Sentinel Features Integration Background
What's new in Life-Support Systems (LSS)
Just 'Check-And-Dive'

Preliminary Information. November 07

Contents

Overview

This document provides information on features of the Sentinel LSS that especially contribute to safety and ease of use. In particular it covers the integration of the mechanical and electronics control systems. This provides an intelligent, but simple to use, life-support system (LSS).

The Sentinel provides the user with a simple **Check-and-Dive** functionality that makes the Sentinel the quickest and safest LSS to prepare for diving.

It uses intelligent monitoring and design experience to determine the appropriate tests and checks that the diver needs to perform to get the LSS ready for diving.

Any problems or remedial action are described clearly on the full-colour graphics screen.

Sentinel is available in 3 user levels:

- Level 1 - 40m no decompression
- Level 2 - 60m Normoxic
- Level 3 - 100m Trimix

All Sentinels have a Heads Up Display (HUD) and a colour primary display.

Sentinel LSS Features and Options

Key	
Standard part	**Y**
Optional part	**OPTION**
Not available	NA

	Sentinel Level 1	**Sentinel Level 2**	**Sentinel Level 3**	**Sentinel M (military)**
	40m Air Diluent	60m Single gas trimix diluent	100m Multiple gas trimix diluent	Multiple gas trimix/nitrox diluent
Features				
STANAG and AMP 15 compliant	NA	NA	NA	**OPTION**
2 L Oxygen cylinder	**Y**	**Y**	**Y**	**Y**
3 L Diluent cylinder	**Y**	**OPTION**	**OPTION**	**OPTION**
2 L diluent cylinder	**OPTION**	**Y**	**Y**	**Y**
Bailout Valve Mouthpiece	**Y**	**Y**	**Y**	**Y**
Hard Covers	**Y**	**Y**	**Y**	**Y**
Flight Case	**Y**	**Y**	**Y**	**Y**
User pack Granular canister	**Y**	**Y**	**Y**	**Y**
Extendair canister	**Y**	**Y**	**Y**	**Y**
Pre-pack granular canister	**Y**	**Y**	**Y**	**Y**
Filter in-out sensor	**Y**	**Y**	**Y**	**Y**
Expedition Battery Pack	**OPTION**	**OPTION**	**OPTION**	**OPTION**
Back-mount counterlung	Y	**Y**	**Y**	**Y**
Over-shoulder counterlung	**OPTION**	**OPTION**	**OPTION**	**OPTION**
Manual Diluent Addition	**NA**	**Y**	**Y**	**Y**
Manual Oxygen Addition	**NA**	**Y**	**Y**	**Y**
ADV	**Y**	**Y**	**Y**	**Y**
Bailout mouthpiece	**Y**	**Y**	**Y**	**Y**
Solenoid isolator	**NA**	**NA**	**Y**	**Y**
ADV isolator	**NA**	**NA**	**Y**	**Y**
Wing/ Harness	**Y**	**Y**	**Y**	**Y**
Primary display	**Y**	**Y**	**Y**	**Y**
Backup display	**OPTION**	**Y**	**Y**	**Y**
Colour screen	**Y**	**Y**	**Y**	**Y**
Intelligent Backup display	**OPTION**	**OPTION**	**OPTION**	**OPTION**
HUD	**Y**	**Y**	**Y**	**Y**
Rear HUD	**Y**	**Y**	**Y**	**Y**
Digital oxygen HP	**Y**	**Y**	**Y**	**Y**
Digital Diluent HP	**Y**	**Y**	**Y**	**Y**
Canister Duration meter	**Y**	**Y**	**Y**	**Y**
Canister filter in/out detector	**Y**	**Y**	**Y**	**Y**
Wired recharger	**Y**	**Y**	**Y**	**Y**
Magnetic recharger	**OPTION**	**OPTION**	**OPTION**	**OPTION**
PC link PIN	**OPTION**	**OPTION**	**OPTION**	**OPTION**
PC link software	**OPTION**	**OPTION**	**OPTION**	**OPTION**
Auto-breathe turn-on detection	**Y**	**Y**	**Y**	**Y**
VPM code	**OPTION**	**OPTION**	**OPTION**	**OPTION**
AUTO O2 calibration	**Y**	**Y**	**Y**	**Y**
Dynamic gas reserve alarm	**Y**	**Y**	**Y**	**Y**
Auto setpoint switching	**Y**	**Y**	**Y**	**Y**

Check-And-Dive – Integrated Life Support (ILS)

The Sentinel Life-Support System (LSS) is designed around a breathing loop, high pressure gas sources and electronics control system - all highly integrated to give an intelligent but simple display of status to the diver while providing life-support.

This gives the user a simple **Check-and-Dive** functionality that makes the Sentinel the easiest LSS to prepare for diving, while ensuring system integrity and improving safety.

It uses intelligent monitoring and design experience to determine the appropriate tests and checks that the diver needs to perform to get the LSS ready for use.

Any problems are described clearly on the Main screen, Status and Summary screens. All of this combines to make a unique ILS system.

The integrated system design means that failures or problems with any part of the system are advised to the diver, either in pre-dive checks and procedures, or as data values or graphics. There is significant background analysis that produces a warning system sensitive to changes in expected levels, but intelligent enough to not confuse and over load the diver with information and situations that may be routine during a dive. These electronic alarms combined with varying levels of mechanical user controls ensure ILS is maintained.

Examples:

- PPO2 changes that may normally cause PPO2 alarms to be triggered are inhibited if they are of the correct characteristic expected during a descent or setpoint change.

- There is a significant amount of mechanical design required to achieve a moisture tolerant breathing loop that reduces distortion of the readings from the PPO2 cells to a minimum. The reliability of the PPO2 readings is further improved by employing a voting algorithm for the PPO2 cells that can ignore data from rogue cells.

The Sentinel design is simple to use, but this simplicity does not mean that the system is simple or stupid in terms of data processing or control analysis. The Sentinel includes many levels of warning and system analysis. Simplified through experience and intelligence to provide a straight forward human interface that does not routinely overload or annoy with status or false warnings.

It takes considerable system intelligence and experience to ensure the warnings do not overload or falsely advise the user of problems. If falsely warned too many times then there is a reduced likelihood of the diver

responding correctly to a truly dangerous and potentially life-threatening situation.

Mechanically it is vital that simple mechanical tasks required to set up the LSS are not ambiguous and prone to user error.

The Heads Up Display (HUD) is an ergonomic addition for the diver, as it give a simplified and quick to follow view of the status of the LSS. The HUD as 3 main warning levels:

- **Flashing Red** - warning is activated when a dive should be aborted on open circuit or not started.
    - **If diving, the diver should switch to the bailout gas.**
    - The HUD **vibration alarm** will vibrate every **¼ second** for 10 seconds, then repeat the 10 second alarm every minute.

- **Solid Green and Blue LEDs** - warning is activated when a manageable error situation is in place. The correct response is to ascend slowly on closed circuit monitoring the Primary display.

- **Solid Green** - means there are no detected problems

The Led states are configured for colour blind as well as highly stressed divers. The position of the LEDs, the flashing or solid state provide conditions that can not be confused with one another. Also, during stressful dive scenarios, the position and status is quick to comprehend and therefore intuitively the desired response is performed.

The white LED indicates decompression status:

- White LED off = no decompression
- White LED flashing slowly = decompression required, currently deeper than deco ceiling
- White LED solid = at decompression stop
- White LED flashing fast = shallower than decompression ceiling

Pre-Dive Checks

With current technology, not all aspects of the safety and working nature of a LSS system can be performed or determined automatically. Therefore, when turning on the Sentinel, there are a series of pre-dive checks that must be performed. The Sentinel also gives guidance in performing these checks. These checks are displayed in sequence on the Sentinel main display unit. Some of these checks rely completely on the diver to perform them correctly – eg check breathing loop for leaks. Other tests can be more positively tested for by the electronics control system and the user needs to confirm that these are OK to dive with – eg that the high pressure cylinders are adequately filled.

These tests are designed to:

a. Check that all functions of the LSS have a high likelihood of operating correctly
b. Detect assembly errors
c. Detect breathing loop errors
d. Advise the user of system measurements that are outside correct operating parameters. These include:
    a) High Pressure readings too low
    b) High Pressure readings dropping too quickly – possible leaks
    c) Battery Levels
    d) PPO2 partial pressure of oxygen in the breathing loop
    e) Calibration of PPO2 cells performed correctly
    f) CO2 absorbent functioning correctly
    g) CO2 Filter inserted correctly
e. Reduce redundant tests so that users are not inclined to skip tests that have been performed correctly, sufficiently recently

During the PreDive checks, a short press of both buttons will bring up a simple alarms status screen so that the user can determine at a glance the status of the system while doing a check. This can be useful to determine why a check is not working correctly.

Decompression and Fly time are available from the options menu.

With these aspects in mind, there are 3 levels of Pre Dive checks:

Full system check with oxygen sensor calibration

These tests are performed:

a. After a canister change has been detected
b. Manual chosen by the diver from the Setup screen

There is a canister detector in the middle of the filter assembly. This detects the white material of the filter device. If the detector becomes

dirty, especially from being covered in CO2 absorbent granule dust, then this auto-detection may not operate correctly.

It is important to keep the filter assembly clean and free of dust and lubricated .

Full system check without calibration

These tests are performed > 18hours since the last full Pre-Dive tests, or if the last Pre-Dive tests were not completed correctly.
All the tests are important. However, due to the nature of LSSs, the most important test is the **Pre-breathe as this helps ensure that there is no breakthrough in the CO2 absorbent filter or seals and that key functions are operating (solenoid etc,).** CO2 breakthrough causes a toxic gas in the breathing loop to gradually build up. This build up may not be detectable by the diver, who will eventually just pass out from breathing an elevated CO2 level.
Leak tests of the breathing loop and high pressure systems must also be performed diligently to ensure the apparatus will function correctly when diving.
HP, PPO2 (and sensor condition) and battery levels are monitored by the system. The readings from these systems are displayed during the pre-dive checks.
The Head Up Display and the Main display are able to advise the user of any readings considered outside safe conditions (See full manual on the alarm conditions).
If you are not happy with any of these readings always check the problem and do not dive the LSS.

Reduced Pre-Dive checks

These tests are performed if the unit has switched off then turned back on again and it is less than 30 minutes since the last full pre-dive checks. These tests are reduced to limit the annoyance of performing the same tests over again and reduce ‘alarm blindness’ where users simply skip tests. However, it is imperative that full system checks and the pre-breathe sequence in particular be performed if any mechanical disturbance or other incidents have occurred since the last full pre-dive checks that may affect the performance of the LSS.

If any Pre-Dive screen is aborted the warning DO NOT DIVE will be shown in the main dry screen. Do not dive the unit until all Pre-Dive checks have been completed successfully. An ABORT is logged in the memory.

An abort at any time will clear all previous checks. This will then force a >18hour pre-dive sequence.

Pre Breathe

Pre-breathing the LSS prior to diving is the most important of the Pre-Dive checks. It checks that the CO2 filtering is operating. If it is not operating correctly, eg there is a bypass of CO2, then any affects such as passing out or dizziness can be treated properly in safe dry conditions. There is a timer on the PREBREATHE screen of 5 minutes. The screen can not be exited (unless by ABORT) until 5 minutes has been completed. Always complete the pre breathe diligently. **If any adverse symptoms are felt or seen by other people during this time then stop breathing and check the filter and seal. Do not dive!**

Auto Calibration

The Sentinel LSS is able to perform accurate calibration of the Partial Pressure Oxygen (PPO2) cells in ambient air. This has particular importance on the ease and accuracy of achieving calibrated PPO2 cells.

The Sentinel is able to measure atmospheric pressure during calibration and make the appropriate calibration adjustments for the PPO2, even at altitude. Cell health is also logged and cell changed-outs are prompted for.

When performing PPO2 cell calibrations, it is important the calibration gas and ambient pressure are known. By using ambient air as the calibration gas this is known accurately.

The Sentinel uses advanced empirical techniques to ensure the accuracy of the ambient air calibration.

To ensure that ambient air is exposed to the cells, a filter detector is fitted to the centre Canister Duration Meter (CDM) spindle of the filter housing. When the detector changes from a filter ‘OUT’ to a filter ‘IN’ condition, the Sentinel immediately performs the calibration. This state change ensures:

a. The breathing loop is exposed to ambient pressure – ie not over pressurised
b. The breathing loop **must** be open. And therefore the gas must be ambient air.

Using the system above has advantages over an oxygen calibration because;

a. Air is a known Cal Gas
b. Over-pressurisation of the loop cannot occur (changing the PO2)
c. There is no flush routine required

This sequence is also triggered when the connector is inserted from the filter CDM module into the system.

The filter detector must be kept clean to ensure correct operation.

When the calibration condition is triggered, the reading from the cells is checked to ensure the PPO2 cells are inserted and are within the correct range. If they are not correct, then the calibration will be completed when the cells are inserted. In this condition, it is advised to ensure PPO2 cells are inserted correctly prior to a filter replacement and the CDM connector being inserted.

When the calibration has been completed, the LSS will restart the full Pre-Dive checks routine, first showing the state of the PPO2 cells.

If an error has occurred during calibration, then an O2Cell Cal-err warning will be displayed in the Status screen. The dry screen saver will show DO NOT DIVE.

The Status screen can be seen in Level 1 units by button pushes when dry, and diving. The Status screen shows detailed status of all alarms and readings taken by the LSS. See full manual for details.

If at any time the user wishes to perform a manual oxygen sensor calibration, this can be initiated from the Setup screen. **However, the canister must be exposed to air and the mouthpiece open. Otherwise an incorrect calibration will be performed.**

It is advised that all the sensors and filter in-out detector be maintained to ensure the automatic calibration performs reliably without the need for manual calibration.

Canister Duration Meter

The Sentinel LSS utilises a patented US Navy designed canister duration meter (CDM) under license.

This meter relies upon the exothermic reaction of the CO2 absorbent. The use of temperature sensors to determine the status of the CO2 absorbent has been performed in laboratory conditions for many years. The system detects a complex reaction wave-front through the absorbent. A proprietary data analysis algorithm then produces a considerably more accurate prediction of absorbent usage than other inventions of this type.

The readings from the CDM are shown as a percentage of canister duration remaining:

99% = fresh canister
0% = Completely used canister with a likelihood of CO2 breakthrough.

The duration of the canister depends mainly on the amount of CO2 being produced by the diver and the depth of the dive. The CDM is a useful feature to get extended duration from the canister when lower CO2 rates are generated by the diver. **After use however, CO2 filters should always be changed every 48 hours independently of the CDM meter reading, even assuming part used filters have been stored in a sealed loop.**

The CDM will not detect breakthrough conditions of a poorly packed canister. Therefore Pre Breathe checks must always be carried out to ensure CO2 is being absorbed correctly by the filter.

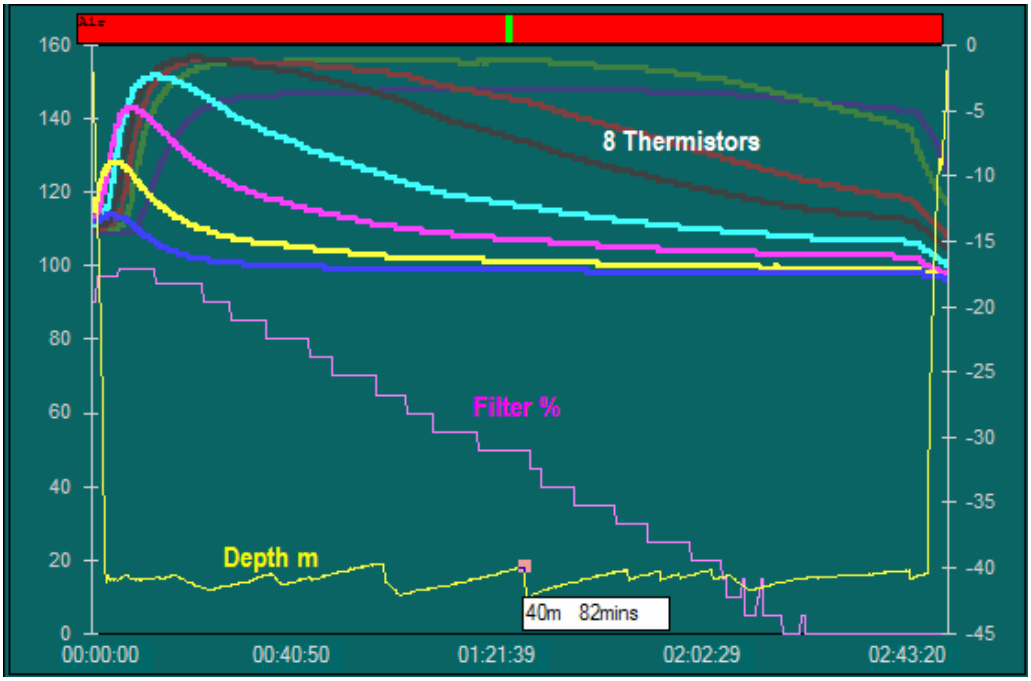
The CDM contains 8 thermistors arranged longitudinally through the canister absorption path. The readings from these 8 thermistors are logged and analysed by the system. In this manual, it is not appropriate to explain this data analysis in detail. However, it is appropriate to describe some of the limitations of the device.

The CO2 absorbent produces heat when CO2 is absorbed. However, there is also a temperature rise even when incomplete absorption of the CO2 in the breathing gas is achieved. This is a potentially dangerous situation, as the system appears to be working correctly as there is still a measurable temperature rise and wave-front in the system. The human body is tolerant to only approximately 5 to 10mBar of CO2 (ref CE standards for a life support system). A well packed fresh canister absorbs all the exhaled CO2 for a period of time until an amount of CO2 starts to creep through. When this level reaches 5mb it is assumed there is no life left in the filter. However even at 5mb there is still considerable thermal activity within the filter.
So be aware that a well packed and well maintained canister is key in achieving a life-support system. The CDM is not a substitute for good system maintenance and Pre-Dive checks. Always use your training and discipline to ensure the sub-systems in the LSS are operating correctly.

Critical components and potential failures are:

a. **The filter seal in the Canister head**
b. **The filter O ring at the base of the CDM**
c. **The auto-packing spring system**
d. **Used or out of date filter material**

Below is a graph of the data log from a chamber breathing system test dive. 1.6litres of CO2 is being fed into the system every minute. The external water temperature is approximately 4 degrees Celsius. It shows the thermistor readings on an arbitrary scale, canister remaining percent prediction and depth in metres. The endpoint of the graph is when the CO2 levels reach 5mBar break through.



The thermistor curves at the beginning of the dive, as the canister heats up, have a different shape to the middle to latter part of the dive. It is not sufficient to simply look for the position of the hottest part of the canister. This will give poor predictions of canister duration. A proprietary technique and algorithm analyses the curve and will generate the appropriate alarm.

If the filter is not changed within 7 days, the filter percent is forced to 0%. The filter should always be kept sealed until required for use. Once installed, the filter should be changed within 48 hours even if it has not been fully used through breathing. When installed and being unused, the LSS should have its breathing loop closed so that external air does not accelerate the degradation of the filter. However, once open and used, even if only a little, the filter will continue to degrade and change its characteristics post dive. Therefore, as previously stated, the filter should always be changed within 48hours of opening and/or use.

Partially used filters should be stored in the LSS with a closed breathing loop.

Backup Canister Duration Meter

The CO2 created by the diver is in direct proportion to the oxygen breathed. The oxygen metabolized by the body is replaced by the injection of oxygen into the breathing loop. By knowing the volume of gas injected, the amount of metabolized oxygen and therefore the amount of CO2 created can be calculated.

From tests, the duration of the filter types has been determined and the corresponding volume of CO2 absorbed before the filter begins to bypass.

Using these principles, the system measures the amount of gas injected by the solenoid valve and converts it to minutes remaining at CE CO2 rates. Although the displayed minutes are at CE CO2 generation standards, the minutes will tick down more slowly if the diver is breathing at a reduced rate. This will be the most common scenario. However, in the unusual condition of CO2 generation at an elevated rate compared to 1.6ltr/min then the minutes will tick off more quickly. If the diver knows a particularly strenuous dive is ahead, they should allow extra conservatism in the minutes remaining counter, for that dive.

The remaining duration in minutes is displayed on the Summary screen (under STACK) and checked for in the alarm system.

The volume count is reset when the filter is replaced and confirmed in the canister changed or filter reset screens.

This minutes counter should be used in conjunction with the CDM to determine the appropriate state of the filter.

For Level 2 and 3 users, excessive manual O2 injection will reduce the accuracy of the back up counter, as the solenoid valve will not fire as often.

If in doubt replace the filter and perform full pre-dive checks.

Auto turn-on

Normal practice and training is for the user to turn the LSS on by-hand and go through the pre-dive checks. The following failsafe additions are to reduce diver error, where the LSS is turned off prior to breathing on the unit.

The basis for the auto-breathe software is to reduce the chance of accidental death by breathing on a LSS that is in off/sleeping state. This has happened in several cases. The common method to reduce the likelihood of this is to have wet contacts that turn the unit on when wet. This is good for surface swimming. However, a chamber or non wet use of the LSS may occasionally occur. Wet contacts can also reduce battery life in wet environments.

Hence this detection of a ppo2 drop (simulating breathing) is an improvement to the wet contact system as it covers most cases of accidental use when the LSS is currently off and when a person forgets to turn the LSS on before breathing on the system.

Breathing detection turn on rules:

1. Turn on if ppo2 <0.17bar and > 0.05bar. If cells are removed or read 0.00 then the unit will only turn on with depth or by the user pressing a switch. This has to be done to conserve battery power when the user takes out ppo2 cells for storage or during transport. Current other LSS designs and CE approvals require a reduce safety margin than achieved even with this power save scenario. In other words, the chance of the user taking out the cells and accidentally not turning the unit on before breathing falls into user setup error that should not routinely occur due to training and a good pre-dive check regime. Other errors of no turn on of hp, etc. are much more likely, and should be reduced by proper training and the intelligent alarm systems.

2. Turn on if ppo2 drops a specified period in a given time.

If the diver does not have hp o2 turned on, alarms on the HUD and Primary display will occur as soon as auto turn-on occurs. Deaths have usually occurred because the diver has not been warned of a dangerous condition. Hence this method provides increased warnings whenever loop ppo2 is breathed when the unit is off.

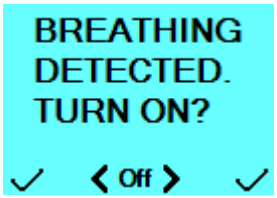
Compared with false turn-ons due to dome removal or flushing with diluent when at the surface or small shortfalls in battery efficiency the auto turn-on is a major safety improvement.

Breathing the loop, in all circumstances where the unit is breathable and ppo2 cells operative, will cause a safe turn-on.

The additional safety features described should never be used as routine. The unit should always be turned on by the user and pre-dive checks carried out as required in training and the operations manual. However, testing and confidence in this auto turn-on should be carried out occasionally under safe

0.70 bar or greater conditions. To do this, ensure the unit is off, flush with diluent until the PO2 falls and the LSS turns on.

The following screen is displayed when the auto-breathe detects breathing when the unit is sleeping:



This screen will remain on until the PO2 goes back to the setpoint currently active. To turn the unit off, a long press of both switches is needed. To continue to the pre-dive setup screen do a press of either switch.

Sensor polling

The LSS has a method of automatically removing O_2 sensor cells from the PO_2 averaging. This is based on a set of rules. For advanced users (Level 2 and 3 only) if the operator considers these are not appropriate for a particular type of cell failure, then any individual cell can be turned off manually. This can be accessed from the Cells option in the Dvo screen.
Rules:

1. If all cells have been disabled by the user the LSS control system is turned off

2. If a single cell is below 0.15 bar or above 3.00bar, then it will be disabled, **the system denotes this with an 'N' next to the cell**.

3. If after item 2, all 3 cells are disabled for the same fault, then all cells will be re-enabled – this ensures that if the O_2 is very high, or very low and all the cells agree, then the O_2 is probably very high or low accordingly.

4. If all cells are enabled and have no faults, then each cell is checked to see how many other cells it is within 0.20bar of.
   a. If all cells are within 0.20bar of each other, then all cells will be enabled.
   b. If two cells are within 0.20bar of each other and one cell is not, then the cell that is not within 0.20bar of the others will be disabled.
   c. If no cells are within 0.20bar of each other, then all cells will be kept enabled.

5. If all 3 cells are disabled with the same fault at this stage, then all will be re-enabled.

6. All enabled cells are then used in the PO_2 averaging. Any cell disabled in these calculations will have a D or N shown against it in the O_2 sensor Screen.

7. Examples:
   a. Cell 1 = 0.5bar, cell 2 = 0.60bar, cell 3 = 0.70bar. All cells used (rule 4a)
   b. Cell 1 = 0.3bar, cell 2 = 0.60bar, cell 3 = 0.70bar. Cells 2 and 3 only used (rule 4b)
   c. Cell 1 = 0.3bar, cell 2 = 0.60bar, cell 3 = 0.14bar. Cell 1 and 2 only used (rule 2)
   d. Cell 1 = 0.3bar, cell 2 = 0.60bar, cell 3 = 0.90bar. All cells used as no obvious fault in any single cell (rule 4c)

HUD and Colour Screen

The LSS can be routinely dived by using the Heads Up Display (HUD) as the main underwater human interface. This frees up the diver to concentrate on the mission or dive in hand.

If the HUD comes out of Green for ‘go mode’, then the diver can refer to the main display and investigate the additional status information.

The main display utilises colour to make it quick to see the general status coupled with unprecedented clarity of information.

To ensure the HUD display is still operating correctly, and to add a “wake-up” call to the diver, all LEDs in the HUD will routinely flash once every minute.

The HUD, colour screen and uncluttered screen layouts are key to providing the diver with essential information in high stress scenarios.

There are 3 main warning levels:

- **Flashing Red** - warning is activated when a dive should be aborted on open circuit or not started.
    - **If diving, the diver should switch to the bailout gas.**
    - The HUD **vibration alarm** will vibrate every **¼ second** for 10 seconds, then repeat the 10 second alarm every minute.

- **Solid Green and Blue LEDs** - warning is activated when a manageable error situation is in place. The correct response is to ascend slowly monitoring the Primary display.

- **Solid Green** - means there are no detected problems

The Led states are configured for colour blind as well as highly stressed divers. The position of the LEDs coupled with the flashing or solid state provide conditions that can not be confused with one another. Also, during stressful dive scenarios, the position and status is quick to comprehend and therefore intuitively the desired response is performed.

The white LED indicates decompression status:

- White LED off = no decompression
- White LED flashing slowly = decompression required, currently deeper than deco ceiling
- White LED solid = at decompression stop
- White LED flashing fast = shallower than decompression ceiling

The Led states are configured for colour blind as well as high stressed divers. The position of on LEDs, the flashing or solid state provide conditions that can

not be confused with one another. Also, during stressful dive scenarios, the position and status is quick to comprehend and therefore intuitively the correct response is performed.

Detailed Alarm conditions

ALARM	DESCRIPTION	ACTION	HUD STATUS
PPO2 OK	Measured PPO2 breathable and in setpoint limits		GREEN
PPO2 OFF	Rebreather control manually turned off	Use open circuit bailout	RED
PPO2 LOW	PPO2 breathable, but just outside setpoint control limits	Check status and operation	GREEN / BLUE
PPO2 HIGH	PPO2 breathable, but just outside setpoint control limits	Check status and operation	GREEN / BLUE
PPO2 VLOW	PPO2 dangerous – do not breathe on LSS	Use open circuit bailout	RED
PPO2 VHIGH	PPO2 dangerous – do not breathe on LSS	Use open circuit bailout	RED
PPO2 mLOW	PPO2 breathable, but outside setpoint control limits	Check status and operation	GREEN / BLUE
PPO2 mHIGH	PPO2 breathable, but outside setpoint control limits	Check status and operation	GREEN / BLUE
PPO2 > LOW	PPO2 breathable, but outside setpoint control limits due to setpoint change or doing ascent	Check status and operation	GREEN / BLUE
PPO2 <HIGH	PPO2 breathable, but outside setpoint control limits due to setpoint change or doing descent	Check status and operation	GREEN / BLUE
PPO2 DO CAL	PPO2 not valid – calibration required of O2 cells	Do not dive. Do O2 cell calibration before using LSS.	RED
PPO2 DO PRB	Breathing loop not tested – Prebreathe required	Do not dive. Prebreathe loop before diving the LSS.	RED
PPO2 SpInc	Auto setpoint adjustment made	Automatic setpoint adjustment just activated	GREEN / BLUE

ALARM	DESCRIPTION	ACTION	HUD STATUS
VALVE OK	O2 solenoid injection valve firing OK		GREEN
VALVE FAIL	O2 solenoid injection valve failed	Use open circuit bailout	RED L1 GREEN / BLUE L2/L3

ALARM	DESCRIPTION	ACTION	HUD STATUS
FILTER OK	Filter duration status OK		GREEN
FILTER CHECK	Filter backup duration meter LOW	Do not dive – change filter	GREEN / BLUE
FILTER LOW	Filter CDM LOW	Do not dive – change filter	GREEN / BLUE
FILTER EMPTY	Filter CDM EMPTY	Do not dive – change filter	RED
FILTER NOTFIT	Filter proximity detector showing filter not fitted	Fit filter, or clean proximity sensor lens	GREEN / BLUE
FILTER FITTED	Filter fitted OK	Filter fitted, but requires cell calibration to be completed	GREEN / BLUE
FILTER NFITCAL	Filter not fitted and cells need calibration	Fit filter, or clean proximity sensor lens	GREEN / BLUE
FILTER FITCAL	Filter fitted and cells need calibration	Filter fitted, but requires cell calibration to be completed	GREEN / BLUE
FILTER NO COMM	No communication with filter	Check connector is plugged in	GREEN / BLUE

ALARM	DESCRIPTION	ACTION	HUD STATUS
		correctly to canister. Check cable is not broken or damaged.	

ALARM	DESCRIPTION	ACTION	HUD STATUS
BAT OK	Battery level OK		GREEN
BAT LOW	Battery level LOW – charge immediately	Charge system immediately	GREEN / BLUE

ALARM	DESCRIPTION	ACTION	HUD STATUS
HP status – Diluent			
OK	HP level OK		GREEN
LOW	HP below reserve level	Turn on HP or fill cylinder	GREEN / BLUE
FAULT	HP reading outside valid level	Check HP sensor and cable for damage. Return for service.	GREEN / BLUE
RATE OK	HP usage OK		GREEN
RATE HI	HP usage high – leak or not turned on	Turn on HP. Check system for leaks.	GREEN / BLUE

ALARM	DESCRIPTION	ACTION	HUD STATUS
HP status – O2			
OK	HP level OK		GREEN
LOW	HP below reserve level	Turn on HP or fill cylinder – bailout if diving	RED
FAULT	HP reading outside valid level	Check HP sensor and cable for damage. Return for service. – Bailout if diving	RED
RATE OK	HP usage OK		GREEN
RATE HI	HP usage high – leak or not turned on	Turn on HP. Check system for leaks. – Bailout if diving	RED

ALARM	DESCRIPTION	ACTION	HUD STATUS
DECO STOP	At correct decompression stop depth	Stop at current depth to complete decompression	SOLID WHITE
DECO VDEEP	Current depth much deeper than deco ceiling	Ascend to decompression stop ceiling depth	SLOW WHITE FLASH
DECO CLOSE	Current depth close to deco ceiling	Ascend slowly to decompression stop ceiling depth	SLOW WHITE FLASH
DECO ALARM	Current depth shallower than deco ceiling	Descend to decompression stop ceiling	FAST WHITE FLASH
DECO NoDEC	No decompression ceiling		WHITE OFF
ASCENT OK	Ascent rate OK		WHITE OFF
ASCENT FAST	Ascent rate too fast	Slow down ascent rate	FAST WHITE FLASH
DEPTH LIMIT	Depth too deep for LSS	Ascend safely to depth within LSS range	GREEN / BLUE

ALARM	DESCRIPTION	ACTION	HUD STATUS
O2Cell OK	Cell calibration OK		GREEN
O2Cell ERROR	Cell or cells not giving valid reading	Replace faulty cells.	RED
O2Cell NOCAL	Cell calibration attempted, but cell readings not valid	Check cells are fitted. If fitted and still no cal, replace cells	RED

ALARM	DESCRIPTION	ACTION	HUD STATUS
O2Cell NOCal	Cell calibration attempted, but cell readings not valid	Check cells are fitted. If fitted and still no cal, replace cells	RED

ALARM	DESCRIPTION	ACTION	HUD STATUS
PREDIVE OK	Pre dive checks completed OK		GREEN
PREDIVE dABORT	Pre dive checks not completed as LSS went straight into dive mode	Abort dive and perform Pre dive checks – HUD warning not shown after 10mins of dive start	GREEN / BLUE
PREDIVE ABORT	Pre dive checks aborted	Perform Pre dive checks before diving – HUD warning not shown after 10mins of dive start	GREEN / BLUE
SERVICE NOW	LSS requires service. Do service before diving.	Send LSS for servicing. Do not dive	GREEN / BLUE
CELL CAL BAD	Cell calibration attempted, but cell readings not valid	Replace faulty cells.	GREEN / BLUE
FAILED PREDIVE	Pre dive checks failed due to measured parameter not correct	Perform Pre dive checks before diving	GREEN / BLUE

Red alarms take priority in the HUD over Green/Blue alarms.

With the Sentinel, a key task has been to process the fault levels and error conditions to indicate the status of the rebreather to:

- OK – system ok to dive – solid Green
- Check alarms – ascend safely on closed circuit – Green/Blue LED
- Abort dive – ascend safely on bailout gas – Red alarm

The status and summary screens provide the user with extra information on an alarm state or states to assist in taking the appropriate action. This information is in English, and all users should be adequately trained in interpreting this information appropriately.

The table shows what status is shown for specific problems:

HIGHEST PRIORITY BAILOUT ALARMS. ***Finish Dive Now On Open Circuit***
RED LED FLASHING
PPO2 Very High
PPO2 Very Low
PPO2 VARYING FROM SETPOINT (system failure)
VALVE NOT FIRING
FILTER EMPTY / NOT FITTED
OXYGEN HP LOW OR HIGH-USAGE
CELL mV LOW
CALLIBRATION REQUIRED

MEDIUM PRIORITY ALARMS ***Finish Dive Now On Closed Circuit***
BLUE ON + GREEN ON
DILUENT HP LOW OR HIGH-USAGE
PPO2 > VARYING FROM SETPOINT (depth change)
PPO2 SETPOINT TRANSTIONING
BATTERY LOW
PRE-DIVE CHECKS INCOMPLETE
DEPTH LIMIT EXCEEDED

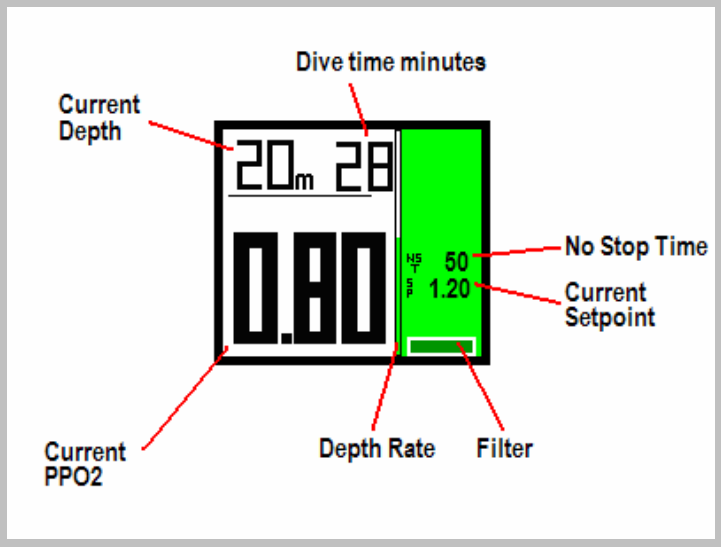
The main colour screen display provides more detailed alarm status including:

- PPO2
  - On setpoint
  - Too high above setpoint
  - Too low below setpoint
  - Transitioning (automatic setpoint changing or ascent/descent causing large ppo2 changes)
  - Hypoxic
  - Hyperoxic
- High Pressure
  - Oxygen Too Low
  - Oxygen usage too high (leak)
  - Diluent Too Low
  - Diluent usage too high (leak)
- Decompression
  - Stops required
  - Too shallow – ceiling limit breached

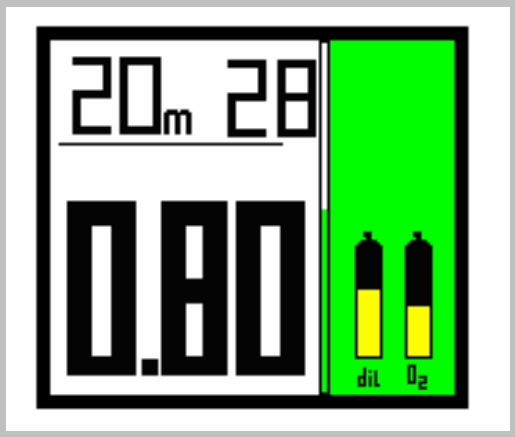
    - At deco stop ok
    - Close to decompression stop
- Gas change
- Valve firing ok
- Battery
    - Low
    - Empty
    - Charging
- Ascent rate
- Depth limit
- Pre-Dive checks incomplete
- Cells
    - Cell calibration incorrect
    - Cell calibration not performed
    - Cell error – readings out of range
- Filter
    - percentage
    - not fitted
    - empty
    - low

New User Interface Screens

Dive screens



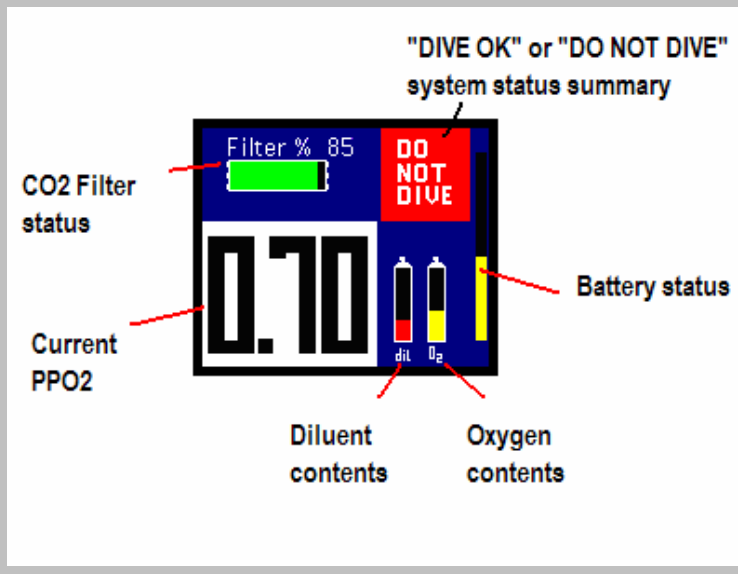
Main Dive screen



HP contents

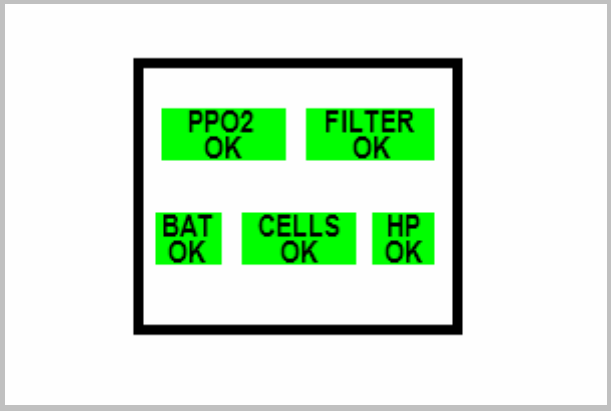
The HP contents are displayed for 10seconds after a short press of the right button.

Surface dry screen

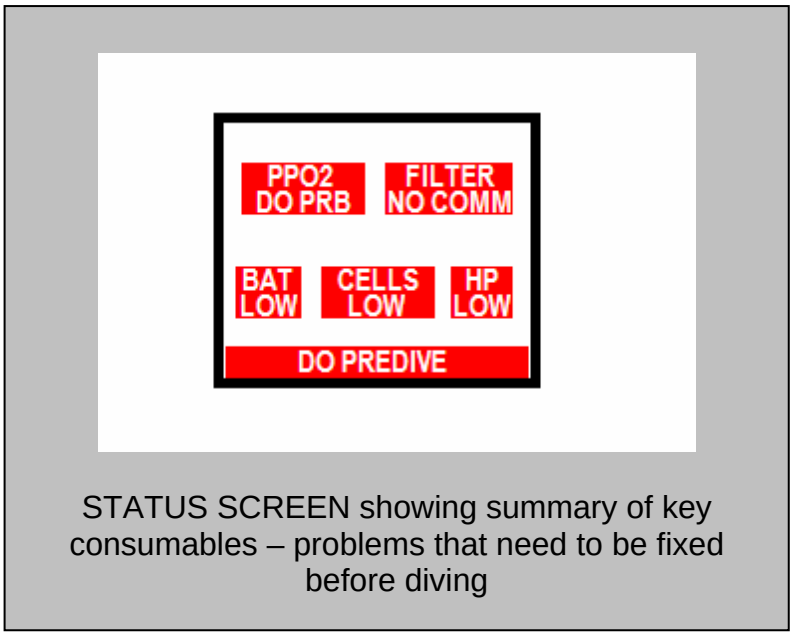


MAIN DRY SCREEN showing vital information and status

The Surface Dry Screen above shows key information, including a summary of error states advising either DIVE OK or DO NOT DIVE. If DO NOT DIVE is displayed, do not dive the LSS. Check the summary screen and perform the necessary remedial tasks.



STATUS SCREEN showing summary of key consumables – all ok



STATUS SCREEN showing summary of key consumables – problems that need to be fixed before diving

See the alarms tables for a full list of errors. The screen above shows a short form of the alarms. To see the full error information, do a short press of both buttons from this Status screen. The full summary screen is then displayed. See full manual on description of the summary screen.

In the Level 1 unit, all critical information and tasks are performed during the pre-dive checks. In Level 2 and 3 units, the gases and diluent being used need to be configured and checked prior to each dive. The additional menus and features that make the Sentinel able to show advanced and graphical information (eg depth profile of logged dives) as well settings to adapt the LSS to your particular preferences and style of diving.

As the ‘Check and Dive’ simplicity of the Sentinel makes it quick and easy to get confidence that the LSS is ready for use!

Using intelligent monitoring and experience the integrated system determine the appropriate tests and checks that the diver needs to perform to get the LSS ready for use.

Any problems are described clearly on the Main screen and Summary screen.

The on screen check list guides you through all the steps. Any problems are described clearly on the Summary screen and Main dry screen.

Both of these screens show additional information that may be interesting or useful to the diver.

The Status screen can be seen in Level 1 units by buttons when dry, when diving. The Summary screen shows detailed status of all alarms and readings taken by the LSS. See full manual for details.

The options screen can be seen in Level 1 units by pushing a button when in surface mode. The options menu gives access to other screens such as Log book, Setup and simulate screens. See the full manual for a list of all options available.

See the menu flow chart for a summary of how to access the different screens.

When in dive mode, and the system is OK, if the user displays a screen other than the main diving screens, eg deco or DVo, the PPO2 is displayed in the top right corner of the screen, together with the status LS OK. This allows the diver to see the PPO2 even if performing other tasks on the LSS.

Screen and menu navigation

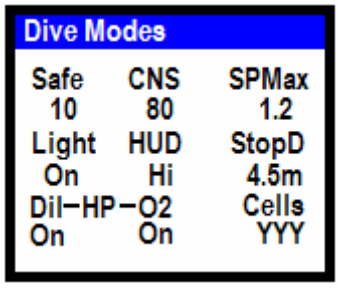
See the menu tree diagrams for details on where the menus are for different dive and level configurations.

Dive options screen

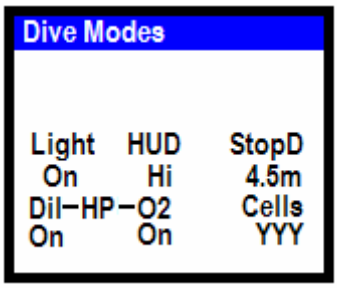
For Level 1 units, this is only accessible in surface mode from the options menu. For Level 2 and 3 units, this can also be accessed while diving from the decompression information screen.
This screen allows the diver to change parameters appropriate to the specific mission or personal preferences. These are:

- Light Mode
    - On
    - On when diving, timed when in surface mode
    - Timed when diving and in surface mode
- HUD brightness
    - Hi brightness for daylight and bright conditions
    - Low for cave and night diving
- Last stop depth
    - 3m or 10ft
    - 4.5m or 15ft
    - 6m or 20ft
- Safety factor (Level 2 and 3 only)
- CNS alarm level (Level 2 and 3 only)
- Auto Setpoint max (Level 2 and 3 only)
    - 1.2Bar
    - 1.3Bar
- HP alarms for Dil and O2 (Level 2 and 3 only)
    - This allows the diver to turn off High pressure level and usage alarms when using off-board gases. For safety reasons, if the alarms are turned off, they will be turned back on again when the LSS is restarted or a dive is finished.
- Cells – configuration of PPO2 sensors (Level 2 and 3 only)

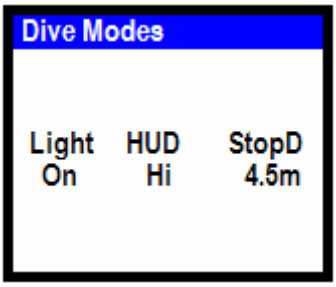
Surface Dvo screen Level 2 and 3:



Dive Dvo Screen Level 2 and 3:



Dvo screen Level 1 – Surface and Dive:



Bailout and gas configuration

Level 1

Air only diluent and bailout gas system.

Level 2

Gas 1 is configurable as the diluent gas. DIL is displayed against the gas number for these gases.

Gas numbers 3, 4 and 5 are configurable as the open circuit bailout gases. OCB is displayed against the gas number for these gases.

Level 3

Gas numbers 1 to 4 are configurable as diluent gases. DIL is displayed against the gas number for these gases.

Gas numbers 5 to 8 are configurable as the open circuit bailout gases. OCB is displayed against the gas number for these gases.

At least one diluent gas and one bailout gas must be configured and set to ON for each dive. The adjust screen can not be exited and the LSS will not turn off until this configuration has been made.
The default state for the gas configuration is Air.
For level 2, the default configuration is for DIL gas 1, and OCB gas 3 to be active.
For level 3, the default configuration is for DIL gas 1, and OCB gas 5 to be active.

When the Sentinel is switched to open circuit bailout during a dive, the diver will be prompted to accept the open circuit bailout gas configured for use at their current depth based on the maximum operating depth configured for each gas. The user can go into the gas configuration menu and adjust both diluent and bailout gases while diving.

Setpoint configuration

Level 1 units only run in auto setpoint mode to a maximum of 1.2Bar PO2. Level 2 and 3 units can run in auto setpoint mode, or manual mode up to 2.0Bar PO2. Manual mode allows the user to adjust the LSS setpoint in 0.05Bar steps or quickly to preset values of 0.7 and 1.2Bar. Levels 2 and 3 also allow adjustment of the auto setpoint maximum of 1.2Bar or 1.3Bar.

Auto Setpoint

Auto setpoint intelligently chooses an appropriate setpoint for the current depth and dive duration. The Auto Setpoint flow chart describes the mechanism in detail.

The main reasons and design criteria for the auto- setpoint adjustment system are:

1. Remove tasks from the diver for safe and optimised diving
2. To ensure that the setpoint is not set too high too quickly and thus cause a severe spike in PPO2 should the diver continue descending with a high PPO2 already in the breathing loop.
3. To ensure an optimum setpoint is used to reduce the on-gassing of inert gas in the body
4. To ensure an optimum setpoint during decompression
5. Oxygen gas is not wasted in trying to achieve an elevated setpoint not achievable at the current ambient pressure – eg 1.2Bar at the surface.

Before diving, in surface mode, the Sentinel will operate to a setpoint of 0.4Bar.

When the LSS enters dive mode (see dive mode on how this occurs), the Sentinel changes setpoint to 0.7Bar minimum.

As the diver descends the setpoint is incrementally increased based on the maximum depth up to a maximum setpoint of 1.2Bar at 33metres. If the diver descends beyond 33m the setpoint will not be further increased.

The user can override the automation under certain conditions.

If decompression stops are required, the setpoint will be kept at 1.2Bar automatically.

On ascent, and where there are no decompression stops remaining, as the diver becomes shallower than 6m, the setpoint will return to 0.7Bar.
The setpoint can be immediately set to 1.2Bar by doing a specific long button press. A further long press of this button will revert the setpoint to the previous minimum value. A further press of the button toggles between the minimum

and maximum setpoint values. The minimum value is always calculated using the depth adjustment algorithm described above.

Setpoint changes and ascents & descents

When a setpoint is changed, the rebreather will require time to adjust the PO2 to the new level. Likewise, during ascent and descent, depth changes immediately change the PO2 in the breathing loop, and the LSS requires time to adjust the PO2 accordingly.

Therefore the ILS detects both of these types of normal diving disruptions to the PO2, and downgrades the alarm type during these transitions.

This system reduces the alarm blindness without reducing the safety of the system. PO2 Hypoxic and Hyperoxic alarms will still create the highest level of alarm during the transition, but breathable mixture inside these limits and appropriate to the depth change or setpoint change detected will be temporarily down graded.

Dynamic reserve

The Sentinel monitors the High pressure (HP) contents of both the diluent and oxygen cylinders.

The Sentinel includes two warning system for the HP contents.

1. Contents below reserve level
2. Rate of use of gas is too high indicating a leak or that the HP cylinder valve is turned off and gas is being added

For the Level 1 unit, the diluent gas cylinder can also be used for bailout. Therefore, the diluent gas content must always be sufficient to do a controlled ascent in open circuit mode and still exit the water with the reserve level still intact.

To achieve this, the diluent gas is monitored along with the current depth. Then using an estimated breathing rate, the look ahead calculation is performed to check that there is sufficient gas to exit the water with the reserve still intact. As the LSS mainly uses diluent gas only when descending, this generally does not cause the dive to be curtailed for dives within the normal operating range of the Level 1 unit. It does however generally require that the diver keep the diluent cylinder at an adequately high level for the depth of dive to be performed and therefore should be refilled before each dive.

For the Level 2, 3 units and for the oxygen contents, the reserve level is also dynamically adjusted based on depth. However, as the cylinders are not required for bailout, the reserve depth adjustment is much less severe.

Battery type and charging

The Sentinel uses efficient Lithium Polymer batteries. These rechargeable batteries are very efficient and provide many years of reliable operation.

Rechargeable Lithium batteries can be recharged at any time and **do not** have a significant memory affect, which would otherwise cause unreliable battery operation. The batteries are UL listed and are double sealed to reduce the chance of leakage to a minimum.

As extra confidence, the battery pack includes 3 separate batteries to achieve operation even under multiple battery failure scenarios.

The battery reserve alarm will indicate as the unit switches to the 3rd battery giving 1/3rd battery life remaining.

Two of the batteries can be considered as main batteries. These are the first to be used during normal operation. When these two batteries become low, the third back up battery starts to be used. Failure of any battery will not affect the operation of the others.

The Backup PO2 display (Levels 2 & 3) has an independent rechargeable battery.

The user should keep the batteries recharged and topped up to ensure there is always maximum capacity for any dive.

There are two battery pack options with approximate operation hours:

- Standard pack – total 30 hours nominal with light on
- Expedition pack – total 60 hours nominal with light on

The table below gives battery information on charging and use for both types of pack:

Recharging time from empty			
Function	**Standard pack**	**Expedition pack**	**Comment**
Wired charger	3 hours	6 hours	1 hour of charge gives 10 hours of Light on use
Wireless magnetic charger	12hours	24 hours	1 hour of charge gives 4 hours of Light on use

Operational hours			
Function	**Standard pack**	**Expedition pack**	**Comment**
Timed light mode	80	160	Occasional light on
Light On mode	30	60	Light always on

It is advised to use the wired charger to quickly recharge a completely empty set of batteries, or to charge the LSS for the first time. Always dry the connector before unplugging the cover.

Check that all parts of the charger are kept dry and only used indoors.

When the batteries are reasonably full, keep them topped up using the wireless magnetic charger. This is better for harsh environments as there are no connectors and metal parts to take apart. This reduces the chance of corrosion of the connector in common diving locations, especially around sea water. A 12volt wireless charger system is available to facilitate charging from a car or boat 12volt system. Do not use on 24volt or other voltage systems!

Battery level alarms will come on when the main set of batteries get low. When a battery low alarm comes on, the light mode will be forced to a timed mode to conserve battery life.

Tip – always keep the batteries topped up using the magnetic charger!

For Level 2 and 3, when charging, the charging symbol is displayed on the main dry screen. When fully charged this symbol will disappear. 90 to 99 % indicates a fully charged battery.

For all units, the main dry screen saver displays a battery meter bar graph on the far right of the display. A full bar of green indicates full batteries. When charging the bar goes magenta in colour.

There will be a range of charger power source options available and will include;

1. 240v to 100v AC
2. 12v DC
3. Solar powered emergency pack (charging an emergency pack which can then be used to charge the main pack)

Bailout and Dive abort

Should the operation of the LSS become unsustainable the diver should bailout to an open circuit system. When this is done, the decompression calculation can still be used in the sentinel by selecting open circuit mode. In open circuit mode the LSS still **tries** to maintain a 0.4 setpoint in case the loop is still breathed on during an ascent.

There is also a dive abort mode where the diver should keep breathing from the loop. An example of this in Level 1 units is where the diluent gas has had a leak. The diver will be warned with flashing blue and green LEDs. The loop will be able to maintain a breathable gas without the addition of diluent as long as the diver ascends safely immediately. The oxygen addition will continue normally, but the diver should surface safely immediately.

Maximum operating depth

The Sentinel will warn on the main display if the maximum operating depth of the unit is exceeded. These maximum ratings are:

Level 1	40m, 131ft
Level 2	60m, 196ft
Level 3	100m, 328ft

The Sentinel will not freeze the user out of operation if these depths are exceeded. However, the system and diver are being taken out of the normal operating conditions and therefore these limits should never be routinely exceeded. Exceeding these limits is not condoned by the manufacturers.

The Level 1 and 2 units will flash the blue and green LEDs should the depth limit be exceeded.

No Stop Calculator

The Level 1 unit includes a no-stop dive time calculator. This is accessed from the Options menu.

The depth and surface interval can be adjusted for the no stop calculator. See the full manual for details.

Internet reprogramming

The Sentinel can be reprogrammed and upgraded with new software downloads from the internet. The PC Link option needs to be purchased to enable use of this feature. Contact the manufacturer, web site or your dealer for more information.

Some upgrades will be chargeable. Other upgrades may be free.

Mechanical Features

The Sentinel LSS is mechanically and electronically upgradeable. Any level of unit is also re-configurable.

For a full range of standard configurations and options please see the attached chart.

Harness/BCD

Sentinel can be used with any standard BCD. As per CE requirements, the unit ships with a Wing style BCD and adjustable harness and light-weight stainless steel backplate.

Counterlung

The LSS comes complete with a single back-mounted counterlung (BCL). This is attached via a quick-disconnect system to the canister head to allow easy cleaning.

An option will be available in 2008 to remove the BCL and fit a single front-mounted counterlung (FMCL). This uses a different outer case, and can enable a configuration with no casing at all, if required.

Cylinders

Sentinel is available with either 2 or 3liter cylinders (see options chart for details). If the FMCL is used without the cases then larger cylinders may be attached.

Outer Case

The outer case is available in Carbon or Plastic (available 2008).

Travel Mode

There are two levels of Travel Mode.

With the existing cases, the cylinders can be removed and the extendable base foot slides up into the case to reduce the shipping length of the case. This foot can also be moved to suit body length or different cylinder configurations.

When the Front Mounted Counterlung (FMCL) is available it will be possible to remove the outer cases completely and attach the cylinders to the canister via quick release clamps. In this mode the unit has the smallest/lightest shipping profile.

Over-pressure Valve

Sentinel uses a combined and balanced over-pressure release valve. The balanced valve ensures that (when the release pressure is set on the surface), the underwater release pressure is near-constant in any orientation.

When the unit vents it also removes any water from the system. This function can also be performed manually.

Bail-out Valve (BOV)

All levels of Sentinel come with a Bail-out Valve (BOV). Levels 2 & 3 can have an optional standard mouthpiece. The BOV attaches to the diluent circuit (on-board for level 1 or on-board/off-board for 2 & 3). The BOV is designed as the primary bail-out at level 1 and as the 'sanity breath' valve at all other levels. A switch to off-board open circuit gas should then be performed as soon as possible.

Backup PO2 Display

Level 1 does not have a Backup PO2 display. Levels 2 & 3 have it as standard. The display has its own power source and is separated from the main electronics. The calibration potentiometers are positioned on the electronics compartment cap on the canister head and are water sealed adjusters (no need to remove the cap).

Intelligent Backup Display

An optional Intelligent Backup Display will be available in 2008. This unit will be an independent decompression computer as well as a backup PO2 display and data logger. Calibration of this display is automatic when the main unit calibrates.

CO2 Filter Systems

The Sentinel series comes complete with three CO2 filter options;

1. User-packed granules using 797 grade absorbent.
2. Pre-packed granules, which come in a disposable plastic container, in a sealed bag. Simply remove the bag and insert the canister (see user manual).
3. Extendair absorbent cartridge system

All three CO2 filter systems will interface with the Canister Duration Meter.