technical matters

Column by Cedric Verdier

Images of divers courtesy of Silent Diving Systems

Safety Margins with a CCR

There used to be a time when there was no safety margin in any activity that the human being wanted to participate in. In a merciless prehistoric world, on a daily basis, the cave men were hunting with stones and sticks, a large variety of predators the size of a truck, expecting to feed a hungry family. Then, Winchester gave men the ability to kill wild animals while staying at a comfortable distance, without risking their lives. Safety margin was born.

As recreational divers, we were taught to plan for realistic safety margins. One of the first rules states that you should always start your final ascent with at least 50 bar/500 psi in your cylinder. As a technical diver, however, you suddenly discovered that this safety margin wasn't enough when doing deeper dives with required decompression, or even worse, when diving in an overhead environment. So, as rebreather divers, what kind of safety margin do we have?

Rebreather diving is not an exact science

Let's put it this way—cooking pasta, launching sky rockets or diving with a rebreather all share a common point: ***Nothing is ever guaranteed to work.***

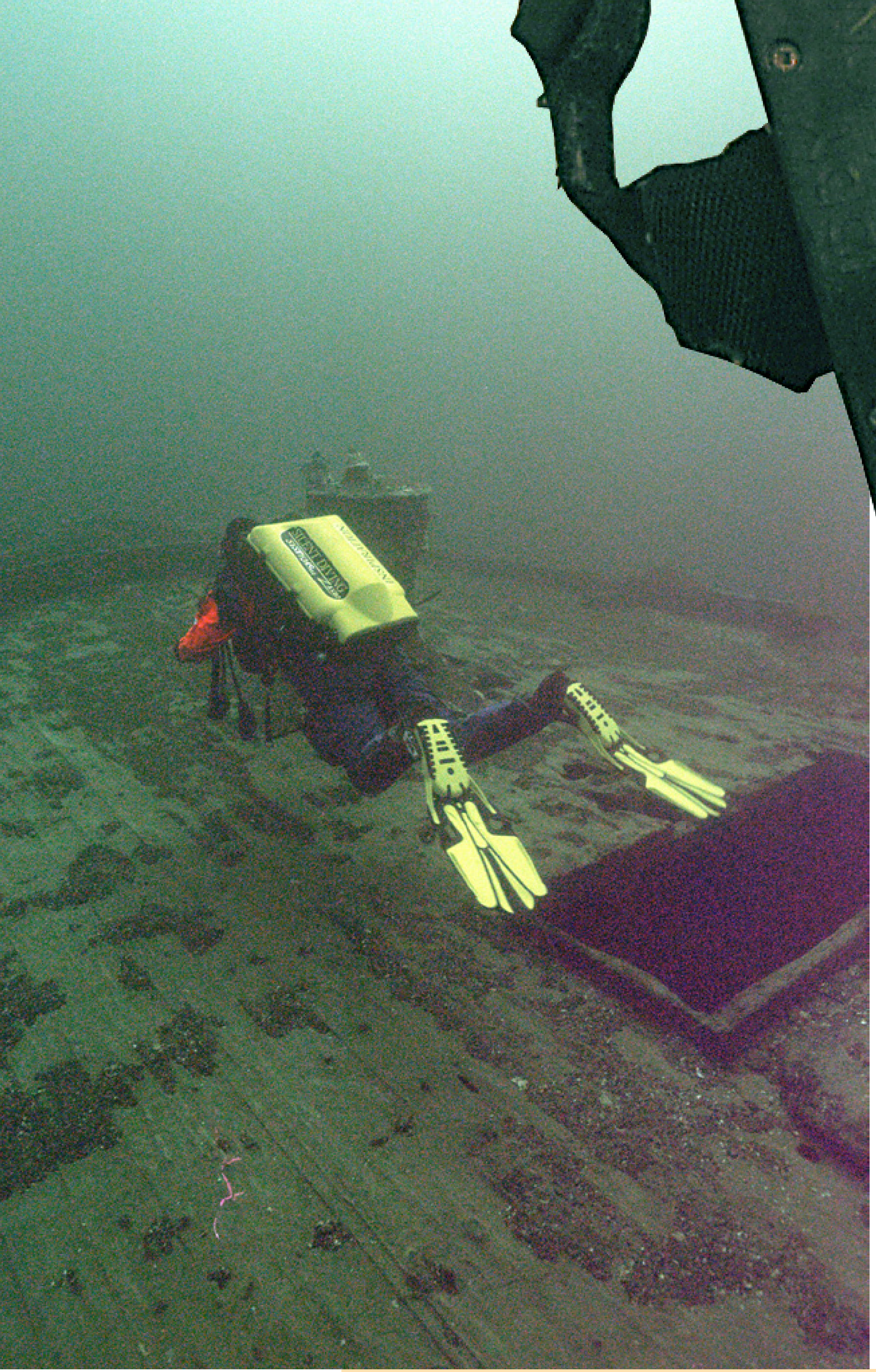
pO_2 readings are not accurate

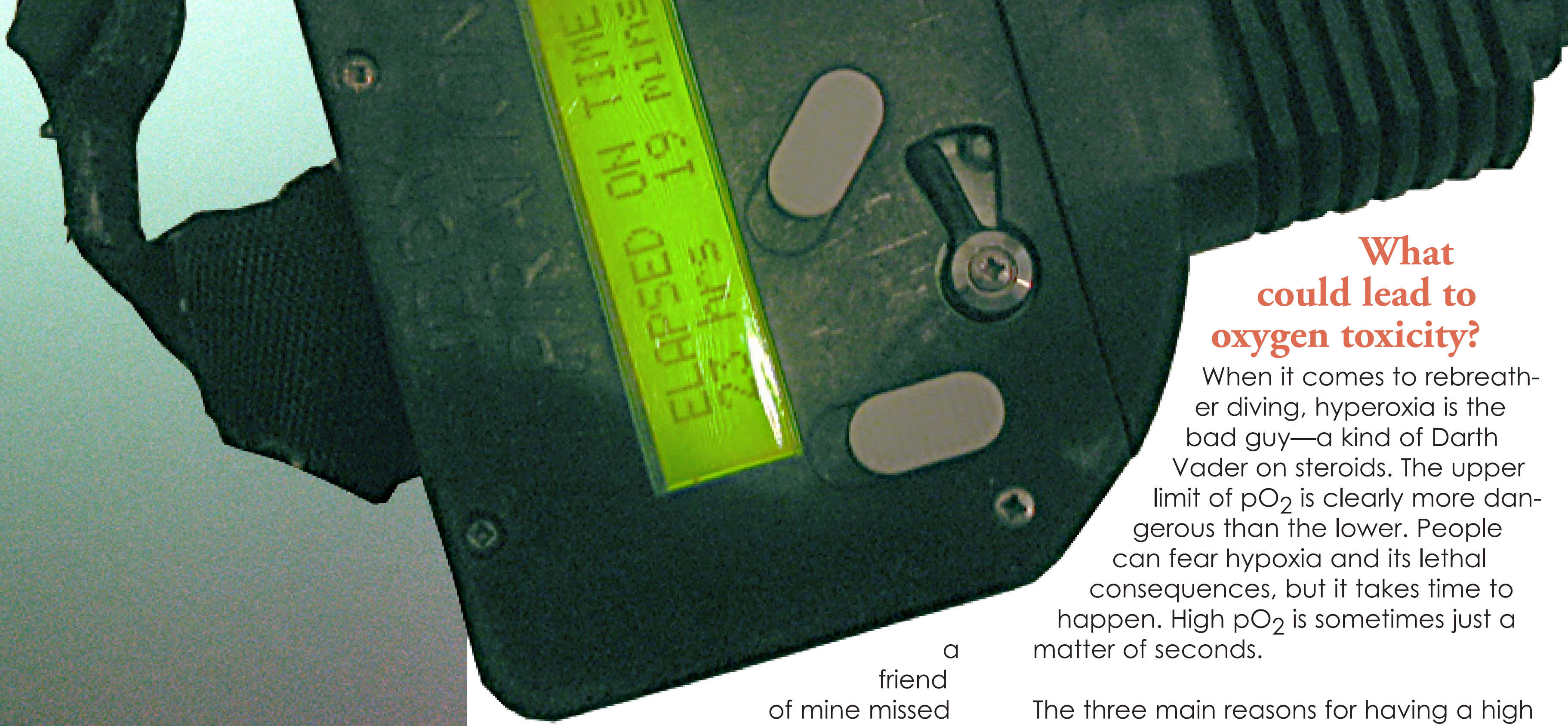
Even properly calibrated, oxygen sensors fail to show the same oxygen content in a loop. Their age, their chemical properties or simply the humidity in the loop, all work to limit the accuracy of the pO2 readings. Even the famous voting logic is a pathetic attempt to get a little closer to the exact pO_2. And it becomes even worse when the calibration is improperly done.

O_2 exposure limits are variable

When dealing with oxygen exposure, the sources come across quite vague. The NOAA tables are based on empirical data. The calculations for repetitive oxygen exposures are more than unclear. Even the maximum pO_2 could change from one day to the next in the same person, as shown by Kenneth Donald during the Second World War.

Decompression calculations are approximate. In this area, the motto seems to be: "Nobody knows". Everything is as confusing as Sherlock Holmes and his riddles. A lot of theories, algorithms, procedures and decompression curves are discussed and experimented every day by "guinea pig" technical divers. During a dive at 60m,





a friend of mine missed one hour deco and simply stayed at the surface, expecting signs and symptoms of DCS that never came. Is that individual variation luck, or a huge safety margin implemented in the decompression softwares?

Offgassing could be impaired by a lot of factors contributing to DCS

Age, fitness level, illness, PFO, body fat or even history of DCS—pick your choice. How could a complex phenomenon like inert gas off-gassing could realistically be mimicked by a mathematical equation? Add one or all of these contributing factors, and you get something that looks as complex as understanding the graffiti made by a gang of drunken ghetto rappers on a wall just before a nuclear explosion.

So, if everything is so complex, how could we possibly understand what could happen to a rebreather diver from a physiological standpoint? If the pO_2 in the loop is too high, how could we predict the threshold of the oxygen toxicity? If the pO_2 is too low, will the decompression requirement planned be in accordance with what the diver actually experienced?

What could lead to oxygen toxicity?

When it comes to rebreather diving, hyperoxia is the bad guy—a kind of Darth Vader on steroids. The upper limit of pO_2 is clearly more dangerous than the lower. People can fear hypoxia and its lethal consequences, but it takes time to happen. High pO_2 is sometimes just a matter of seconds.

The three main reasons for having a high level of oxygen in a rebreather loop are:

1. A problem with the electronics
One of the causes is a bad calibration. It could be due to:

- A different level of humidity in the gas one uses for calibration, compared to what could be found in the loop during the dive.
- An incorrect ambient pressure when the sensors are calibrated in altitude, if the user indicates that it's done at sea level
- An incorrect fO_2 in the oxygen used for calibration
- An incorrect fO_2 in the air used for calibration; in case of a two-point calibration, any excessive pressure in the loop during the calibration. This pressure is generally caused by an obstruction on the flow rate (closed mouthpiece, stuck OPV, backpressure caused by an analyzer connected to the loop, etc.)

But it could also be a *false pO_2 reading* on the handsets. Most of the time, the problem seems to be an old cell or a current-limited cell.

2. An user error

- A fast descent will create an O_2 spike
- A wrong setpoint will unnecessarily increase the O_2 content in the loop, for instance, selecting a high setpoint before descending

Terms:
DCS: DeCompression Sickness
PFO (Patent foramen ovale) is a persistent opening in the wall of the heart, which did not close completely after birth. Often goes unnoticed.

- An excessive manual pO_2 injection
- A wrong diluent selection, if the oxygen content in the diluent is too high for the depth planned
- An oxygen exposure exceeding the physiological limits

3. A problem with the gas supply

- Using a wrong gas, if the O_2 or diluent tanks haven't been analysed
- An O_2 leak in the loop, either because of the solenoid stuck in an open position or because of a leaking schraeder valve

Why do rebreather divers mostly use high pO_2 setpoints?

One of these factors is Setpoint selection (user error). In technical diving, dive planning is all about safety margins. So, why don't we plan for some safety factors when we choose the Setpoint for deep CCR dives? Why do rebreather divers mostly use high pO_2 setpoints?

A poll on the Rebreather World forum showed that more than half of the CCR divers use pO_2 setpoints higher than 1.2 bar throughout the dive, sometimes increasing this setpoint during the last part of the ascent.

The reason for such a practise could be found in the fear of hypoxia (solenoid stuck closed or rapid ascent). It could also be seen as a way to decrease decompression obligation. But the main reason may be the fact that 1.3 is the default setpoint on the Inspiration/Evolution, the most popular units on the market. For some divers, it's simply easier to use the default setpoint than modifying it every time the electronics is turned on.

Poll Results: **What's your pO_2 for deep dives?**

Less than 1.0 for the bottom phase	0.00 %
1.0 for the bottom phase	3.39 %
1.1 for the bottom phase	3.39 %
1.2 for the bottom phase	14.41 %
1.3 for the bottom phase	41.53 %
More then 1.3 for the bottom phase	1.69 %
I use the same pO_2 for the deco phase	13.56 %
I use a higher pO_2 for the deco phase	21.19 %

On the other hand, a lower pO_2 setpoint gives a lot of benefits:

Lower Oxygen Exposure:
A low pO_2 in the loop during the working part of the dive helps to keep the oxygen exposure quite reasonable. Therefore, the body's natural ability to deal with high pO_2 levels will be saved for the latter part of the dive and the decompression stops.

Time to deal with emergency:
A lower setpoint gives more time to deal with an increasing level of oxygen in the loop. Whatever the cause of the problem (mechanical, electronics, user error), a rebreather will always take more time to go above 1.6 bar, if the starting point is 1.0 instead of 1.3. It provides the CCR diver with a buffer against major oxygen spikes.

Better PO_2 readings
The sensors give a more accurate reading when dealing with low oxygen content. The user may not be aware that one of the O_2 cells is current-limited and has some difficulties reaching a high pO_2. During the calibration process, all cells are supposed to reach 1.0, but nothing—except an O_2 flush at depth—proves that the cell can read a higher value.

So much for the benefits of using a lower setpoint, but what about decompression?

With air as diluent:
If your pO_2 is 1.3bar at 40m, the actual fraction of N_2 in the loop should be around 73 percent. If the setpoint is 1.0, this fN_2 becomes 80 percent.

For a 60-minute dive, the decompression requirement is (according to V-Planner):

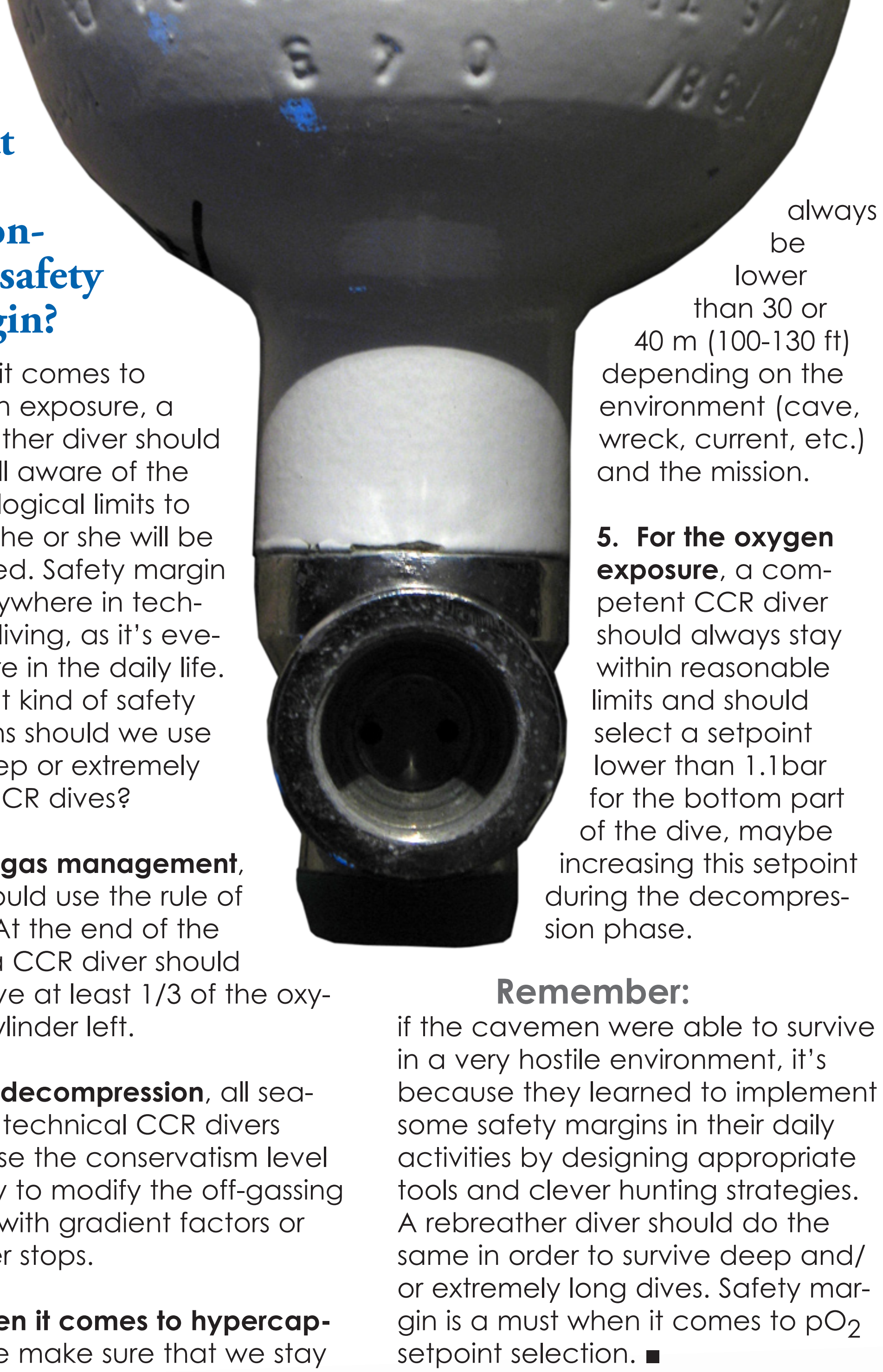
Setpoint at depth	Setpoint during deco	Ascent time
1.3	1.3	48 min
1.0	1.0	86 min
1.0	1.3	60 min

With trimix (Heliair 10/52) as diluent: If your pO_2 is 1.3 at 80m, your fraction of inert gases in the loop should be around 86 percent. If the setpoint is 1.0, this fN_2 becomes 89 percent.

For a 30-minute dive, the decompression requirement is:

Setpoint at depth	Setpoint during deco	Ascent time
1.3	1.3	141 min
1.0	1.0	218 min
1.0	1.3	157 min

With the proper setpoint selection (low setpoint at depth and higher in the shallows) it's only a 16 minute longer ascent for an almost three hour long dive. So, we are speaking about a 10 percent increase in the decompression time. And deeper or for longer bottom times, this increase is even smaller.



What is a reasonable safety margin?

When it comes to oxygen exposure, a rebreather diver should be well aware of the physiological limits to which he or she will be exposed. Safety margin is everywhere in technical diving, as it's everywhere in the daily life.

What kind of safety margins should we use for deep or extremely long CCR dives?

1. **For gas management**, we should use the rule of 1/3's. At the end of the dive, a CCR diver should still have at least 1/3 of the oxygen cylinder left.

2. **For decompression**, all seasoned technical CCR divers increase the conservatism level and try to modify the off-gassing curve with gradient factors or deeper stops.

3. **When it comes to hypercapnia**, we make sure that we stay well within the recommended duration of the scrubber.

4. **For narcosis management**, we should always make sure that the END at the maximum depth will always be lower than 30 or 40 m (100-130 ft) depending on the environment (cave, wreck, current, etc.) and the mission.

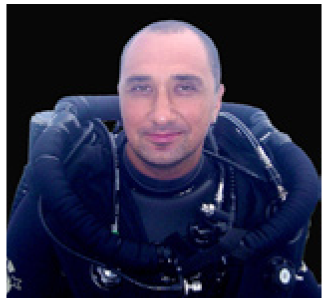
5. **For the oxygen exposure**, a competent CCR diver should always stay within reasonable limits and should select a setpoint lower than 1.1bar for the bottom part of the dive, maybe increasing this setpoint during the decompression phase.

Remember:

if the cavemen were able to survive in a very hostile environment, it's because they learned to implement some safety margins in their daily activities by designing appropriate tools and clever hunting strategies. A rebreather diver should do the same in order to survive deep and/or extremely long dives. Safety margin is a must when it comes to pO_2 setpoint selection. ■


And, oh.... this is, by the way, the Winchester rifle, that the cavemen did not have

About the Author



Cedric Verdier is the founder of the TRIADE Project, established in 1999, discovering and exploring more than 20 virgin wrecks located in the south of France between 70 and 130m (230 ft) and 430 fsw. In 2002, he was the first diver to identify and dive the British cruiser *HMS Manchester* off Tunisia. Amongst other dive firsts, he pushed the limits of the Sra Keow cave in Thailand in May 2006, using his Megalodon Closed Circuit Rebreather, to an Asia-Pacific cave depth record of 201m (660 ft). He is currently planning the Yamishiro Project, an international expedition aiming to dive the Japanese battleship *HIJMS Yamashiro* sunk in the Battle of Leyte in the Philippines in November 1944 and resting at a depth of 200m (660 ft). Cedric is a PADI Course Director and a Trimix Instructor Trainer for IANTD, PSAI, ANDI, DSAT and TDI. He spends most of his time teaching cave and mixed-gas rebreather courses at the diver and the instructor level. He is a past Regional Manager for PADI Europe and DAN and has written five books and more than 150 articles about diving. As he is always travelling all over the world, you can mainly contact him by email at: **info@cedricverdier.com** or visit his website at **www.cedricverdier.com**

References

Oxygen and the Diver by Kenneth Donald

Partial Pressures of Oxygen Selection in Closed circuit rebreathers by Rod Nairne

Setpoint Selection by Stephane Havard

Rethinking Oxygen Limits by Dr. R.W Bill Hamilton

Oxygen exposure management by Richard D. Vann

Physiology of Rebreathers by Dr. David Sawatzky

Chapter 17 and 17b of the *US Navy Diving Manual*