may choose between these 2 options as the reference for the GF Hi. The setting "last deco stop" is the default and leeds to little shorter deco times at the last (shallowest) stop. The setting "sirface" calculates a little longer last (shallowest) deco stop.

The choice "only calculated" in the box "Deco stops" implies that Decotrainer strictly bases its calculations on the formulas. Consequently, the distance to the following closest deco stop can be greater than the usual 3 m.

The choice "all" in the box "Deco stops": The user has to choose the option "all", if she/he chooses to avoid the above and instead wants to adhere to stopping every three metres beginning from the deepest deco stop. Decotrainer then calculates a stop although there is no obligation for deco.

Deep stop (= PYLE stop): according to RICHARD PYLE (PYLE 1996), see ➔ 2.3.
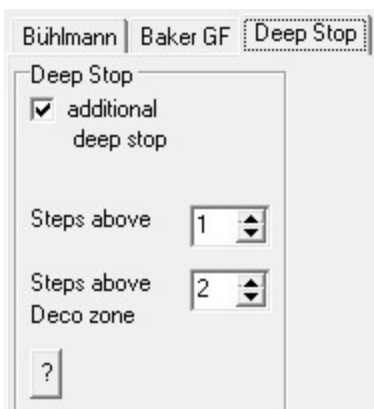
Decotrainer can calculate a deep stop where the user decides on the duration of the deep stop as well as on the distance above the deco zone. In this context, one "step" is the distance between two deco stops (usually 3 m). The deco zone during ascent begins as soon as the first tissue shows a saturation that is greater than the current ambient pressure. Only from this point in time it makes sense to add a decompression stop for desaturation.

Breathing Gases
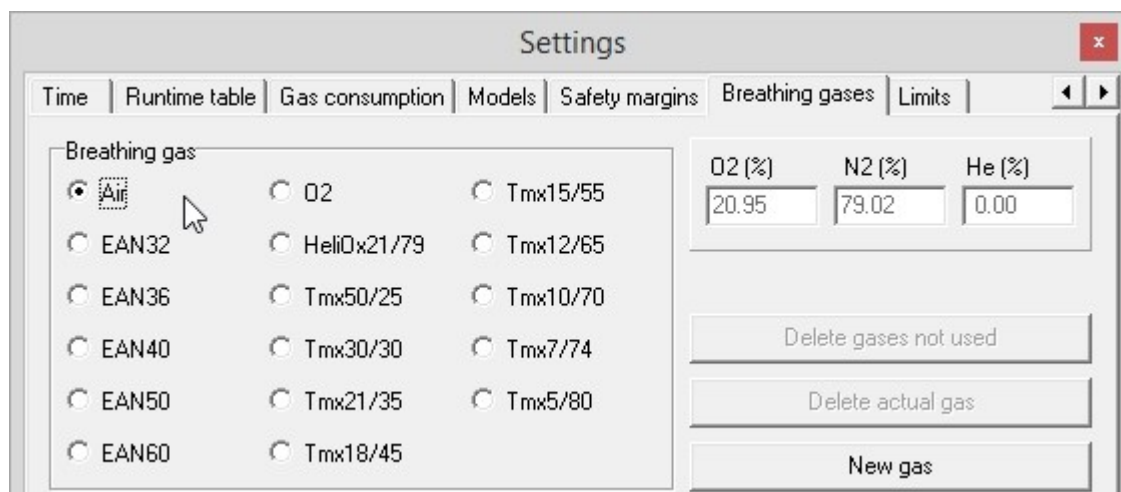
In this area the user can access Decotrainer's internal gas management. All available breathing gases are displayed and are listed for the user's choice. The gases displayed in the example are pre-set in Decotrainer and can neither be changed nor deleted by the user.

The user can create a new gas. After finishing this action the window "Gas Calculator" (➔ 3.4.7. Extra - Gas Calculator) opens where the new gas can be created, e.g. as Best Mix for the given operating depth. The user can also delete a selected gas. The user can automatically delete all gases that are not used. The latter is an useful option when a lot of un-used gases render the list long and confusing.

Limits
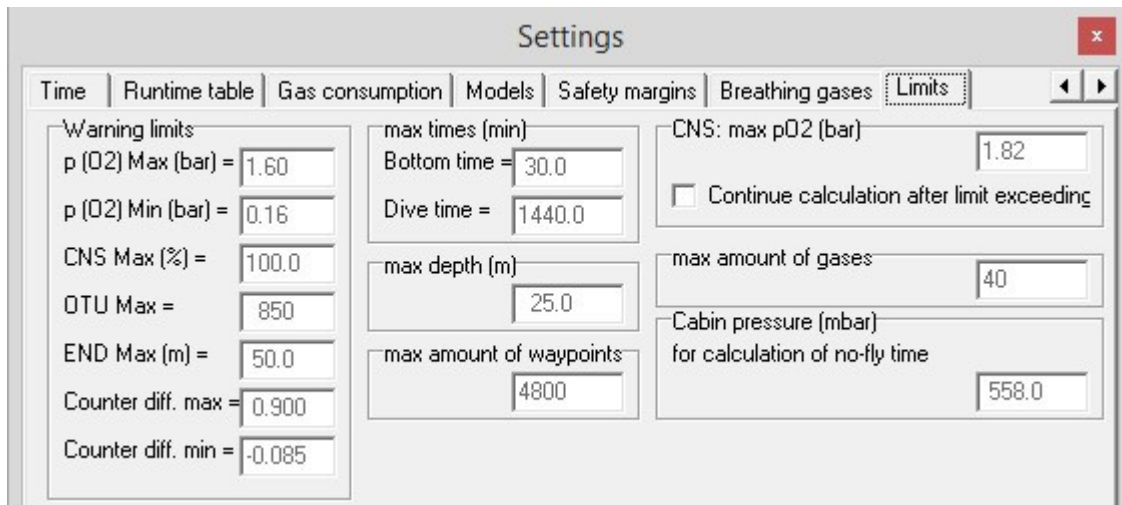
Here, all limiting values relevant for calculations and for warning limits are displayed. All limiting values are preset and cannot be changed by the user.

Box "Warning limits": The values for p(O₂) max, p(O₂) min, CNS max and OTU max indicate the limiting values for oxygen exposure (➔ 1.4.1 Oxygen). The value END max indicates the maximum nitrogen-equivalent narcotic depth (➔ 1.4.2 Nitrogen). The values for counter diff. max and counter diff. min indicate the upper and the lower warning limit for critical counter diffusion (➔ 2.4. Counter Diffusion).

In Decotrainer, all other limiting values are used internally for calculations.
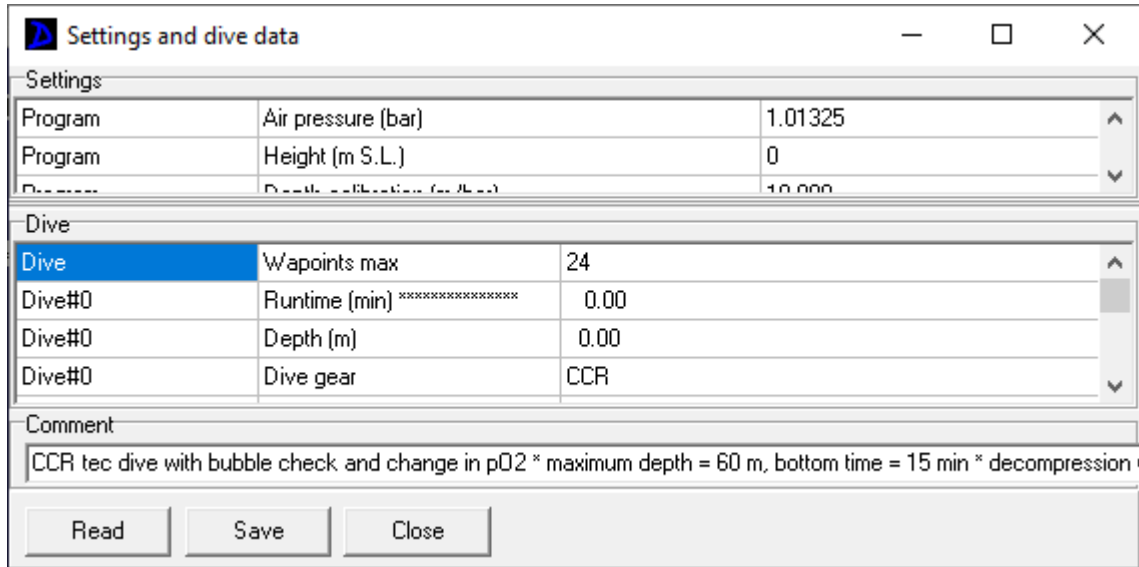
The maximum oxygen partial pressure to calculate CNS percentages according to the NOAA table is indicated. In the standard setting, exceeding this limiting value results in the cancellation of the calculation.

A cancellation can be avoided by agreeing to the checkbox "Continue calculation after limit exceeding". In this case, there will be a warning message and Decotrainer will continue calculating with extrapolated CNS values. (➔ 1.4.1 Oxygen). These extrapolated values are not backed scientifically, and thus

unrealistic and should only be seen as rough reference values. Decotrainer informs about the latter in the course of the calculations.
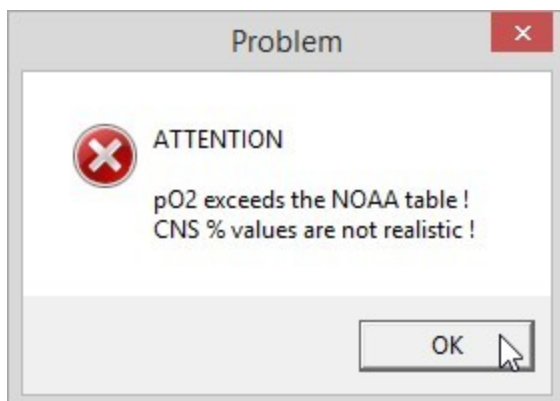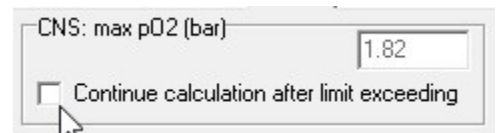
Overview

An overview on all current settings and all current dive data. As in the main menu, dives can be read and saved with all settings via the buttons "Read" and "Save". The field "Comments" allows to enter and save a comment. The Asterisk symbol "*" serves to separate lines if necessary.

3.4.3. Descent Plan

The user can choose between different options to automatically calculate the descent. The automatic setting will only work, if there is a tick in the box for "Descent plan". If this is the case, the checkbox "Descent Plan" in the main form, where all dive data is entered, is also active.
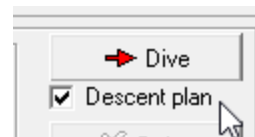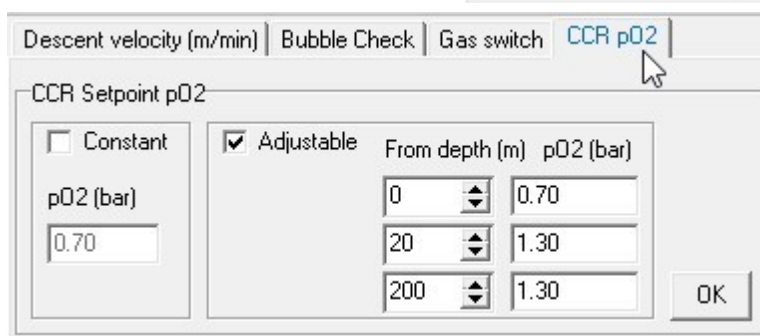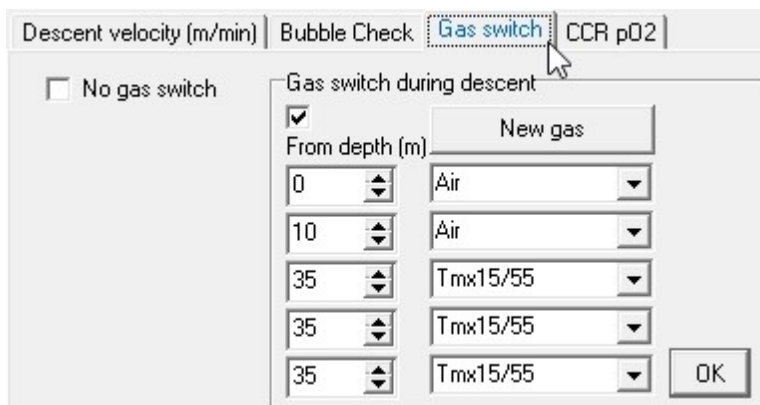
Descent velocity can be held constant or be adjusted as a function of depth. Changes have to be confirmed with "OK".
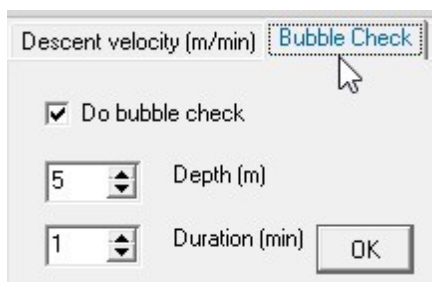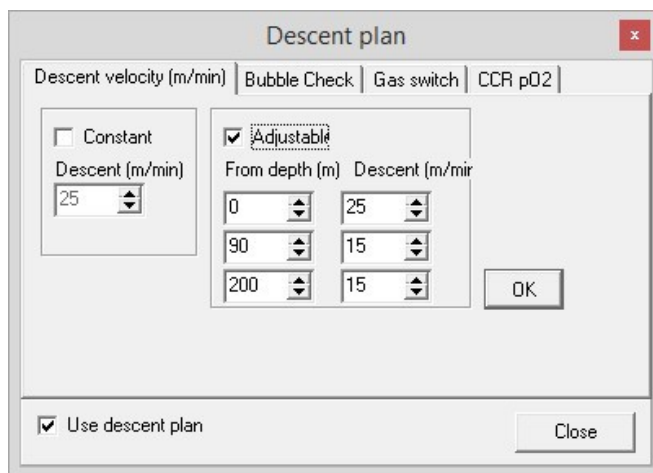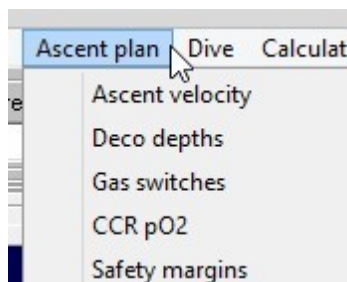
Bubble check at the beginning of the descent. Changes have to be confirmed with "OK".

Gas switch during descent. If no suitable gas appears in the list, the user can define a new breathing gas and add it to the list. Changes have to be confirmed.
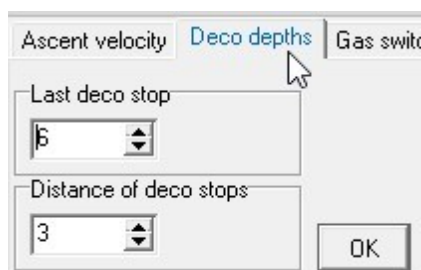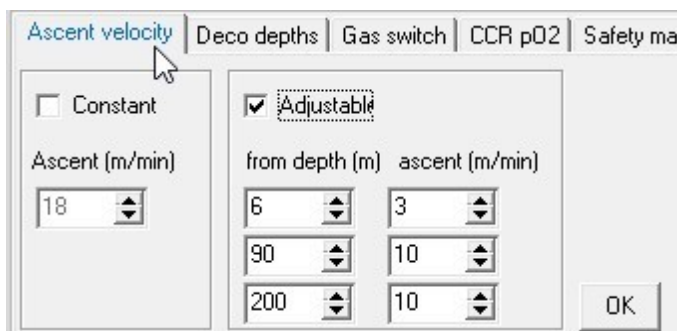
Setpoint O_2 change during descent. Changes have to be confirmed.

3.4.4. Ascent Plan

Here, the user can choose between options for automated calculations of the ascent.

Ascent velocity can be held constant or be adjusted as a function of depth. Changes have to be confirmed.

Deco depths are levels of depth used for decompression calculations. The last deco stop is the most shallow deco stop. Based on this depth, all depths for other deco stops are defined by the distance of the deco levels. Changes have to be confirmed.

Gas switch during ascent. If no suitable gas appears in the list, the user can define a new breathing gas and add it to the list. Changes have to be confirmed.

"Suggest": The user can have the program calculate a list of suitable gases for the ascent automatically. The following form appears.
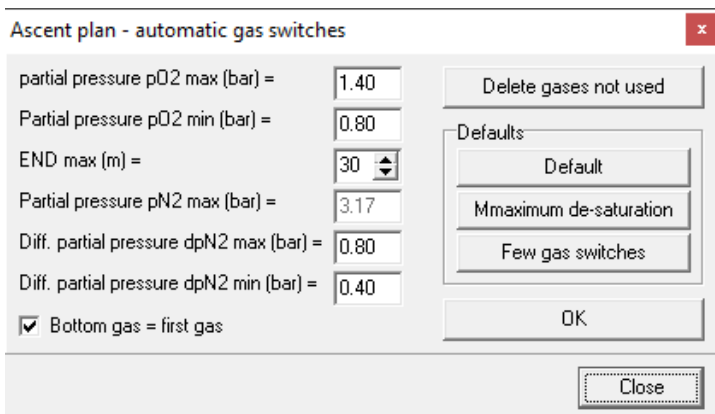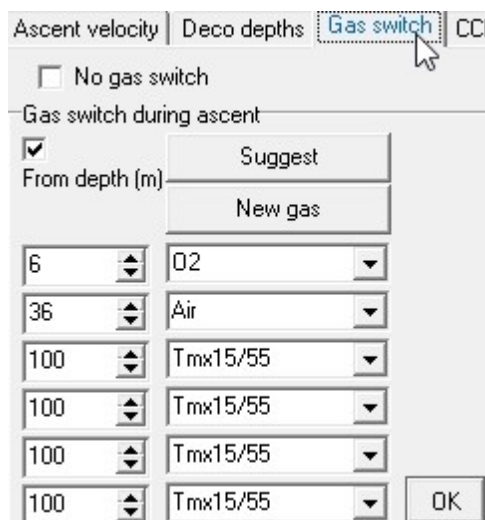
Automatic gas switch during ascent

Based on the displayed limiting values for partial pressure, Decotrainer calculates an optimised list of gases for the ascent. During the optimisation process Decotrainer weighs up two factors:

- Minimisation of counter diffusion of inert gases
- Maximisation of desaturation of inert gases

When defining a new breathing gas, Decotrainer proceeds as follows:

- The percentage of oxygen is determined by the maximum partial pressure of oxygen at a given depth.
- The percentage of nitrogen is calculated from the partial pressure of nitrogen of the last breathing gas at the given depth plus the maximum difference of partial pressures. The maximal difference of N_2 partial pressures, which can be adjusted by the user, limits counter diffusion of inert gases during the decompression phase. Dependent on current depth, the maximal difference of N_2 partial pressures is linearly interpolated between the two given values.
- The percentage of helium is the difference to 100 %.
- The change to a new gas is initiated by reaching the minimum O_2 partial pressure.

The user can delete unused gases of the list and choose between different standard settings. Changes have to be confirmed with "OK".

Gas breaks during the last deco stop. This option aims to avoid damage to the body caused by breathing oxygen under increased partial pressure. It only makes sense to choose this option, if there is a longer decompression with pure oxygen or EAN 80 on the last deco level. The breathing of oxygen can be split up in certain intervals for a certain duration by breathing a different gas with a low percentage of oxygen (e.g. air). Changes have to be confirmed.
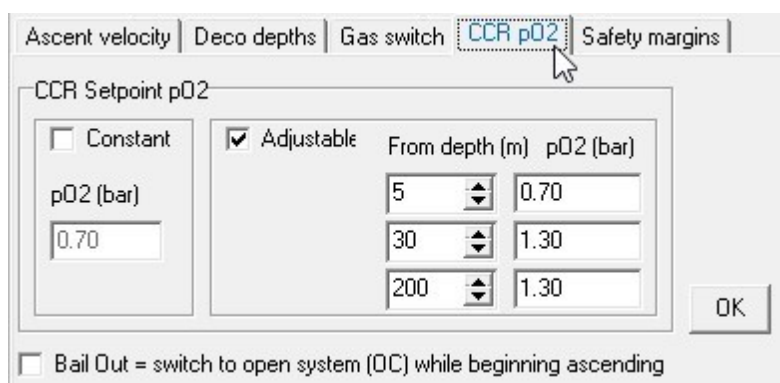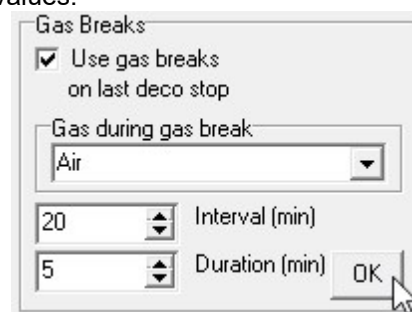
Setpoint O_2 change during ascent.
"Bail Out": At the beginning of the ascent the user can choose to change from the CCR circuit to an open system (OC). Changes have to be confirmed.
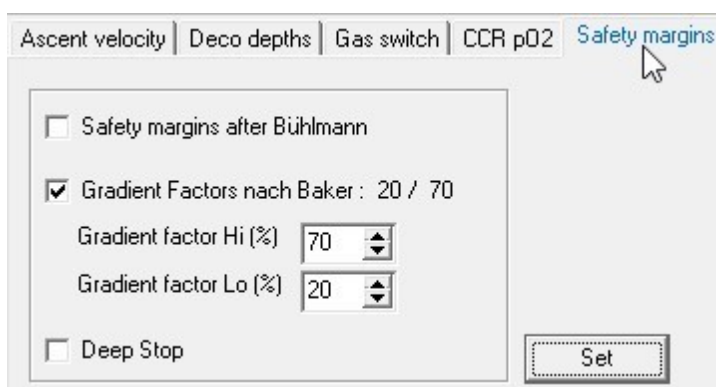
Safety margins for decompression during ascent. Gradient factors can be changed directly in this form. Further adaptations can be made via "Set". More information on all possible settings, see
→ 3.4.2 Settings - Safety margins.

3.4.5. Diving
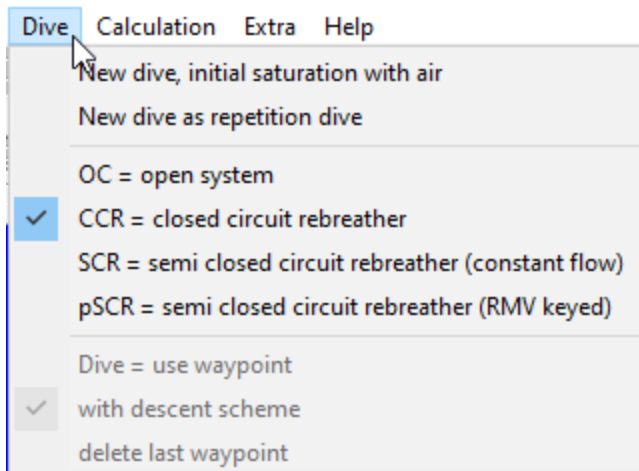
New dive, initial saturation with air: All parameters are reset. Saturation with inert gases is set to the value that equals saturation at equilibrium, with air as the breathing gas under the given air pressure.

New dive as repetition dive: Calculation of saturation continues until the end of the surface interval and is based on the saturation with inert gases following the preceding dive. The user is asked about the surface interval. This saturation is the starting value for calculations of a consecutive dive.

OC, CCR, SCR or pSCR: Settings for current dive system in regard to the following entry of waypoints.

Dive = use waypoint: Current settings (depth, runtime, dive system, breathing gas, ...) are accepted for the following waypoint. Instead of using the main menu, one can click the button "Dive" (➔ 3.7. Screen Area "Set Waypoint").
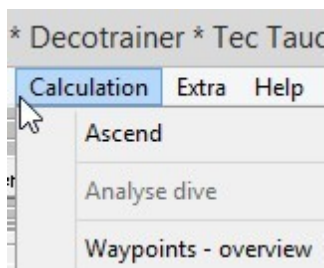
If "**Descent plan**" is active, all settings for the descent plan are taken into account when entering the waypoint.

Delete: The waypoint entered last is deleted. Instead of using the main menu, one can click the button "Dive" (➔ 3.7. Screen Area "Set Waypoint").

3.4.6. Calculation

Ascent: The program calculates the dive. First of all, Decotrainer calculates descent and bottom time based on known waypoints. In a following step, Decotrainer calculates the ascent based on the current ascent plan (ascent velocity, gas switch, setpoint p(O_2) change, gradient factors, ...). Some of the control elements are blocked for the user during the time of dive calculation.

As an alternative to the main menu, the button "Ascent" (➔ 3.7. Screen Area "Set Waypoint") can be used.

By clicking "Cancel calculation" the user can stop the current calculation (➔ 3.7. Screen Area "Set Waypoint").

Analyse dive: The program calculates the dive. Decotrainer calculates from the first to the last known waypoint. This option is independent of the current ascent plan. Following the calculation, the program analyses the parameters and displays them in a summary.
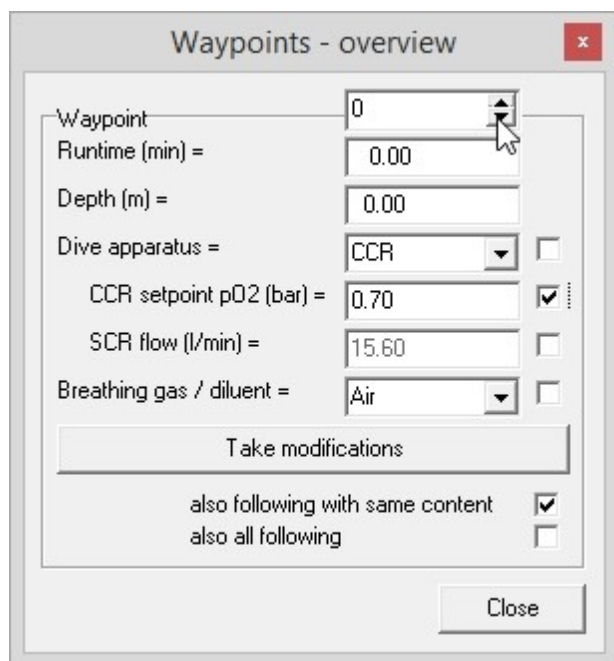
Waypoints - overview: The form appears and displays all main data for every waypoint (➔ 3.4.1. Dive and ➔ 3.10.1. Import Dive).

This overview allows to have a look at every waypoint via the corresponding checkboxes. The user can change values and confirm them by clicking "Take modifications". Optionally, changes will automatically be accepted for all following waypoints with the same output value.

This form is useful when the user wants to re-calculate a saved dive, e.g. with a different breathing gas, at a later point in time.

3.4.7. Extra
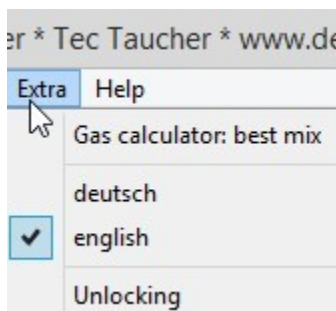
Gas calculator: best mix

The Gas calculator allows for the calculation of gas mixtures ("Calculate mix" is checked off) or a calculation of $p(O_2)$ and END of a given gas mixture, both depending on the operating depth.

Best mix stands for the optimal gas mixture with given standard values for oxygen partial pressure $p(O_2)$ and END (equivalent N_2 depth).

Into the gas list: The displayed gas is added to the gas list.

Gas check: Current limiting values are calculated from the percentages of the breathing gas' components and the operating depth. Example:
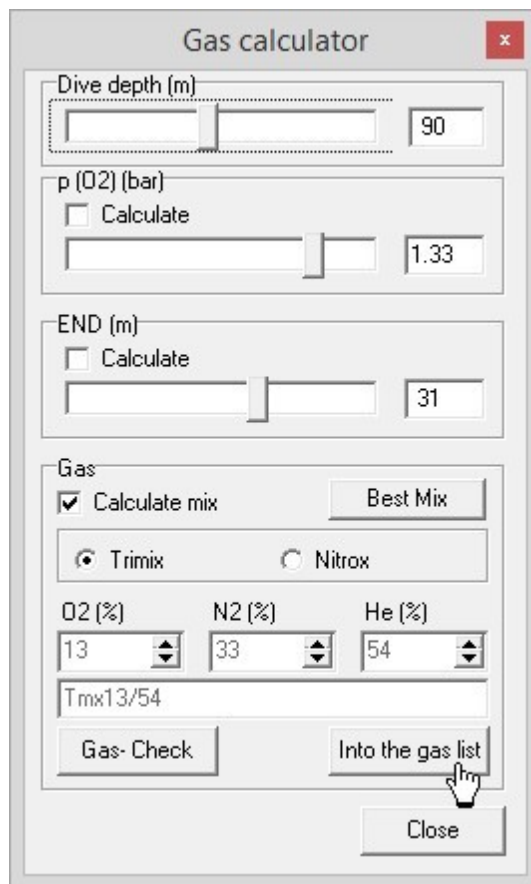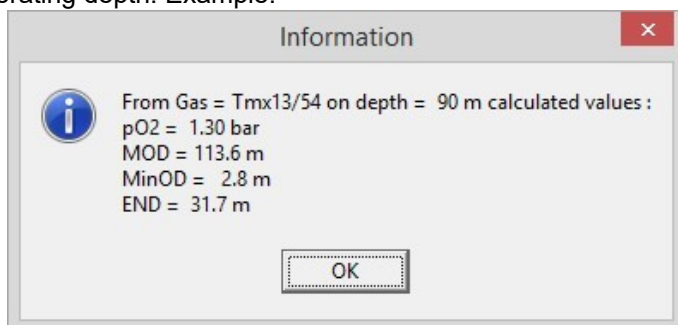
Language

Decotrainer offers 2 options for the language: German and English.

Un-Locking / Activation

Current activation data - Computer-ID, user name and unlocking key - appear. Should Decotrainer run on a USB hardware key, there will be a notice.

This form is used by the user to enter user name and unlocking key following the first installation of Decotrainer (➔ 3.2.).

3.4.8. Help

Read manual: The Decotrainer manual (= this document) is opened and displayed. This requires a program to be installed that can show pdf files (e.g. Adobe Acrobat Reader).
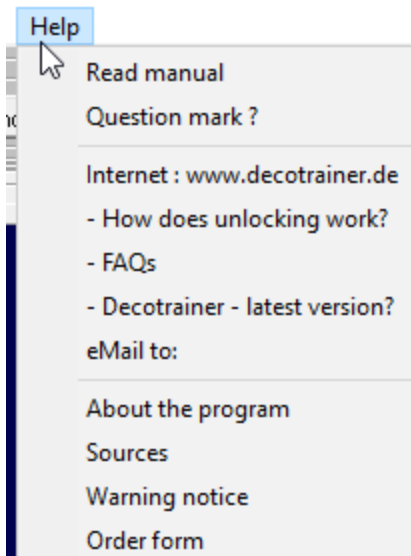
Question mark ?: An explanation to the question mark which shows when moving the cursor over certain control elements.

Internet: Corresponding pages of Decotrainer's online presence will open. This requires a browser to be installed and a connection to the Internet.

eMail to: Opens a new eMail to the given eMail address in the installed eMail program. This requires an installed eMail program and finally a connection to the Internet.

About the program: Information on the program Decotrainer, with a focus on the installed version.

Sources: List of the most important literature and other references.

Warning notice: Safety and warning note / application instruction. Form that also opens during the process of starting the program.
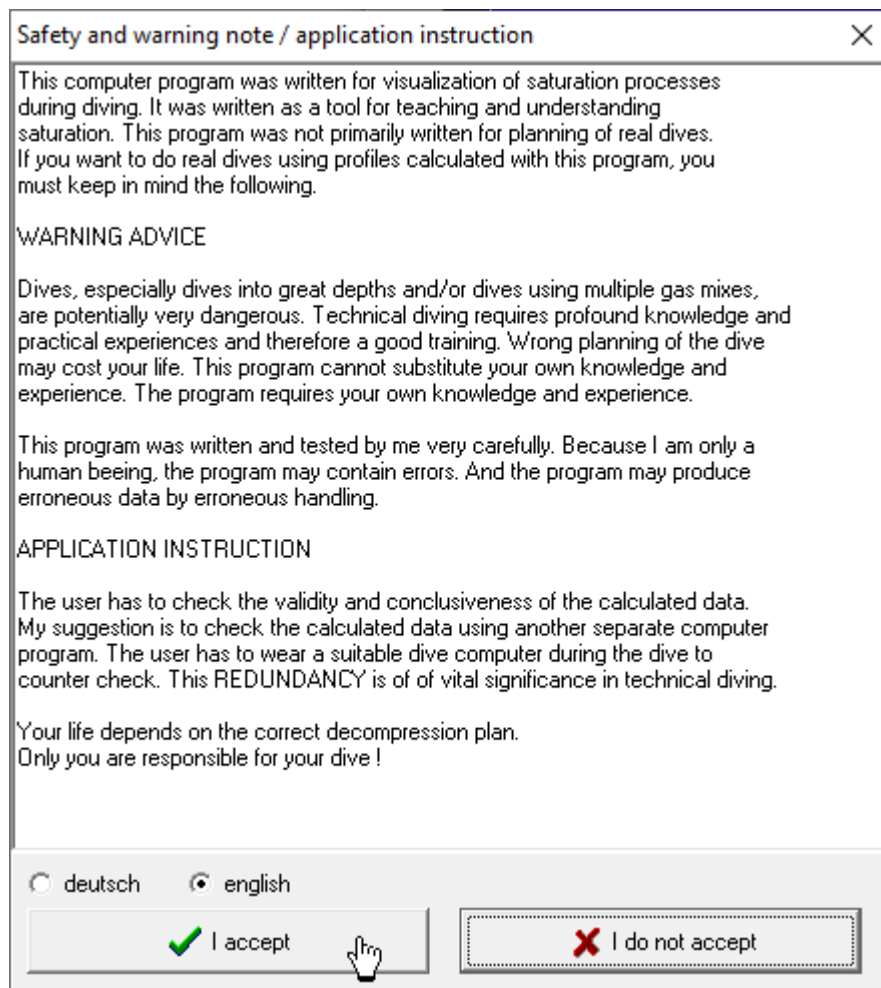
Order form: An order form stored in the program directory, which the user can use to order e.g. additional licenses or a hardware key at a later date. The form has to be filled in accordingly and submitted.

3.5. Screen Area "Settings"

Settings: → 3.4.2. Settings

Air pressure (mbar): only displayed, cannot be changed at this point.

→ 3.4.2. Settings - Air Pressure.

Descent plan: → 3.4.3. Descent Plan

Ascent plan: → 3.4.4. Ascent Plan

Calculation Models: → 3.4.2. Settings - Models

The option for model selection can be hidden at this point

→ 3.4.2. Settings - Displays

Exit: → 3.4.1. Dive

3.6. Screen Area "Dive Graphics"
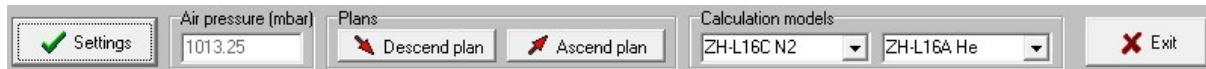
Depending of the current status of the program Decotrainer, dive graphics differ in appearance as well as functionality.

Dive graph when entering waypoints
The user can move the cursor with the left mouse button. The new position (runtime and depth) will be read. Alternatively, the user can enter a new runtime and a new depth in the corresponding fields of the screen area "Set waypoints".
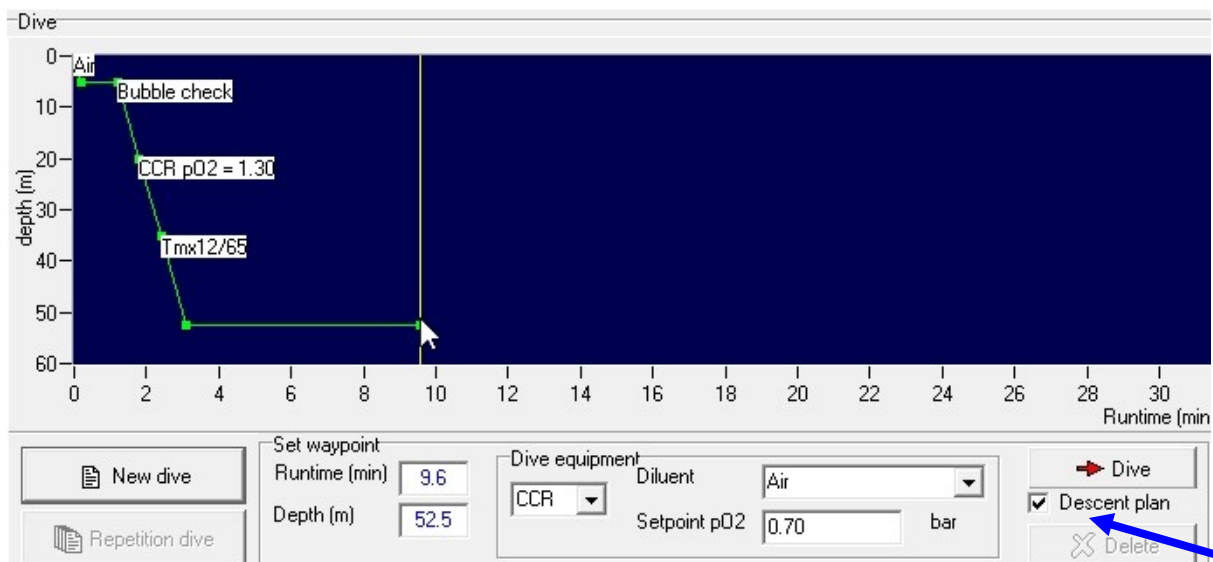
The new dive profile based on the selected descent plan (→ 3.4.3. Descent Plan), the current runtime and the current depth is calculated and displayed, when the checkbox "Descent plan" in the screen area "Set waypoint" is active.

When the automatic descent plan is not activated, all settings for the descent plan are irrelevant and current data for runtime, depth, dive system, breathing gas/diluents as well as setpoint pO_2 are accepted unchanged from the displays in the screen area "Set waypoint". Please see the following result as an example:
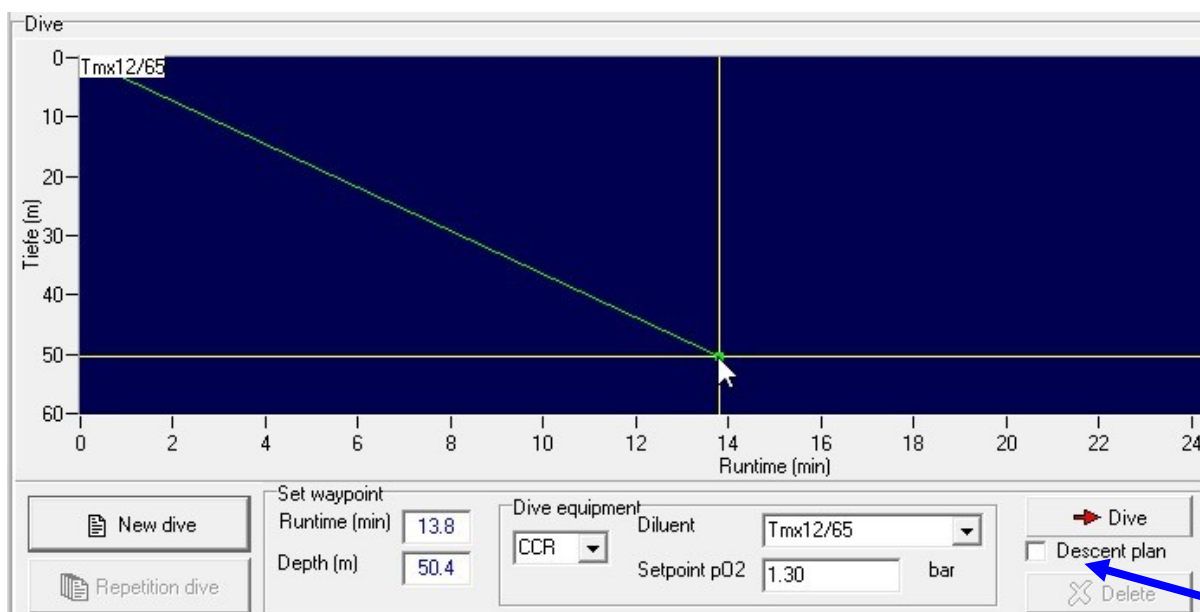
The exceeding of limiting values, e.g. by using an unsuitable breathing gas, will be indicated by warning messages that are highlighted in red.

Dive graphic when calculating a dive
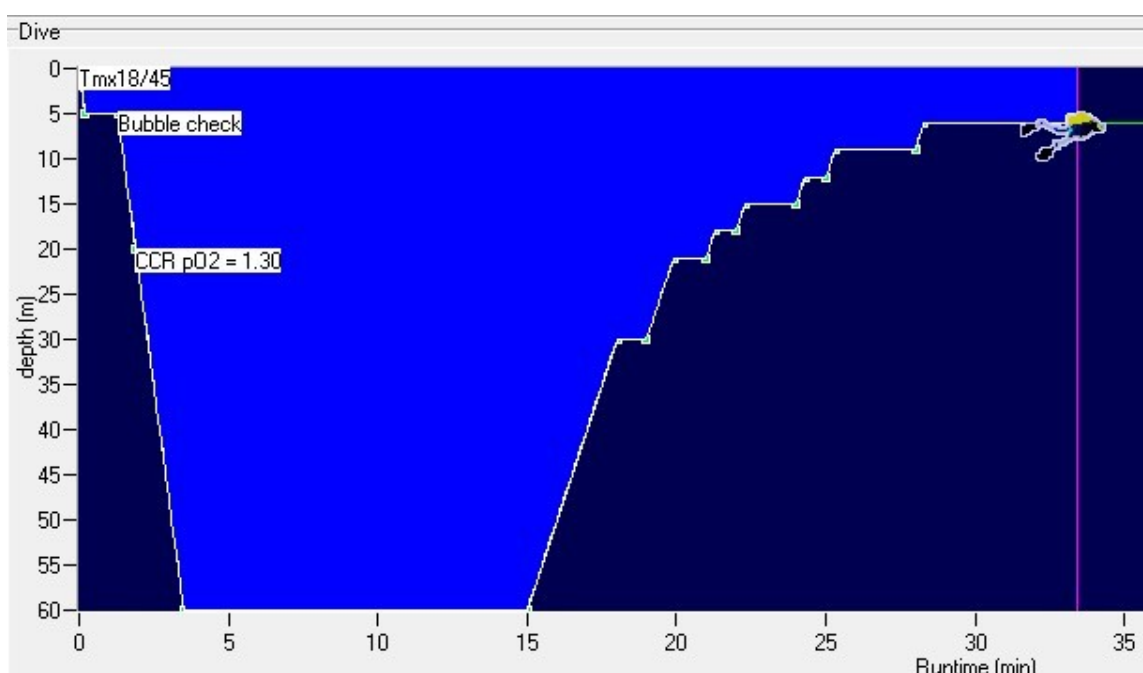
After selecting the button "Ascent" in the screen area "Set waypoint", Decotrainer calculates the dive. The current position can be identified in the dive graph by the cursor that shows a diver, and by the background colour. The user can adjust the symbol of the diver and other displays during the calculation of the dive (➔ 3.4.2. Settings - Displays).

In the course of the calculation, the symbol of the diver will move to the right. The current status of all parameters is displayed (➔ 3.8. Screen Area "Calculations", ➔ 3.9. Tissue Saturation). Changes to the dive plan, e.g. gas switch, are highlighted in white, possible warning messages in red. During the phase of active dive calculation the user can not access or influence the dive graphic.

Dive graphic when analysing a dive
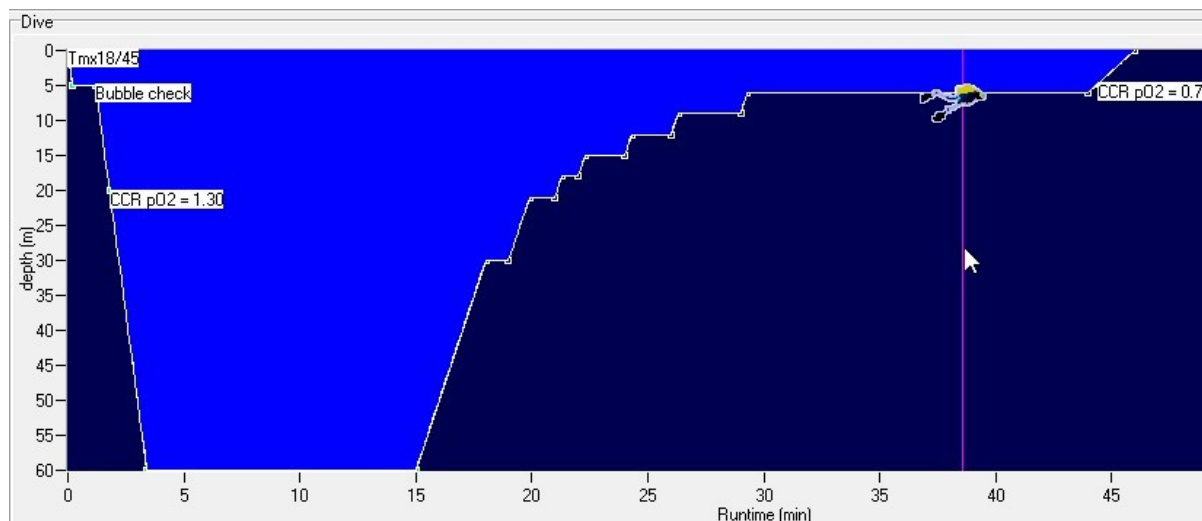
As soon as the dive has been calculated, the user can view and analyse all current parameters (e.g. tissue saturation) to any point in time of the dive. In order to do this, the user has to move the cursor with the diver symbol. Decotrainer will read the position of the cursor and subsequently show the current status of the chosen position (➔ 3.8. Screen Area "Calculations", ➔ 3.9. Tissue Saturation.

The user has three options to move the cursor:

- take hold with the mouse, press the left mouse button (left-click, hold) and move left or right
- use the keys "arrow left" and "arrow right" to move the cursor by one position (= 0.1 min) to the left or to the right
- use the keys "PgUp" and "PgDn" to move the cursor by 10 units (= 1 min) to the left or the right

3.7. Screen Area "Set Waypoints"

Depending on dive system and current status of calculation by Decotrainer, the visual appearance will differ:

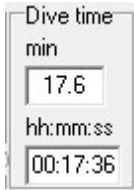New dive: A new dive is initialised

                       ➔ 3.4.5. Diving - New dive, initial saturation on air

                       ➔ 3.4.5. Diving - New dive as a repetition dive

Repetition dive: A repetition dive is initialised

                       ➔ 3.4.5. Diving - New dive as a repetition dive

Runtime (min):		Current runtime in min.
Depth (m):		Current depth in m.
Dive equipment:	Type of dive system (OC, CCR, SCR, pSCR)	
	→ 3.4.2. Settings - Gas Consumption	

Gas/diluent: Breathing gas (OC) or diluent (CCR, SCR, pSCR)

→ 3.4.2. Settings - Gas Consumption, → 3.4.2. Settings - Breathing Gases

Setpoint pO₂: Setpoint pO_2 = target value of O_2 partial pressure (CCR) in bar.

→ 3.4.2. Settings - Gas Consumption

Constant flow: Constant dose of fresh gas flow in L/min (SCR)

→ 3.4.2. Settings - Gas Consumption

Diving The selected waypoint is integrated to the dive plan.

→ 3.10.1. Input by user - Dive = use waypoint

Descent plan If this checkbox is activated, Decotrainer will calculate the dive profile for the descent based on all input for the descent plan.

→ 3.4.3. Descent plan

→ 3.6. Screen Area "Dive Graphics"

Delete The last entered point is deleted

→ 3.10.1. Input by user - Delete last waypoint

Ascent The dive is calculated based on all values set for the ascent. While calculations are running, several control elements are locked and the annotation of the button changes to "Cancel calculations".
→ 3.8. Screen area calculation, → Ascent

Cancel calculation: The running calculation is cancelled as soon as the next following waypoint is reached. Decotrainer shows the cancellation of the dive, and thus no data in the following information areas: Dive summary, runtime table, gas consumption, information on deco, warnings.

3.8.   Screen Area "Calculations"

In this screen area of Decotrainer, one can get an overview on all current as well as the latest calculated data and information.

Status
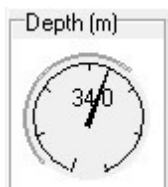
These displays show the current status of all parameters. Some of the displays can be de-selected by the user (→ 3.4.2. Settings - Displays).
Current depth in m.

Current END in m. END = Equivalent Nitrogen Depth. Red area = Area > critical END

→ 3.4.2. Settings - Limiting values

→ 1.4.2 Nitrogen

Dive time = Dive time in minutes depicted as a decimal number (intervals of a tenth of a minute) and in the format hh:mm:ss.

Start time of the dive and current runtime as time of the day in the format hh:mm:ss

time of day
Start
16:45:04

Runtime
17:02:40

Gas (i %)
O2 = 29.8
N2 = 31.7
He = 38.5

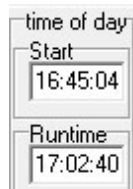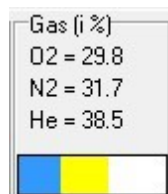Proportional composition of the gas currently breathed. For the system OC this corresponds with the composition of the currently used breathing gas. For CCR and SCR systems the program calculates and displays the current composition of the breathing gas in the circuit.

p O2 (bar)

Oxygen partial pressure pO_2 in bar of the gas currently breathed.

Red areas = critical areas with too low or too high pO_2

➔ 3.4.2. Settings - Limiting Values

CNS (%)
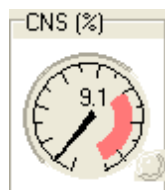
Current status of the short-term exposure with oxygen indicated by the CNS clock with CNS percentages as a unit.

Red area = critical zone of CNS > 100 %

➔ 3.4.2. Settings - Limiting Values, ➔ 1.4.1 Oxygen

OTU

Current status of the long-term exposure with oxygen indicated by OTU values.

Red area = critical zone of OTU > 850

➔ 3.4.2. Settings - Limiting Values, ➔ 1.4.1 Oxygen

Ambient pressure and saturation pressure

Black indicator, black figure in the centre: Current ambient pressure in bar. ➔ 3.4.2. Settings - air pressure, ➔ 3.4.2. Settings - water pressure.

Pressure (bar)

Yellow indicator, yellow field: Current pressure of saturation with inert gases (nitrogen + helium) of the critical tissue. ➔ 3.9.Tissue Saturation (absolute pressure).
Black figure at the bottom right: critical tissue = tissue that currently shows the highest saturation with inert gases.

Differential pressure of the inert gases nitrogen (on the left) and helium (on the right) between tissue and breathing gas (➔ 2.4. Counter diffusion).

Differential pressure N2, He (%)
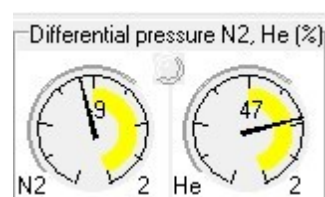
Differential pressure $N_2 = p_G(N_2) - p(N_2) / p_G(max)$
Differential pressure $He = p_G(He) - p(He) / p_G(He)$
Figure on the bottom right = critical tissue

where p_G = partial pressure in the tissue, p = partial pressure of the breathing gas, $p_G(max)$ = maximum allowable over-pressure of the tissue.

The maximum tolerable excess pressure of the tissue depends on current safety settings (➔ 3.4.2. Settings - safety margins). If the pressure in the tissue is greater than the partial pressure in the breathing gas (tissue is over-saturated with the inert gas, the inert gas diffuses from the tissue via the blood and lungs to the breathing gas), the difference in partial pressures is positive. If the pressure in the breathing

gas is greater than the partial pressure in tissue (inert gas enters the tissue and saturates the tissue further), the difference in partial pressures is negative. There is counter diffusion (➔ 2.4.), if both differential pressures equal in their sign. If, according to Decotrainer's criteria, counter diffusion becomes critical, a red "LED" will light up between the displays for N$_2$ and He.

Current gradient factor in percent on a scale between 0 and 100 % (➔ 3.4.2. Settings - safety margins).

Dark-grey = GF Lo. Light-grey = GF Hi

Figure on the bottom right = current critical tissue, see display for pressure (bar).
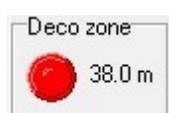
During ascent the deco zone is defined as the zone where at least one tissue is over-saturated, i.e. its saturation is greater than (>) the ambient pressure. Depth will show the beginning of the deco zone. If there is at least one over-saturated tissue in the current calculation, a red LED will light up.
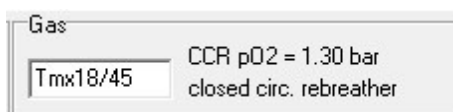
Current breathing gas (OC) or diluent (CCR, SCR, pSCR) and current dive system (OC, CCR; SCR, pSCR).

Current warning, e.g. before limiting values are exceeded or counter diffusion occurs.
➔ 2.4. Counter Diffusion,
➔ 3.4.2. Settings - Limiting Values.

Summary

The dive currently calculated is summarised as shown below.

```
Status  Summary  Runtime table

Summary of dive
    Air pressure    = 1.013 bar
    Water column    = 10.000 m/bar
    maximum depth   =  60.0 m
    Deepest ceiling =  31.3 m at runtime = 15.2 min
    Deco zone begins =  38.0 m at runtime = 17.2 min
    First deco stop =  30.0 m *   1.0 min
    Last deco stop  =   6.0 m *  15.7 min
    Bottom time     =  15.0 min
    Ascent time     =  31.0 min
    Total dive time =  46.0 min

Oxygen O2
    max. CNS  = 24.05 %
    max. p(O2) =  1.52 bar
    min. p(O2) =  0.70 bar

Safety settings
    GF Lo         =  0.20
    GF Hi         =  0.70

Counter diffusion and pressure gradients of inertgas
    No counter diffusion
    maximum partial pressure change of inert gas during over pressure phase is < 0.1 bar

Warnings
    No fly time = > 48.0 hours
```

Report

```
┌─Calculations────────────────────────────────────────────────┐
│ Status │ Summary │ Report │ Report CSV │ Runtime table │     │
│                                                              │
│   ┌─────────────┐   ┌──────────────┐                         │
│   │ 🖨 Print    │   │ 📄 Clipboard │                         │
│   └─────────────┘   └──────────────┘                         │
│                                                              │
│ Calculated with Decotrainer (Version 4.00 ~ 27.4.2020) on 28.04.2020
│ Dive = (not saved)                                           │
│                                                              │
│ Runtime table ............................................   │
│                                                              │
│ Depth Runtime Gas          Action              System  Warning
│  (m)   (min)                                                 │
│ ─────  ─────  ───────────  ──────────────────  ──────  ──────
│   0.0    0.0  Tmx18/45     START               CCR 0.70     │
│   5.0    0.2  Tmx18/45     Descent 25.0 m/min  CCR 0.70     │
│   5.0    1.3  Tmx18/45     Bubble check        CCR 0.70     │
│  20.0    1.9  Tmx18/45     Descent 25.0 m/min  CCR 0.70     │
│  20.0    1.9  Tmx18/45     CCR pO2 change      CCR 1.30     │
│  60.0    3.5  Tmx18/45     Descent 25.0 m/min  CCR 1.30     │
│  60.0   15.0  Tmx18/45     Bottom              CCR 1.30     │
└──────────────────────────────────────────────────────────────┘
```

A summarizing report of the dive is displayed. The report consists of the runtime table, the actual summary und the actual gas consumptions. The memo can be copied into the Windows clipboard (for copy + paste) for a further work with e.g. a text program. The button "Print" will sent the report, combined with a graphics of the dive to the printer.

Report CSV

```
┌──────────────────────────────────────────────────────────────┐
│ Status │ Summary │ Report │ Report CSV │ Runtime table │     │
│                                                              │
│   ┌─────────────┐   ┌──────────────┐   ┌──────────┐          │
│   │ 🖨 Print    │   │ 📄 Clipboard │   │   Save   │          │
│   └─────────────┘   └──────────────┘   └──────────┘          │
│                                                              │
│ " runtime(min),depth(m),pressure(bar),gas,system,pO2(bar),CNS(%),
│   0.0,   0.00, 1.013,Tmx18/45,CCR,0.70,   0.0, 73.64, 11.89, 14.46
│   0.1,   2.50, 1.263,Tmx18/45,CCR,0.72,   0.0, 60.01, 18.05, 21.95
│   0.2,   5.00, 1.513,Tmx18/45,CCR,0.74,   0.0, 51.07, 22.08, 26.85
│   0.3,   5.00, 1.513,Tmx18/45,CCR,0.72,   0.1, 49.37, 22.84, 27.78
│   0.4,   5.00, 1.513,Tmx18/45,CCR,0.69,   0.1, 47.68, 23.61, 28.71
│   0.5,   5.00, 1.513,Tmx18/45,CCR,0.70,   0.1, 48.05, 23.44, 28.51
│   0.6,   5.00, 1.513,Tmx18/45,CCR,0.70,   0.1, 48.05, 23.44, 28.51
│   0.7,   5.00, 1.513,Tmx18/45,CCR,0.70,   0.1, 48.05, 23.44, 28.51
│   0.8,   5.00, 1.513,Tmx18/45,CCR,0.70,   0.1, 48.05, 23.44, 28.51
│   0.9,   5.00, 1.513,Tmx18/45,CCR,0.70,   0.2, 48.05, 23.44, 28.51
│   1.0,   5.00, 1.513,Tmx18/45,CCR,0.70,   0.2, 48.05, 23.44, 28.51
│   1.1,   5.00, 1.513,Tmx18/45,CCR,0.70,   0.2, 48.05, 23.44, 28.51
│   1.2,   5.00, 1.513,Tmx18/45,CCR,0.70,   0.2, 48.05, 23.44, 28.51
│   1.3,   5.00, 1.513,Tmx18/45,CCR,0.70,   0.2, 48.05, 23.44, 28.51
└──────────────────────────────────────────────────────────────┘
```

A summarizing report of the dive with comma separated columns (CSV data format) is displayed. This report may be printed or copied into the Windows clipboard (for e.g. table calculations)

Runtime table

```
┌──────────────────────────────────────────────────────────────┐
│ Status │ Summary │ Report │ Report CSV │ Runtime table │     │
│                                                              │
│   ┌─────────────┐   ┌──────────────┐   ┌──────────┐          │
│   │ 🖨 Print    │   │ 📄 Clipboard │   │  Adjust  │          │
│   └─────────────┘   └──────────────┘   └──────────┘          │
│                                                              │
│ Calculated with Decotrainer (Version 4.00 ~ 27.4.2020) on 28.04.2020
│ Dive = (not saved)                                           │
│                                                              │
│ Depth Runtime Gas          Action              System  Warning
│  (m)   (min)                                                 │
│ ─────  ─────  ───────────  ──────────────────  ──────  ──────
│   0.0    0.0  Tmx18/45     START               CCR 0.70     │
│   5.0    0.2  Tmx18/45     Descent 25.0 m/min  CCR 0.70     │
│   5.0    1.3  Tmx18/45     Bubble check        CCR 0.70     │
│  20.0    1.9  Tmx18/45     Descent 25.0 m/min  CCR 0.70     │
│  20.0    1.9  Tmx18/45     CCR pO2 change      CCR 1.30     │
│  60.0    3.5  Tmx18/45     Descent 25.0 m/min  CCR 1.30     │
│  60.0   15.0  Tmx18/45     Bottom              CCR 1.30     │
│  30.0   18.0  Tmx18/45     Ascent 10.0 m/min   CCR 1.30     │
│  30.0   19.0  Tmx18/45     Deco                CCR 1.30     │
└──────────────────────────────────────────────────────────────┘
```

Runtime table = The runtime table of the current dive is displayed. The runtime table may be printed or copied into the Windows clipboard for e.g. handling it in a text program.

Adjust: The user can customise the output of the runtime tables to her/his needs.

➔ 3.4.2. Settings - Runtime Table

Gas Consumption

```
Gas consumption | Deco info | Warnings |

Gas            consumption  consumption       tank volume
                            + safety 50%
---------      -----------  ---------------   -----------
Air            898.6 barL      1347.9 barL           7
O2             623.9 barL       935.8 barL           5
Tmx15/55      2414.8 barL      3622.2 barL      2 x 10

RMV = 20 l/min * RMV(deco) = 15 l/min


----------------------------------------------------------
Gas consumption / only descend + bottom time
Gas            consumption  consumption       tank volume
                            + safety 50%
---------      -----------  ---------------   -----------
Air            111.6 barL       167.4 barL           3
Tmx15/55      1980.0 barL      2970.1 barL          15
```

Decotrainer calculates the values for gas consumption and displays the results. Calculations for gas consumption for normal OC dive systems are based on respiratory minute volume (RMV). As far as CCR, SCR or pSCR dive systems are concerned, consumption is calculated from the simulated breathing circuit where oxygen consumption is one criteria (➔ 3.4.2. Settings - Gas Consumption).

Gas consumption can be displayed separately for the ascent (➔ 3.4.2. Settings - Displays). For a CCR dive with Bail Out (change to an open system OC for the ascent), this is a sensible option.

Deco info

This field shows a summary of all decompression stops.

```
Gas consumption | Deco info | Warnings |

   30.00 m    1.00 min
   21.00 m    1.10 min
   18.00 m    0.70 min
   15.00 m    1.70 min
   12.00 m    0.70 min
    9.00 m    2.70 min
    6.00 m   15.70 min
```

**Warnings**

```
Gas consumption | Deco info | Warnings |

counter diffusion.
No fly time = > 48.0 hours
```

This field contains all warnings that Decotrainer has generated, e.g. for exceeding limiting values.

Warnings also appear as red text boxes in the corresponding status field in the dive's graph during its calculation - as well as in the dive summary after finishing all calculations.

3.9. Tissue Saturation

Tissue saturation (absolute pressure)
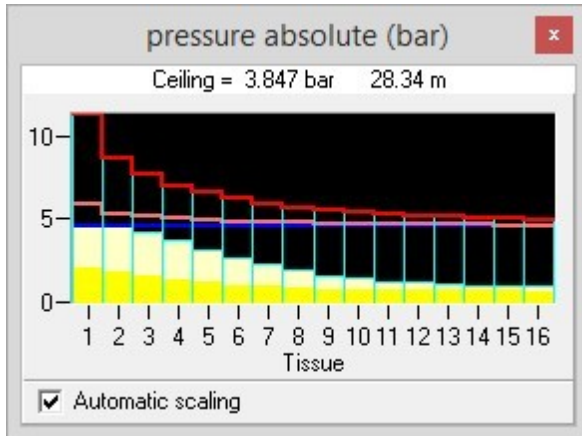
pressure absolute (bar)

Ceiling = 3.847 bar   28.34 m

Tissue

☑ Automatic scaling

The current saturation with the inert gases nitrogen and helium of all 16 tissues is displayed in the form of absolute pressures.

Ceiling: Currently possible minimum ambient pressure (in bar) or minimum depth (in m). Up to this point, it would be possible to ascent safely without decompression risk. The ceiling is calculated from the current state of saturation, and based on current maximum allowed over-saturation tolerances (➔ 3.4.2. Settings - safety margins).

Red line: Maximum tolerable over-saturation of all 16 tissues, calculated using the BÜHLMANN coefficients (➔ 2.1. Calculation of Saturation and Desaturation by BÜHLMANN).

Light-red line: Maximum tolerable over-saturation of all 16 tissues, calculated using the gradient factors according to BAKER (➔ 2.2. Gradient Factors - Modifications by BAKER).

Blue line: Ambient pressure in bar.

White bars: Percentage of partial pressure of the current saturation with the inert gas helium.

Yellow bars: Percentage of partial pressure of the current saturation with the inert gas nitrogen.

Automatic scaling: If activated, the scale for pressure is automatically adapted to currently calculated maximum values.

Tissue Saturation (relative pressure)

Saturation (%) pMax	Saturation (%) pMax	pMax(0, air)	pMax - p	p N2	p He	pMax	pMax(0)
40%	40%	100%	0%	1.952	1.979	9.928	3.266
54%	54%	100%	6%	1.831	2.304	7.643	2.555
58%	58%	100%	1%	1.630	2.320	6.799	2.265
58%	58%	100%	0%	1.439	2.146	6.172	2.051
54%	54%	100%	0%	1.271	1.850	5.814	1.867
49%	49%	100%	0%	1.142	1.528	5.480	1.706
43%	43%	100%	0%	1.040	1.211	5.217	1.607
38%	38%	100%	0%	0.962	0.930	5.003	1.537
33%	33%	100%	0%	0.903	0.698	4.845	1.489
30%	30%	97%	0%	0.866	0.541	4.729	1.449
27%	27%	90%	0%	0.842	0.433	4.648	1.417
26%	26%	84%	0%	0.823	0.345	4.575	1.384
24%	24%	80%	0%	0.808	0.275	4.512	1.353
23%	23%	77%	0%	0.795	0.217	4.451	1.323
22%	22%	73%	0%	0.786	0.172	4.401	1.303
21%	21%	71%	0%	0.779	0.136	4.352	1.282

Inert gas pressure (bar)

Display ⦿ ○ ○ ○   Display ○ 1   ○ 2   ○ 3   ⦿ 4

Current saturation with the inert gases nitrogen and helium of all 16 tissues is displayed in the form of a relative and/or absolute saturation. Tissue one represents the topmost bar and tissue 16 the lowest.

Display: Here, the user can adjust the scope of the display. In a first step (as shown in the example on the left, this is the standard setting) all information is displayed in a minimised way. Via steps 2, 3 and 4 (example on the right) more information is displayed step-by-step.
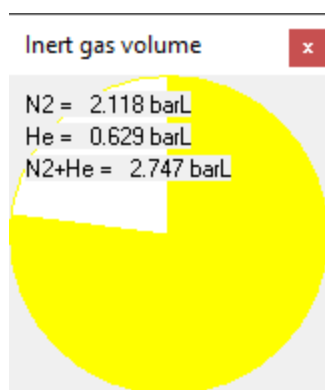
Saturation (%)

pMax $\qquad$ = [$p_G(N_2)$ + $p_G(He)$] / $p_G(max)$
pMax(0, air) $\qquad$ = [$p_G(N_2)$ + $p_G(He)$] / $p_G(0)$
pMax - p $\qquad$ = gradient factor GF

Inert gas pressure (bar)

pN$_2$ $\qquad$ $p_G(N_2)$
pHe $\qquad$ $p_G(He)$
pMax $\qquad$ $p_G(max)$
pMax(0) $\qquad$ $p_G(max\ 0)$

where $p_G(N_2)$ = partial pressure of the inert gas nitrogen in the tissue in bar, $p_G(He)$ = partial pressure of the inert gas helium in the tissue in bar, $p_G(max)$ = maximum tolerable inert gas excess pressure in the tissue in bar, $p_G(max\ 0)$ = maximum tolerable inert gas excess pressure in the tissue at the surface in bar, p(ambient pressure) = ambient pressure in bar.

Tissue saturation (volumes)

Inert gas volume

N2 = 2.118 barL
He = 0.629 barL
N2+He = 2.747 barL

The actual quantitatve saturation of all 16 compartments with inert gases. The inert gases are calculated as gas amounts for surface conditions (in barL 0 normalized litres). The following points are important for calculation:

- The solubility coefficients of the inert gases N$_2$ and He for solutions in water and olive oil (Bühlmann 2002, p. 91).
- The amount of body fat is 22.5 % and of body water is 57.5 %. The body fat portion is combined with the olive oil solubility.
- The body weight of 75 kg with densities of 1.03 kg/L (overall), 0.9 kg/L (fat) and 1.0 kg/L (water).
- The solubilities of all 16 compartments are equal.
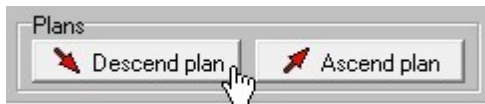
3.10. Enter Dive Data

3.10.1. Data Entry by the User

The following aims to explain the standard procedure when entering dive data in the form of an example. The exemplary dive is a CCR dive of 15 min to 60 m, using Tmx 10/50 as the diluent. Further specifications:
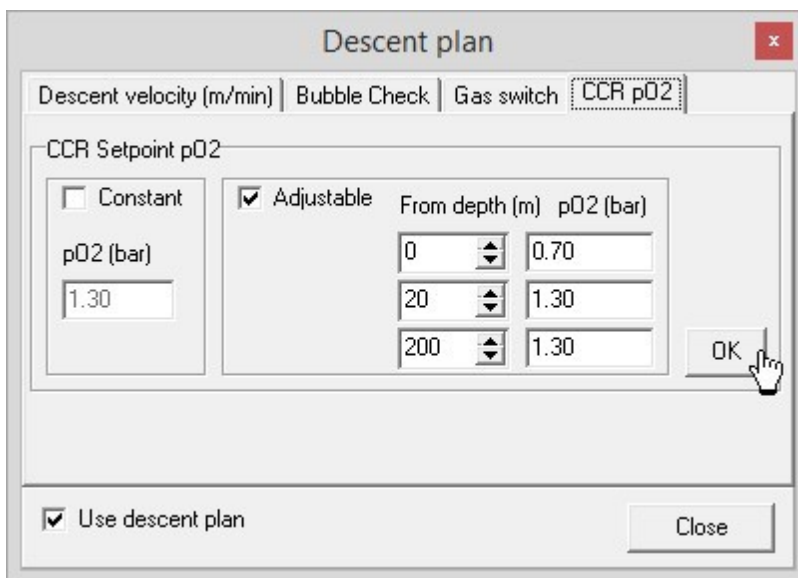
Descent plan: A Bubble Check is to be calculated at a depth of 5 m shortly after the beginning of the descent. During descent the O_2 setpoint is to be changed from 0.7 bar to 1.3 bar at a depth of 20 m.

Ascent plan: The ascent velocity is to be set to 10 m/min. The last deco stop is supposed to be at 3 m and the final ascent to the surface to be very slow, not exceeding a rate of 3 m/min. A gas switch is not part of the plan. For safety, the gradient factor 30/80 is to be used.

Procedure

Open the form containing the descent plan.

Enter all required data. Here: Change setpoint pO_2.
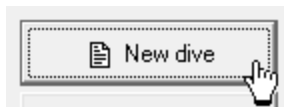
New dive → Saturation is reset to initial status (= complete saturation with nitrogen as the single inert gas under the given air pressure).
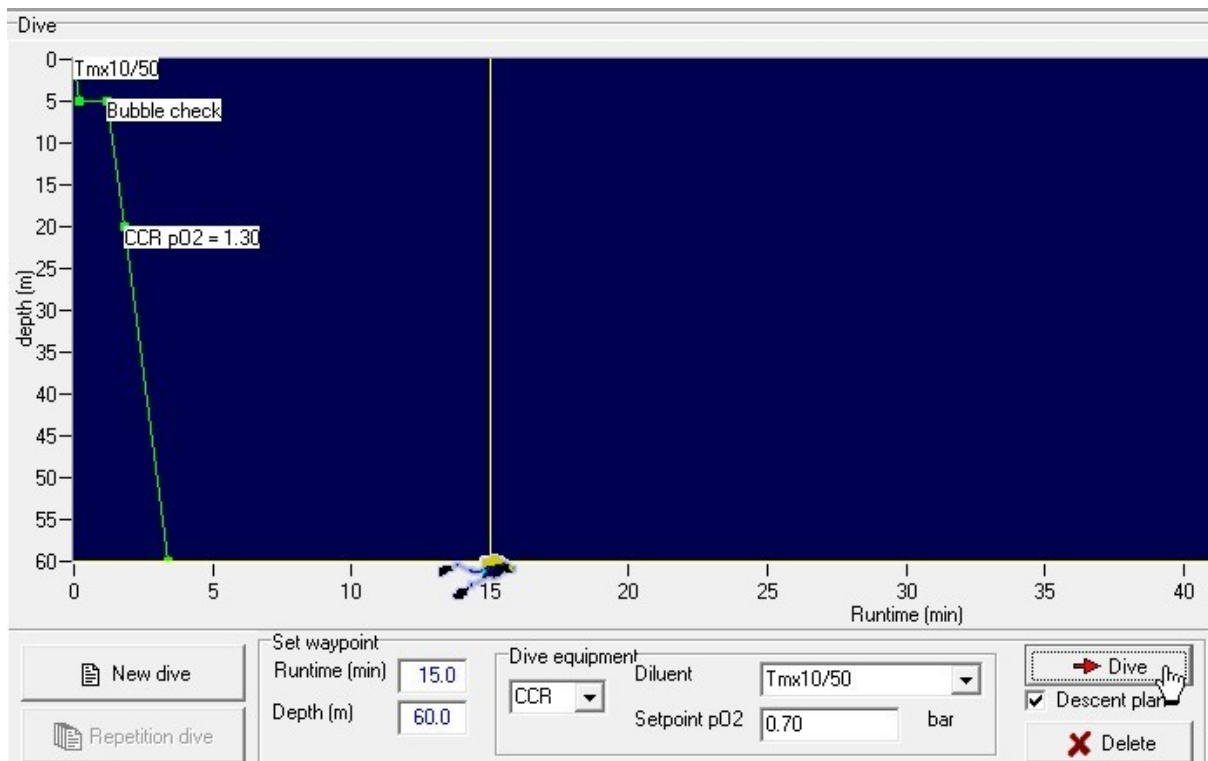
The correct data is entered to the input fields: Runtime = 15 min, depth = 60 m, dive system = CCR, diluent = Tmx10/50, setpoint pO₂ = 0.7 bar, descent plan is activated.

When clicking "Dive" Decotrainer calculates all corresponding waypoints and generates a preliminary dive profile in the field of the dive graphics.
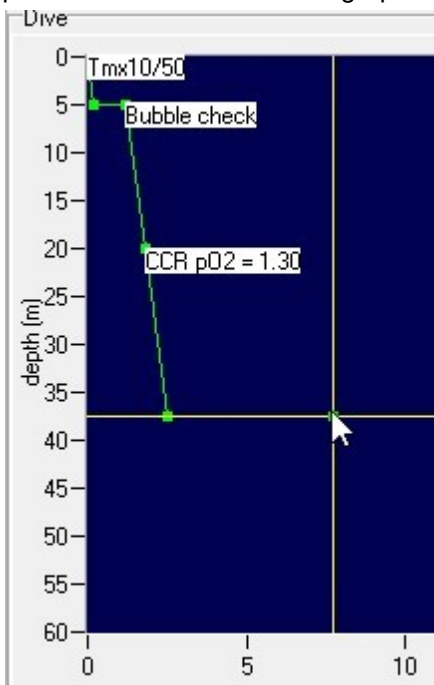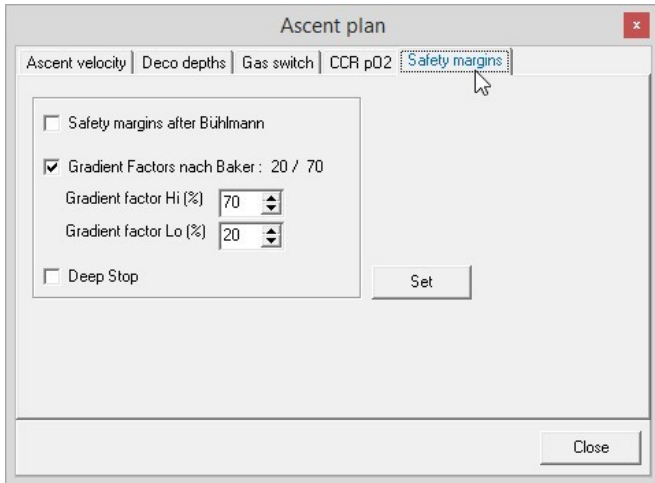

Alternatively, the user can enter runtime and depth by grabbing the cursor with the mouse and moving it while pressing the left mouse-button.

Decotrainer calculates all corresponding waypoints to the pre-set descent plan and shows them in white boxes.
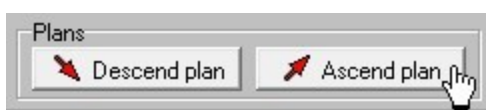
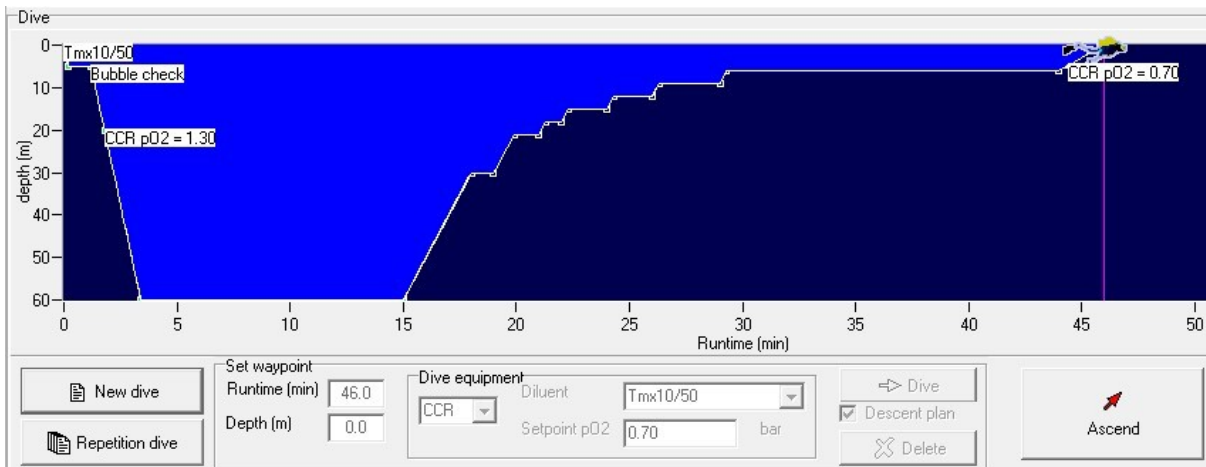Open the form for the ascent plan.

Set necessary changes to the ascent plan.
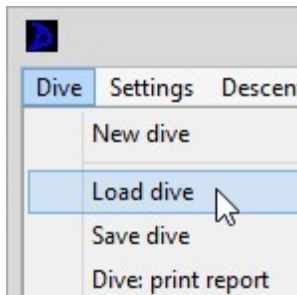
Here: Determination of gradient factors.

Click "Ascent" to have the entered dive calculated.
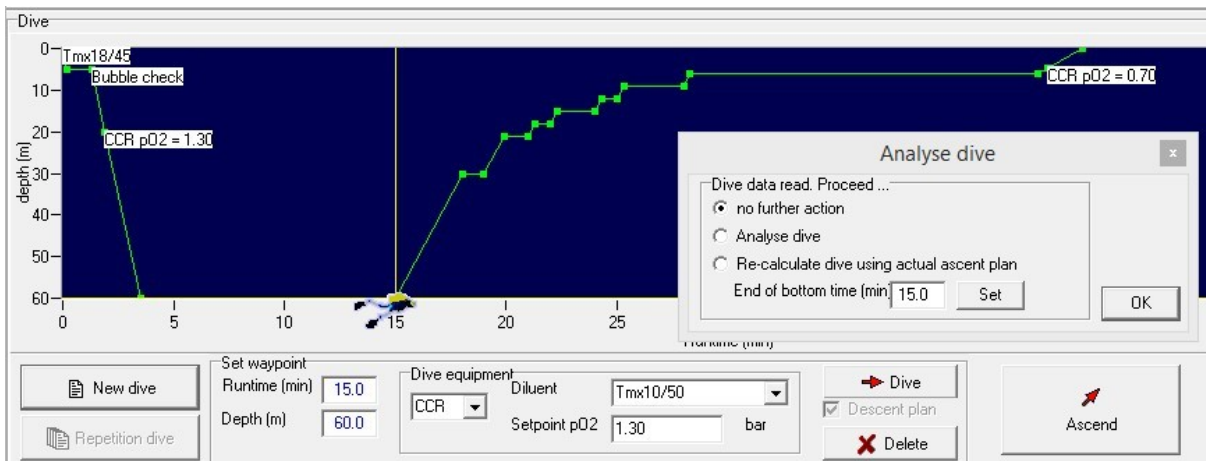
continue with ➔ 3.11. Calculate Dive

Calculation of the dive is complete:

3.10.2. Load Dive

A dive saved in the Decotrainer data format is loaded.

The dive is displayed and the user asked about the next action.

"no further action"	→	no further calculation
"Analyse dive"	→	3.12. Analyse Dive.
"Re-calculate dive ascent using actual ascent plan"	→	3.11. Calculate Dive

3.10.3. Import Dive
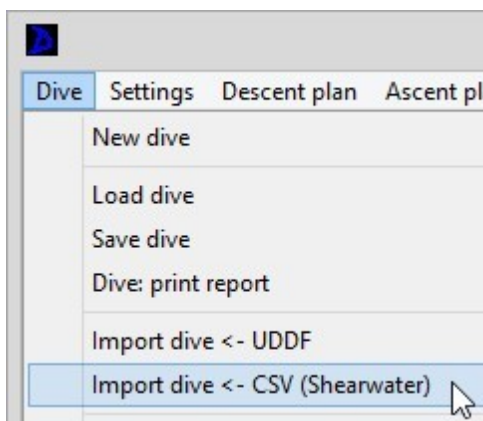
A dive that is not saved in the Decotrainer data format is imported. The example shows a Shearwater CSV file.

There will be a window that allows to access saved waypoints. These waypoints can be changed by the user, e.g. to re-calculate a dive with a different setpoint pO_2 or to use a different breathing gas.

In the example on the left the breathing gas is changed from "Air" to "EAN32".
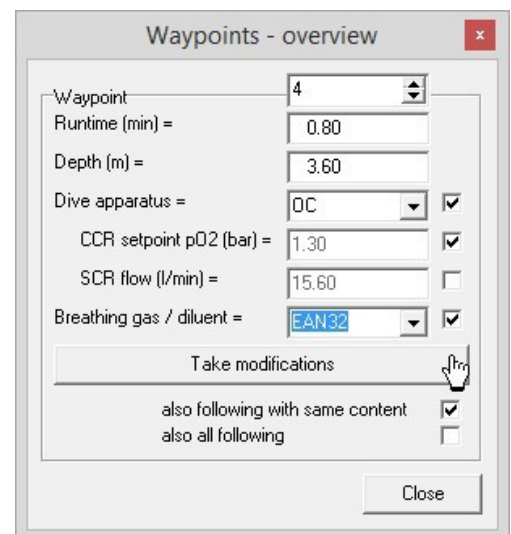
The tick in "also following with same content" makes the program change the breathing gas from "Air" to "EAN32" for all following waypoints. If one of the consecutive breathing gases is not air, it is not changed nor are any of the following breathing gases.

If the tick is set to "also all following", all following breathing gases are changed to "EAN32".

After closing the overview on waypoints, the system displays a dialog window prompting the user to take further action. From here the path is identical to menu point "Load Dive" (➔ 3.10.2. Load Dive).

"no further action"   ➔ no further calculation
"Analyse dive"   ➔ 3.12. Analyse Dive.
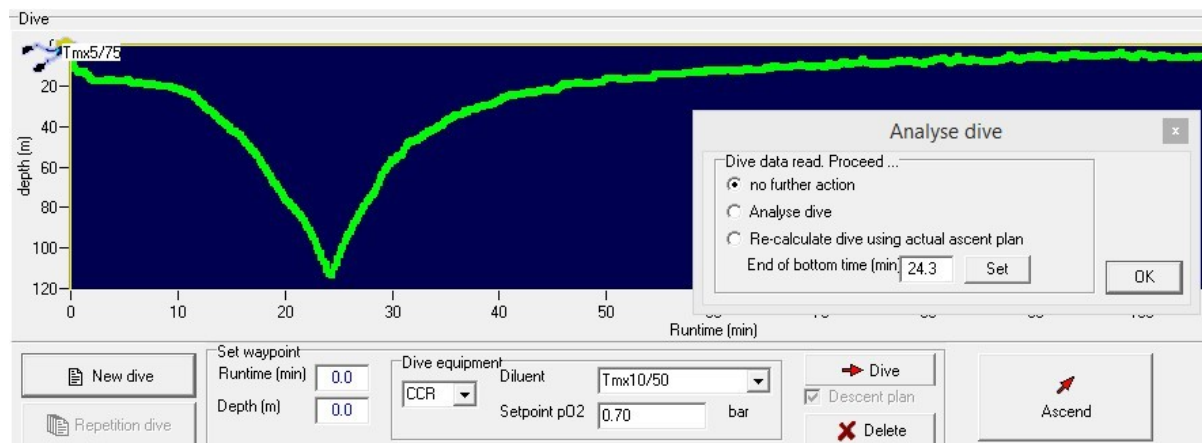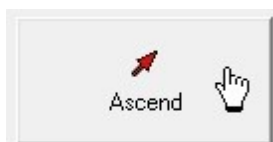"Re-calculate dive ascent using actual ascent plan"   ➔ 3.11. Calculate Dive

3.11. Calculate Dive

Following the entry of dive data by the user.
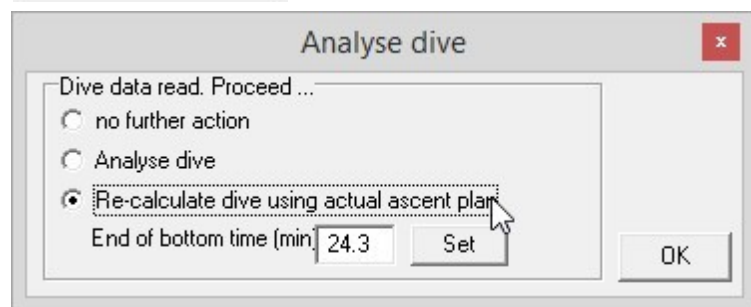
Following the loading or import of a dive.

The dive is calculated with all current settings. Decotrainer will not change any waypoint up to the beginning of the ascent. All waypoints from the beginning of the ascent are newly calculated and set based on the current ascent plan.

The advantage of this procedure is that (1) the same dive can be calculated with different settings in the ascent plan from the start of the dive to the beginning of the ascent, and (2) this renders comparable results.

When the user enters dive data, this sets the time of the beginning of the ascent. Following the loading or import of a dive, the user can determine the time of the beginning of the ascent (= End of bottom time (min)) in the window "Analyse dive" (in the example above 24.3 min).

3.12. Analyse Dive

Following the loading or import of a dive.

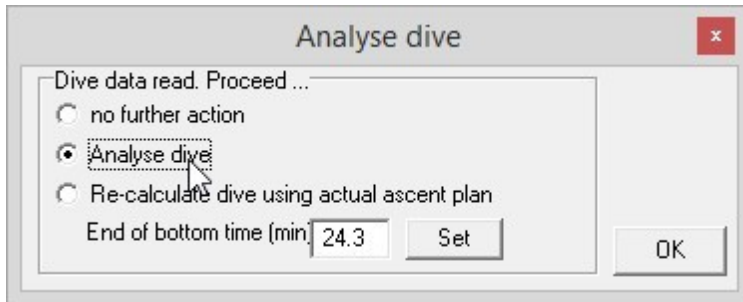The dive is calculated with all current settings. Decotrainer uses all waypoints unchanged from the beginning to the end, i.e. until the surface is reached. No waypoints will be re-calculated.

3.13. Save Dive
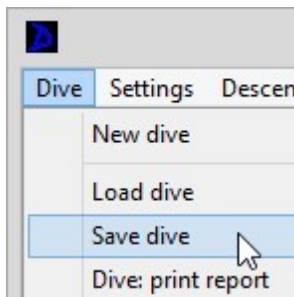
The current dive is saved with all settings in the Decotrainer data format. Alternatively, the dive data can be exported (UDDF, CSV). The respective data formats are explained in ➔ 3.10.3 Import dive and ➔ 3.4.1. Dive.

3.14. Information on Decotrainer

Licence agreement

The user of the software agrees to the following conditions:
The user may:
1. Install the software on ONE computer per licence purchased.
2. Create a safety copy of the software.
3. Passing the software on to a third party requires written consent of the author.
The user is not allowed to:
4. Sell or lend the software or parts of it to a third party nor hand out sub-licences.
5. Try to access the source code (by reverse engineering, decompiling or other methods).
6. Use an earlier version as soon as the user has received an up-date.

Extended licence terms

Potential additionally supplied components are subject to the licence terms of the respective manufacturer.

Guarantee

The author guarantees that the software has been developed and created with care. As the software is very complex, the author cannot guarantee that it is completely free of errors.

Liability

For possible damage that results from the use of the software, the author is not to be held liable.

Version

The manual relates to the software Decotrainer in the version 4.10 of february 2024.

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4. List of Abbreviations

A   Area.
a   Coefficient by BÜHLMANN.
at   Technical atmosphere, unit of pressure.
atm   Physical atmosphere, unit of pressure.
b   Coefficient by BÜHLMANN.
bar   Unit of pressure. 1 bar = ca. air pressure at the surface.
barL   Unit of gas amount in bar*Litre
c   Concentration.
CCR   Closed Circuit Rebreather. Exhaled air is freed of CO_2, replenished with O_2 and reused.
CNS   Central Nervous System. The unit "CNS %" is an indication for intoxication of the central nervous system caused by the breathing of hyperbaric oxygen.
CO_2 Carbon dioxide.
d   Depth.
dCal   Calibration for depth in m/bar.
END   Equivalent Nitrogen Depth or Equivalent Narcosis Depth.
F   Force.
fHe   Fraction of helium in a gas mixture.
fN_2 Fraction of nitrogen in a gas mixture.
fO_2 Fraction of oxygen in a gas mixture.
GF   Gradient factor.
GF Lo   Gradient factor low.
GF Hi   Gradient factor high.
h   Height in m.
hPa   100 Pascal, unit of pressure.
IEDCS   Inner Ear DeCompression Sickness.
k   Constant.
kp   Kilo-pond, unit of pressure.
He   Helium.
HPNS   High Pressure Nervous Syndrome.
lb/cm^3 see psi.
L   Litre, unit of volume.
m   Metre, SI unit for length.
mbar   Milli-bar = one thousandth of a bar, unit for pressure.
min   Minute(s).
MinOD   Minimum Operating Depth = minimum operating depth of a breathing gas in m limited by minimum tolerable pO_2.
MOD   Maximum Operating Depth = maximum operating depth of a breathing gas in m limited by maximum tolerable pO_2.
N   Newton = SI unit for force.
N_2 Nitrogen.
NN   German "Normal Null" = mean sea level.
NOAA   National Oceanic and Atmospheric Administration. Source of the CNS percent and OTU tables.
O_2 Oxygen.
OC   Open Circuit. Term for "normal" dive system that uses demand-controlled regulators which transfer exhaled air to the water.
OTU   Oxygen Tolerance Unit. A unit for the long-term damage of the lung due to hyperbaric oxygen.
p   Pressure, also partial pressure.
p_G Pressure in the tissue, also partial pressure of the tissue.
pHe   Partial pressure of helium.
pN_2 Partial pressure of nitrogen.
pO_2 Partial pressure of oxygen.
Pa   SI unit for pressure = N/m^2.
pSCR   Passive Addition Semi Closed Rebreather. Diving system with a semi-closed breathing system. Exhaled air is partially dumped into the ambient water (e.g. 10 %), the remaining gas remains in the respiratory loop and is freed of CO_2, replenished with O_2 and reused in the cycle. Fresh gas is added automatically to the cycle.
psi   Pounds per square inch. Unit for pressure, see lb/cm^2.
RMV   Respiratory minute volume.
SCR   Semi Closed Rebreather. Diving system with a semi-closed breathing system. Exhaled air is partially freed of CO_2, replenished with O_2 and reused in the cycle. Unused gas is permanently added automatically to the cycle via a constant flow.
SI   Système International d'unités = International System of physical units. It is a metric system where m (metre) is the basic unit for length. The Anglo-Saxon system where feet (ft) are used as the basic unit for length is no SI system.
t   Time.
Tmx   Trimix (also Tx, TX, TMX).
Torr   Torricelli = mm Hg = millimetre of mercury. Outdated unit for pressure, now (only) still used in medicine.
UPTD   Unit Pulmonary Toxicity Dose, values comparable to OTU. A unit for long-term damage of the lung due to hyperbaric oxygen.
V   Volume.
xHe   Percentage of helium in the gas.
xN_2 Percentage of nitrogen in the gas.
xO_2 Percentage of oxygen in the gas.

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Wikipedia: Online Encyclopaedia "http://en.wikipedia.org", see corresponding links.