

# How Rebreathers Kill People

## Updated to 2016

# Sources of Safety Data

- ◆ Failure Mode Effect and Criticality Analysis (FMECA)
- ◆ Incident Reports:
  - Interview with survivors of incidents reported from dive clubs
  - Coroner's Reports
  - Fully Documented Fatalities
  - Web sites maintaining partial rebreather fatality lists
  - Forums advising of accidents, with follow up interviews where possible
  - CCR Manufacturers' reports
  - HSE Reports
  - IMCA Reports
  - BSAC Dive Accident Reports
  - DAN Accident Reports

# Diving Hazards and Rebreathers

- ◆ Diving is in itself a hazardous activity, with risk of fatality between 1 in 10,000 and 1 in 80,000 hours: around 1 in 9,000 diver years.
- ◆ The highest socially acceptable risk is considered to be that of a woman giving birth in a developed country: a 1 in 9000 risk of a fatal outcome. Some rebreathers are more than 100 times more dangerous.
- ◆ The fatal accident rate on CCRs is as high as 1 in 13 units manufactured for particular rebreather models, and is around 1 in 100 on average (in 2016). That is an extraordinarily high risk.
- ◆ Risks posed by diving in general are catalogued in “The Physiology and Medicine of Diving”, P. Bennett & D. Elliott (4<sup>th</sup> Edition).
- ◆ CCR diving entails a much higher level of risk than Open Circuit diving, from DAN, HSE and BSAC reports. This implies there are additional hazards not listed by Bennett & Elliott.
- ◆ The increased risk of CCR diving is not explained by lack of training: CCR divers tend to be much more experienced and trained than the Open Circuit divers.
- ◆ In FMECA reviews of third party CCR designs, a strong correlation between design defects and the accident rate of any particular rebreather was observed: that is, between a low MTBCF and a high fatality rate.
- ◆ This report describes some rebreather incidents, the failure modes those reveal, and how the associated risks can be reduced.

# FMECA Reports

- ◆ Requirement of EN14143 that manufacturers perform a FMECA (Failure Mode Effect and Criticality Analysis).
- ◆ No requirement within EN14143 to publish the FMECA or any test results.
- ◆ Most manufacturers are keeping their FMECA confidential, if it even exists at all.
- ◆ EN14143:2003 requires Functional Safety compliance to EN 61508, which in turn requires 1 billion hour fault tolerance, but is not implemented by manufacturers (CE Marks are being put on equipment falsely).
- ◆ In 2013 manufacturers succeeded in removing Functional Safety requirements from the CE process: compliance with IEC EN 61508 was removed from EN 61508, against the advice of many safety specialists.
- ◆ Non-CE rebreathers being sold, with NO testing even of ability to control PPO2. Users and Government Safety Organisations are turning a blind eye to the death rate.
- ◆ Result is no pre-2011 rebreather can tolerate one worst-case failure.
- ◆ Result is users have not the faintest idea of the safety of what they are diving.
- ◆ Result is no-one can challenge wrong conclusions in a FMECA.
- ◆ Result is there is no FMECA data on which to build better systems.

**Recommendation:** All manufacturers selling any piece of life critical equipment to the public should publish the full FMECA Report on their web site along with the EN 61508 calculation and safety case.

# Some of the incidents

- 1) Computer decided to do an O2 sensor cal underwater, all on its own
- 2) Rebreather controller hanging
- 3) Displaying completely wrong PPO2 values on all cells due to water block
- 4) Sudden massive flood, including CO2 hit and caustic cocktail
- 5) Two O2 sensors fail (from same batch)
- 6) ISC APECS bug injects only 1/20<sup>th</sup> the amount of O2 intended
- 7) Mistakenly injecting O2 on descent instead of diluent
- 8) Loss of diluent on descent
- 9) O2 injector sticks on
- 10) Connector mismatched: flood
- 11) Manifold O ring fails
- 12) CO2 retention due to increase in Work of Breathing caused by fitting faulty component
- 13) CO2 hits due to scrubber failure
- 14) Unit not switched on
- 15) PPO2 falls below that required to sustain life due to water block
- 16) O2 injection rate insufficient for ascent
- 17) PPO2 set point allowed to be lower than that required for safe ascent
- 18) Errors in O2 sensor calibration
- 19) Bugs in decompression software
- 20) CNS toxicity
- 21) Use of uncalibrated "O2"
- 22) Solenoid power drain causes PPO2 to read incorrectly, affecting PPO2 control

# Incident 1: Jump to O2 Cal

**Location:** Scapa Flow, May

**Dive Profile:** Diving to 100ft, displays showed PPO2 at set point of 1.3.

**Incident Report:** “I heard O2 injector come on and stayed on all of its own accord. Looked at handset. The Inspiration controller had jumped to performing a calibration and was injecting pure O2. No alarms. Bailed out.”

**Cause:** System checked by qualified electronics engineer.

- Unused memory locations were random codes when they should have been a jump to a recovery point.
- There was no Watchdog Timer installed – an essential safety feature.
- The brown-out circuit was completely ineffective. Power supply circuit prone to brown-out.

Manufacturer advised, corrected shortcomings on new product, but did not recall anything. These faults were not disclosed to coroners investigating deaths, in circumstances where the coroner may have concluded the CCR controller was the cause if disclosure was made. The electronics design and software design was absolutely incompetent. It later transpired that APV had used Nick Hester to perform this work when Mr Hester had no engineering training whatsoever – he was a salesman. Project Manager also had nil engineering training.

**Recommendation:** Functional Safety requirements need to be reinstated and enforced: application of EN 14143:2003 and its requirement to meet EN 61508, would have prevented deaths where the cause was the circuit errors listed above. Employing competent staff would have avoided the above. The sale of these controller is damnable.

# Incident 2: Hanging Controller

**Location:** Scapa Flow, June

**Dive Profile:** Diving to 110ft, displays showed PPO2 at set point of 1.3.

**Incident Report:** “It occurred to me that the O2 injector was not firing (it was silent for too long). Did a flush. Displays stayed the same. Did not respond to buttons. Concluded computer had hung. No alarms sounded.

Tried switching off and back on. Computer insisted on calibrating sensors. On cal, computer injected pure O2 even though depth was 110ft.

Bailed out. If I had not been listening for the O2 injector, I would be dead.“

**Cause:** System checked by qualified electronics engineer.

Unused memory locations were random codes when they should have been a jump to a recovery point.

There was no Watchdog Timer installed.

The Brown-Out Circuit was tested and design found to be completely ineffective.

Power supply circuits were prone to brown out.

Manufacturer advised, corrected shortcomings on new product, but did not recall any product

Many deaths on this product are due to the above fault.

**Recommendation** same as Incident 1. Note the same causes, result in a different fault manifestation: what happens depends on what random address the program jumps to.

# Incident 3: PPO2 Reading False

**Location:** Turkey

**Incident Reports:** 3 cell analogue PPO2 monitor fitted to inhale counterlung, using a third party cell holder, and this then routed to eCCR controller as eCCR controller was untrustworthy. On quayside, eCCR was maintaining a PPO2 of 0.7 atm well. Prebreathe of 5 minutes. Dived in, noticed PPO2 was not changing. At 10m injected O2, and PPO2 display still did not change. Bailed out and aborted dive. Back on quayside, unplugged O2 cell holder and analogue PPO2 display was still showing 0.7 for all cells for several minutes in air. Slowly cell outputs changed to show 0.21. Water could be seen drying from cell membranes.

**Cause:** Water block on cell membranes, meant the rebreather controller was effectively blind. This can produce both hypoxia and hyperoxia, depending on what the cells are showing when the water block occurs.

## **Recommendations:**

Manufacturers MUST test for PPO2 accuracy in worst case conditions of maximum length dives, in both coldest and hottest water, with rapid ascent and descent.

Never locate O2 cells in condensing locations, such as the counterlungs or immediately post scrubber.

Cell holder must form a water well. Cells should have a rapid gas flow across them – e.g. in a breathing hose.

# Incident 4: Sudden Flood

**Location:** Lower Clyde, June

**Dive Profile:** Deep Support Diver for an extremely deep dive

**Incident Report:** “Sudden massive flood and CO2 hit. Caustic cocktail inhaled, lots of it. Difficult getting back to surface and staying on surface due to loss of buoyancy because of flood. When CO2 hit, under influence of CO2 hit, caustic cocktail in mouth but hallucinated it was in nose. No warning headache. Became a critical situation. Averted by last second bail out. Due to CO2 did not think of dropping my weight belt.”

Forums and bulletin boards contain a number of similar reports.

**Cause:** Caused by inadequate keying of hose connector into scrubber: unit passes pressure tests with hose rotated and not in keyed position, if hose nut is tightened down. However, a bump on the hose causes it to fail with water pouring into the scrubber. The hose keying is a serious design fault.

Manufacturer advised, disregarded problem. Charged for service of rebreather, writing “Not dishwasher proof” on inside of scrubber lid after user completely stripped it down and tried a dishwasher to remove caked on caustic chemicals. Early warning of a flood (gurgle) not covered in course.

**Recommendation:** FMECA should have highlighted the problem. This indicates that no adequate FMECA was carried out. The manufacturer has since changed their training procedure and manuals to highlight the effect of a flood.

# Incident 5: Two O2 Sensors Fail

**Location:** Dunbar, August

**Dive Profile:** To 160ft, Beside Bass Rock

**Incident Report:** “One O2 sensor failed during dive (lower than others). Running on 2 sensors. Then injector was injecting more often than I would expect given constant depth. Flush indicated PPO2 was different to what I expected, but not massively. I made an error in this due to narcosis. Concluded (incorrectly) that O2 injector was firing more often due to blockage in O2 line. Aborted dive remaining on closed circuit. During ascent suddenly injector firing problem cleared. Descending again caused injector problem to return. Further O2 sensor developed a ceiling fault. Based on depth and set-point at which injector was working normally (25ft, PPO2 of 1.2) I recognised this as a ceiling error on the other two cells.”

**Cause:** Bad O2 cell batch and unsafe O2 injection algorithm: PPO2 was far above the normal PPO2 that was displayed. How far above was unknown. It could be from 2.5 bar to 5 bar! Replacement of all cells at the same time is a bad practice. Voting logic is prone to follow cell failures.

## **Recommendation:**

- A fault tolerant PPO2 controller is mandated in Europe, but the law is not applied.
- Cells should not be replaced at the same time with cells from same batch.
- CCRs should not use voting logic for O2 controllers to substitute for a properly designed sensor management subsystem.

# Incident 6: Lethal ISC APECS Bug

**Location:** 13 fatal accidents investigated, along with lab and manned testing

**Dive Profile:** Chamber dives and manned diving on Megalodon RB with APEC 2.01J

**Incident Report:** At least 1 in 13 of Megalodon rebreathers with APECS software revisions before 2.01K were involved in fatal accidents. To understand why, Meg bought by Deep Life and tested both in a chamber and in manned dives in Turkey. Reported poor PPO2 control to manufacturer but manufacturer did not reply that it is a known bug.

**Cause:** Software bug switches on injector for 0.25s instead of 2.5 seconds. As a result, the maximum O2 flow is 0.7lpm instead of 17 lpm. User must change setting before every dive. If reset occurs during dive, then diver is back to a maximum of 0.7 lpm of O2 injection. No recall (“against ISC's company policy”, regardless of what the law says or morals demand). Fatal accidents appear to be still occurring in 2015 from a bug fixed in 2006! There is also a dangerous scrubber bypass path on these early ISC Megalodon units.

## **Recommendation:**

The rebreather was never tested before sale. This is damnable.

Total recall should have occurred.

Manufacture;s response was totally inadequate and self serving.

Even in the Rev 2.01k bug fix, the PWM control was incompetently programmed.

See <http://www.rebreatherworld.com/showthread.php?4631-Meg-owners-need-some-help-from-you.../page3>

# Incident 7: Injecting O2 Accidentally

**Location:** Dunbar, September

**Dive Profile:** To 130ft, Beside Bass Rock

**Incident Report:** “Was very tired that day as I had had a lot of hassle. Still thinking about it during start of dive. Thought alarm was from another diver who had something bleeping (boat load going down together). Before I saw the bottom, felt very bad and left eye was twitching then left eye closed out (like seeing a curtain come down half way and what was left was in negative colour). Saw handset with other eye which was normal. Rebreather was full of O2, instead of DIL.

Bailed out and simultaneous did max rate ascent to 20ft. Ascent so fast it was off scale of dive computer, a Cochran, which locked out afterwards. Then from 20ft slow ascent to surface. Took about 10 minutes for eye to return to normal.”

**Cause:** User error - kept pressing O2 button instead of dil button on descent.

## **Recommendation:**

- BOV Auto Shut-Off valve would eliminate this type of user error.
- O2 manual button should be very distinct and be flow limited, e.g. to 16lpm. This simple measure would have eliminated this source of user error. I.E. it is a design error not to do so because safety products must apply the ALARP principle.
- Requires clearer alarms, such as voice annunciation or HUD display, so diver is aware when his unit alarms, when diving in a group.

# Incident 8: Loss of Dil

**Location:** Dunbar, September

**Dive Profile:** To 60ft

**Incident Report:** “Dil injector came off during descent. Descent accelerated while trying to turn on bail out gas to bail out reg. Hit the bottom so hard it formed a mushroom cloud in the water. Fortunately only 60ft. Embarrassing minute. Had been concentrating on turning on bail out gas (switched off because I did not want freeflow on diving into the water), rather than filling the BCD which I should have done: when in a real squeeze, you get tunnel focus on breathing rather than depth.”

Diver involved was experienced in freediving – without that experience this incident could have become a fatal mishap.

**Cause:** Dil connector not plugged in properly and requires only one action to disconnect. No ADV fitted by rebreather manufacturer.

## **Recommendation:**

All essential connections should require two actions to disconnect.

ADV is a basic safety requirement and would have avoided this incident.

Suggested to manufacturer and to forums that an ADV be created. Many disagreed with need for ADV with connector that is not plug-in.

# Incident 9: O2 Injector Stuck On

**Location:** Scapa Flow, April

**Dive Profile:** To 110ft

**Incident Report:** “O2 alarms went off. Injector was on continuously.”

## **Cause:**

Injector stuck on, after first stage changed without changing interstage pressure.  
Solenoid Injectors fail too easily. Solenoid not designed for life critical systems.

## **Recommendation:**

Cheap solenoid injectors designed for machine automation should not be used for rebreathers as they are prone to rust and cannot tolerate the full range of intermediate pressures provided by dive first stage regulators in common use. Both failure modes the injectors have are unsafe: either stuck on, or stuck off.

The injector should be made from a rust free material, with reasonable oxygen compatibility, such as SS 6ML. Iron parts should be coated to prevent corrosion, e.g. with DLC.

Whole question of whether solenoids are suitable at all for control of PPO2 in a rebreather.

# Incident 10: Connector Unplugs

**Location:** Scottish West Coast, May

**Dive Profile:** To 90ft

**Incident Report:** “Flood. After an earlier flood event, I had changed the original BCD to OMS 110lb dual wing, so no problem with buoyancy, so was able to do instant bail out with no buoyancy problems.”

**Cause:** Connector at the back of the unit: connector seals before it has positive ident. This allows unit to pass all negative and pressure tests with connector not properly engaged.

**Recommendation:** Where connectors are used in the breathing loop, they must not seal until locked.

# Incident 11: Manifold Ring Fails

**Location:** Swimming Pool, Edinburgh

**Dive Profile:** To 12ft

**Incident Report:** “Lots of bubbles suddenly. Rotating around I could see it was from back of the unit. Manifold cap came loose. Just swam back on the surface. Rarely use the manifold. Removed it now permanently: it is completely unnecessary.”

**Cause:** Superfluous manifold, created additional failure points.

**Recommendation:** FMECA had failed to remove all non-essential points of failure.

# Incident 12: WOB Failure

**Location:** Bushman's Hole, South Africa

**Dive Profile:** To 900ft

**Incident Report:** See Report on Dave Shaw fatality on <http://outside.away.com/outside/features/200508/dave-shaw-1.html> and analysis of fault on <http://www.rebreatherworld.com/showthread.php?t=1337&page=2&pp=10>.

**Cause:** Fitting incorrect scrubber filter material.

## **Recommendation:**

Fit a Respiratory Monitor, so when respiratory rate becomes too high, or tidal volume too low, warn the user to breathe more deeply and slowly. Same monitor could detect increase in WOB at outset.

Deep Life have a WOB monitor using the same hardware components as scrubber monitor. This means that adding a WOB monitor does not cost a cent more in terms of hardware build.

Could be useful to fit a fan as an emergency assisted WOB, and this can double up as a breathing-bag-drier during battery recharge.

# Incident 13: CO2 Hits

**Location:** Numerous reports, including a fatality by group preparing for 2<sup>nd</sup> dive on HMS Dasher.

**Dive Profile:** Occurs usually during decompression

**Incident Reports:** <http://www.rebreatherworld.com> and <http://www.btinternet.com/~madmole/divemole.htm>

**Cause:** Scrubber expires and no alarm.

Manufacturer had not published adequate information to assess the suitability of the scrubber for deep dives. In fact, scrubber duration was a tiny fraction of that expected, because the manufacturer's durations were for a 40m “profile” not 40m flat or flat for other depths.

## **Recommendations:**

Publish clear information on duration based on flat profiles.

Fit a CO2 alarm or fit an effective scrubber life monitor.

Redesign the scrubber so it does not fail suddenly, but gradually, giving time for the alarm to sound and for the diver to take corrective action.

Eliminate spacers and other parts that must be fitted to avoid bypass.

# Incident 14: Unit not turned on

**Location:** Several deaths where the unit has been found to be switched off

**Dive Profile:** Not applicable

**Incident Reports:** List of fatalities maintained on Diver Mole web site

**Cause:** User error and design omission

## **Recommendations:**

All eCCRs should turn on automatically when PPO<sub>2</sub> is less than 0.20.

When the unit is switched on automatically, it is essential the design is one where it cannot hang under any possible circumstance. Therefore the user should never need to switch it off underwater.

# Incident 15: PPO2 falls below that required to sustain life due to slow O2 sensors

**Location:** Found using formal verification tools checking O.R. design, reported on a dive forum, then users of existing rebreathers reported near fatal accidents due to use of slow sensors.

**Dive Profile:** Rapid ascent

**Incident Reports:** On dive forums

**Cause:** User error and design limitation

## **Recommendations:**

1. The sensors should be keyed so users cannot change the sensor type
2. The control software should check the rate of change of the sensors during cal and reject slow sensors. No existing CCR did this: it was possible to pass cal on all rebreathers that were checked, using sensors with 25 second response.
3. 9 of the 11 possible O2 sensor failure modes result in a low PPO2 reading or a slow sensor reading. The sensor voting algorithm can track this. The sensor processing should test for slow O2 response.
4. Use of an Auto Shut Off Valve safeguards the user in the event of this fault

# Incident 16: O2 injection rate insufficient for ascent

**Location:** Found using formal verification tools checking O.R. design, then cross checked with existing rebreathers and found to correlate with high fatality rate on particular units

**Dive Profile:** Low PPO2 set point followed by rapid ascent.

**Incident Reports:** On dive forums

**Cause:** Design limitation

## **Recommendations:**

1. EN 14143:2003 needs a “work around” to comply with the standard while allowing the CCR to inject more than 6 litres per minute of O2 in emergency. One work around is to fit multiple injectors (as in the O.R. design).
2. Manufacturer must allow ascents up to 350ft/min (max possible with an inflated BCD), from the maximum depth and with the lowest PPO2 set point supported by the CCR.
3. OPVs should never be in inhale counterlung: only on exhale counterlung, otherwise reverse flow occurs so all injected O2 is swept back away from diver into exhale CL and then discharged from rebreather. O2 display looks normal when this occurs.
4. Auto Shut Off Valve would have prevented the deaths caused by this fault.

# Incident 17: PPO2 set point allowed to be lower than that required for safe ascent

**Location:** A distinct variant on Incident 16: Found again using formal verification tools checking O.R. design, then cross checked with existing rebreathers and found to correlate with high fatality rate on particular units

**Dive Profile:** Low PPO2 set point followed by rapid ascent.

**Incident Reports:** On dive forums

**Cause:** Design error on particular rebreathers

## **Recommendations:**

1. The min PPO2 set point when shallow, must allow the diver to “pop” to the surface without the PPO2 falling below 0.21
2. No sports rebreather should allow a setpoint below 0.7 atm. Allowing a 0.4 atm setpoint correlated with fatal accidents on one make of rebreather.

# Incident 18: Errors in O2 sensor calibration

**Location:** Red Sea

**Dive Profile:** Deco dive

**Incident Reports:** Reported and discussed on RebreatherWorld. Note of much higher DCI incidence with CCRs than expected statistically.

**Cause:** User error and design omission, allowed the user to calibrate the CCR as if it was 98% O2, when PPO2 level in the loop could have been as low as 48%. Result was Cat III DCI.

## **Recommendations:**

All O2 sensors should calibrate in air when the unit is open: users should not be asked to calibrate with a gas supply which may not in itself be calibrated, injecting an uncalibrated amount of gas into an uncalibrated loop volume (the procedure used by the manufacturer).

# Incident 19: Bugs in decompression software

**Location:** Multiple locations

**Dive Profile:** Deco dives

**Incident Reports:** Analysis of statistically high incidence of DCI on rebreathers, followed by formal verification of dive software in the O.R. project which compared results with those from several sources. No direct link, but strong indicator of link

**Cause:** Failure to follow mandated design procedures

## **Recommendations:**

All decompression software should be formally verified to prove that the algorithm implemented is actually that intended.

Decompression computations should not be corrupted or reset in the event of a full reset underwater (e.g. a battery disconnect and reconnect).

The PPO2 used by the dive computer lowest PPO2 that the sensors are measuring, not the mean or the highest.

# Incident 20: CNS toxicity

**Location:** Multiple

**Dive Profile:** Long dives

**Incident Reports:** 6 accidents involving of CNS convulsions. See

<http://www.rebreatherworld.com/rebreather-accidents-incidents/1632-o2-convulsion.html#pos>  
and

<http://www.rebreatherworld.com/technical-rebreather-forum/4304-guide-about-setpoint-select>

**Cause:** Incorrect use of CNS calculation. Original papers describing CNS calculation is based on a 4% reduction in vital capacity with 100% CNS loading (Oxygen Toxicity Calculations. E. Baker). NUI research paper indicating 1% of users having CNS toxicity effects at 75% CNS loading. Despite this, users believe they can tolerate 100% CNS loading as a basic plan: some report regular dive planning with 175% and 250% CNS loading.

## **Recommendations:**

Modified CNS algorithm, with margin to reduce statistical incidence of measurable CNS damage. Published on DL Web Site, and on RebreatherWorld, with formal model to enable implementation to be verified

CCR controller should track CNS and maintain within safe limit by adjusting PPO2 set point if necessary

# Incident 21: Low FO2 in O2 Cylinder

**Location:** Singapore and UK

**Dive Profile:** Not applicable

**Incident Reports:** RebreatherWorld

<http://www.rebreatherworld.com/rebreather-accidents-incidents/5513-my-first-screw-up-boris>  
and one incident reported through dive club

**Cause:** User error and design omission allowed user to dive with 60% O2 in cylinder used as 100% O2. Almost a fatality in both cases.

## **Recommendations:**

1. Rebreather itself should check the O2 composition before every dive. It has calibrated O2 sensors (if the recommendation to force calibration in air is adopted), and can inject O2 and check the composition of the loop gas on the surface to give an injector cal. It is not difficult to compensate the injector cal for depth, such that no gas switch can introduce a low FO2 gas
2. Auto Shut Off Valve would have prevented the problem affecting the diver's safety
3. Voice annunciation of the resulting low PPO2 level would have prevented the problem affecting the diver's safety

# Incident 22: PPO2 Falls

**Location:** Leith Dock, October

**Dive Profile:** Quayside

**Incident Report:** “When Inspiration injector fires, display PPO2 drops due to current drain. Almost new batteries. System then keeps injector on for too long, so PPO2 level seesaws.”

**Cause:** Engineers from two companies each specialising in dive safety were present.

Problem caused by lack of screening on O2 sensor cables and poor power supply circuit.

Manufacturer advised, investigated but declined to fix problem until a later legal case increased the priority they gave to safety.

**Recommendation:** Publishing FMECA would have highlighted the problem.

# Culture and Ignorance

- ❑ Too many reports simply cite “User Error”. Needs to be a change of attitude to: “Nobody should die on a rebreather from user error, unless they take the mouthpiece out of their mouth and do not replace it with something breathable.”
- ❑ No testing has been carried out on many rebreathers sold. Users are not aware of this because the manufacturer is a well known name.
- ❑ Test houses used for rebreather certification and active on standards committees have zero training on Functional Safety and no electrical or software safety training. The electronics and software of rebreathers are the most hazardous parts of these products.
- ❑ Functional Safety requirements are removed from the CE standard for rebreathers. No PPE Notified Body involved in rebreather approval currently has any training or competence in Functional Safety.
- ❑ Egos override decency, morals, and common sense.

# Preventing the Deaths

1. Most rebreathers currently are nowhere near the standard expected of other life critical systems.
2. Most manufacturers use staff with no Functional Safety training, to design life critical systems, including the electronics and software in rebreather control.
3. All functional safety requirements were removed from the CE standard for rebreathers in 2013, and prior to that, only one company had the Functional Safety audit carried out.
4. Technologies are available that would have prevented every one of the incidents cited here.
5. People are dying because equipment is designed badly, with inadequate safeguards. There was inadequate testing before sale to the public.
6. Manufacturers are split: a few respond quickly to safety issues, others oppose safety initiatives. The worst units described here, that reset and hang, or which inject just 0.7lpm of O2 instead of 16lpm, have never been recalled.
7. The four sports rebreather manufacturers with the worst safety records try to gag Safety Professionals by sponsoring trolling and slander web sites against them. Those same manufacturers campaigned for standard organisations to drop Functional Safety requirements for rebreathers.
8. It is left to the diver to be aware. Be VERY aware.

# Industry Response

The response of the rebreather industry to these safety issues has been:

1. Industry body created (RESA) campaigning for LOWER standards.
2. RESA founder created slander site targeting whistleblowers and expert witnesses that dare to raise issue with the manufacturers RESA represent.
3. Functional Safety (EN 61508) compliance requirements removed in 2013 from the European rebreather standard.
4. The illusion of adding some clauses from EN 61508 into the rebreather standard is a fiction in practice because no PPE Notified Body has any training or expertise whatsoever in applying Functional Safety (as of February 2016).
5. When instructors report problems to manufacturers, they are sidelined and threatened with removal, taking away their livelihood.
6. Widespread intimidation of experts is a serious obstacle in legal challenges that seek to improve safety or compensate for damage.

Hence, the onus is on the diver to be VERY careful and aware. Remember there have been zero recalls on any of the rebreathers behind the reports here.

Your life as a diver depends on assuming nothing at all has been tested unless the CE test results are published AND the functional safety data for the product has been audited by SIRA and certified. Divers cannot rely on anything otherwise.