CLASSIFICATION **UNCLASSIFIED**

DECLASSIFIED WHEN MATERIAL IS DETACHED
[ ] YES [ ] NO [X] NOT APPLICABLE

DOCUMENT TRANSMITTAL/REQUEST SHEET	**COASTAL SYSTEMS STATION** **PANAMA CITY, FLORIDA 32407-5000**		
FROM: COMMANDING OFFICER COASTAL SYSTEMS STATION	SSIC 10560	SERIAL [redacted]	DATE 15 Apr 04
TO: [redacted]	[ ] FOR INFORMATION AND RETURN BY ______________		
	[X] FOR INFORMATION AND RETENTION		
	[ ] IF MATERIAL IS NOT AVAILABLE FOR RETENTION ACCEPTABLE ON INTER-LIBRARY LOAN		
	[ ] INTER LIBRARY LOAN		
	[ ] RETURN OF LOAN		
	[ ] OTHER (SEE BELOW)		

SUBJECT

REFERENCE

THE MATERIAL DESCRIBED BELOW IS [X] ENCLOSED [ ] REQUESTED (REASON INDICATED)

(1) Safety Evaluation Lithium Manganese Dioxide Batteries in a Diving Life Support Recirculator of 24 Sep 2003

AUTHORIZED SIGNATURE

Barry E Miller By direction

NCSC 5216/12 (REV 09-84)

CLASSIFICATION: **UNCLASSIFIED**

SAFETY EVALUATION
LITHIUM MANGANESE DIOXIDE BATTERIES
IN A DIVING LIFE SUPPORT RECIRCULATOR

NAVAL SURFACE WARFARE CENTER
COASTAL SYSTEMS STATION
DIVING AND LIFE SUPPORT DIVISION
SEPT 24, 2003

John Camperman
Code E50E, D&LS Senior Scientist

Kirk VanZandt
Code E52, D&LS Systems Engineer

Wesley Hughson
Code E53, D&LS Systems Engineer

SAFETY EVALUATION
LITHIUM MANGANESE DIOXIDE BATTERIES
IN A DIVING LIFE SUPPORT RECIRCULATOR

NAVAL SURFACE WARFARE CENTER
COASTAL SYSTEMS STATION
DIVING AND LIFE SUPPORT DIVISION
SEPT 24, 2003

John Camperman
Code E50E, D&LS Senior Scientist

Kirk VanZandt
Code E52, D&LS Systems Engineer

Wesley Hughson
Code E53, D&LS Systems Engineer

1.0 INTRODUCTION

1.1 BACKGROUND

There is considerable mounting pressure in the scientific diving community to conduct dives beyond the limits of open circuit scuba. Rebreathers that allow longer deeper dives with small gas cylinders, and without disruptive bubbles, are very much desired. The National Oceanic and Atmospheric Administration (NOAA) through the NOAA Dive Program (NDP) and the NOAA Undersea Research Program (NURP) is interested in the Inspiration closed circuit rebreather manufactured by Ambient Pressure Diving Ltd. It is commercially available off the shelf, is popular among recreational divers, and is the first rebreather to obtain European Community CE certification. However, concerns regarding lithium batteries in the breathing gas loop, and the resulting potential risks of combustion or toxic offgassing, required investigation.

The Diving and Life Support division of the Coastal Systems Station (CSS) was tasked by NURP to investigate battery safety, as used in the Inspiration rebreather. CSS compiled data, investigated behavior of the Eveready EL223 lithium manganese dioxide battery in simplified diving conditions, and hosted a review panel including representatives from NURP and Silent Diving Systems, Llc (SDS) who distribute the Inspiration in North America.

1.2 SUMMARY

Information gathered from SDS, from Eveready, and from limited investigative tests, indicated that this battery's internal safety features greatly reduce the risk of combustion. A battery submerged in saltwater at one atmosphere, and a battery short circuited under dry hyperbaric conditions, did not ignite.

However, it was also found that offgassing occurred in normal dive conditions that exceeds the most conservative exposure limits. Standing USN practice is to avoid lithium batteries in breathing gas, and allow them only when vigorously evaluated in the particular application. For these reasons comprehensive analysis or redesign to remove the batteries from the breathing gas loop is recommended.

Findings of this report were based on USN life support equipment requirements, manufacturer information, and simplified tests with isolated batteries. Comprehensive rebreather tests may significantly alter the risk assessment of batteries in the Inspiration rebreather.

2.0 APPROACH

This evaluation took place in three phases. First, background materials on the Inspiration Rebreather, its specified lithium batteries, and USN guidance on use of lithium batteries were gathered and reviewed. Second, simple tests were conducted to gain first-hand experience with battery behavior. Third, a review panel was convened including NOAA, SDS, and CSS representatives to document a battery analysis that identified potential hazards and hazard mitigating factors required for a reasonable assurance of safety.

3.0 RESULTS

3.1 BACKGROUND RESEARCH

3.1.1 Battery

The inspiration rebreather incorporates two batteries housed in an unsealed plastic box within the carbon dioxide scrubber assembly lid. This location places the batteries and associated wiring in the breathing gas loop. Figure 1 shows the open battery box and the bottom of the two batteries; the cable junction box, oxygen solenoid, two of the three oxygen sensors, and the PVC insulated cables. The canister assembly, electronics schematic, cable mechanical data, and rebreather operating current requirements provided by SDS are included in Appendix A.

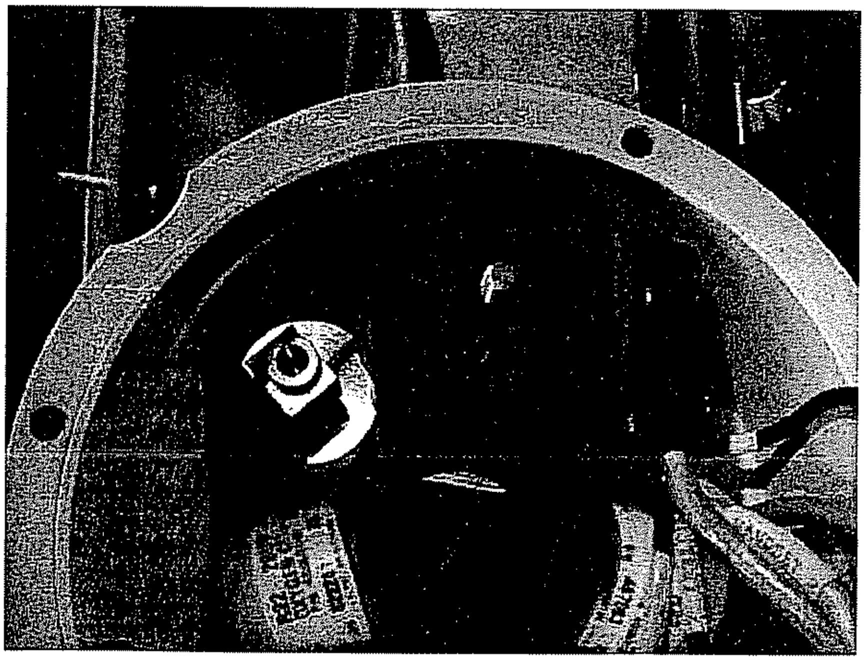


Figure 1. Canister Lid Assembly, Interior View
(www.therebreathersite.nl)

The Inspiration Instruction Manual (1) Section 1.16 specifies, "The 6-volt lithium batteries-Energizer EL223AP. CRP2 or direct equivalent." Review of the Energizer website (2), and subsequent conversations with Energizer technical support (3), indicated that these part numbers represent the Energizer model EL223 battery (AP identifies packaging), and the Panasonic model CR-P2 battery, which is equivalent. An SDS representative confirmed that the EL223 is preferred; this was the battery investigated.

The EL223 is a Lithium/Manganese Dioxide, non-rechargeable battery with three safety features within each of the two 3 volt cells. A Positive Thermal Coefficient (PTC) device limits current in the event of a short circuit to prevent overheating, the 'Separators Pore' also slows current when temperature rises, and a venting diaphragm relieves internal battery pressure before it rises enough to threaten battery jacket rupture. Energizer EL223 Engineering Data and a Product Safety Data Sheet are provided in Appendix B. The Safety Data Sheet indicates no ventilation or respiratory protection is required under normal conditions. Warnings are given for fire, explosion, and burn hazard if the battery is heated above 100° C (212 °F), or opened contents exposed to water.

USN certification was not requested for the Inspiration, but the Naval Sea Systems Command Technical Manual for Lithium Batteries (4) provides guidance for use of lithium batteries. This manual describes detailed requirements including:

a) "Certain lithium batteries.... are exempted from testing requirements:" Section 1-2.b(1) [EL223 meets the stated criteria.]
b) "Any lithium battery proposed for use aboard submarines shall be approved by NAVSEA SEA 92T." Section 1-2.b(2) [Any enclosed space recirculating breathing gas falls under this requirement.]
c) "Each battery.... shall contain a suitable over-current device" Section 1-3.a(1) [EL223 meets this criteria]
d) "Submarine: Total Containment. Internal pressure shall stay below 50 percent of the yield pressure of the battery compartment." Section 2-2.a(4) [This prohibits the relief vent of the EL223 unless the battery box is sealed and has a sufficient internal pressure rating.]

Reference (6) Section 4.12.1 excludes, "Lithium and lithium compounds, except in batteries approved for their intended service conditions.", as toxic or hazardous materials.

Based on the requirements cited above it appears that the EL223 could be qualified for USN use, but not in a breathing loop unless sealed in a pressure housing suitable for maximum external pressure and rated to twice the maximum internal pressure during shorted battery conditions.

3.1.2 Electrical Cabling

Again, the Inspiration does not require USN certification, but reference (5) provides guidance for cabling in enclosed breathing spaces. In particular, Sections A-3.4, A-3.6, B-5.2, and B-10.6 require specific test data showing that toxic offgassing and flammability threats have been addressed.

Reference (6), Section 4.12.1 prohibits toxic or hazardous materials including, "Polyvinyl Chloride (PVC) except when used for part leads." Strong justification indicating why the Inspirations PVC cabling insulation is acceptable, or replacement of the cabling with a preferred material such as Teflon would be required for USN approval.

3.2 INVESTIGATIVE TESTING

The potential battery failure modes of interest were a) overheating or offgassing when externally exposed to fresh water condensate or saltwater b) offgassing due to hyperbaric compression and decompression c) initiation of a fire when shorted in an oxygen rich (80% to 100%) environment which occurs in constant ppO_2 recirculators at shallow depths.

All tests were simplified as much as possible to minimize cost. The goal was to observe general behavior, not to rigorously test for certification purposes.

3.2.1 Battery Exposure to Water

The worst case scenario is continuous saltwater continuity from positive to negative battery poles. A battery was simply submerged in a 250ml beaker of $35^0/_{00}$, or 3.5% saltwater at 29°C (84° F). Electrolysis began immediately with hydrogen generation at the cathode (negative) pole. The positive (anodic pole) corroded rapidly. However, the saltwater resistance and passivation of the cathode must have limited current to a low level because the battery voltage only dropped to 5.9 volts after being submerged for one hour. No noticeable odors were generated during the test, and the only damage was severe corrosion of the positive pole. A subsequent test with a regulated power supply and simulated battery poles indicated that current probably varied from on the order of 600 mA at the start to 200 mA after passivation of the poles.

3.2.2 Battery Exposure to Hyperbaric Conditions

It is often the case that components posing no toxic threat at one atmosphere ambient pressure do emit toxic gases when compressed and decompressed. A test plan was devised to stress the battery as it would be on a rigorous dive. The battery alone was tested under dry conditions in a clean 7.6-liter collection chamber. A thirty-minute helium-oxygen dive to 97.5 meters (320 feet) was selected, following the USN decompression table for a rebreather with 0.7ata ppO_2 (table 17-15 per reference 7). The battery was current loaded to simulate diving conditions. Ascent was stopped at 30.5 meters (100 feet) to provide sufficient collection chamber pressure for gas analysis. The chamber gas was then analyzed using mass spectrometry, gas chromatography, and other methods. The test procedure and resulting data are shown in Appendix C.

Measured offgas concentration levels must be adjusted to surface equivalent values for comparison to Surface Allowed Limits. Accepted protocol assumes that human physiology responds to partial pressure of any inhalant much like it does to oxygen or carbon dioxide (Reference 5, Section E-3.3). Therefore, measured concentration values shown in Appendix C for the simulated 30.5 meter dive (Offgassing Analysis Report #20030815JC01) must be multiplied by 4ata/1ata for comparison with Surface Allowed Limits. All Standard Components tested per references (7) and (8) are acceptable. Three out of five individuals indicated that the gas sample had a very slight odor resembling ether.

The gas sample was analyzed for hazardous ingredients listed in the Eveready EL223 Safety Data Sheet, and the 1, 2-Dimethoxyethane (DME) estimated concentration was 0.06ppm. The corresponding 0.24ppm surface equivalent exceeds the 8-hour time weighted average (TWA) exposure limit of 0.15ppm cited by the Gillette Medical Evaluation Laboratory Material Safety Data Sheet for the equivalent Duracell battery (Appendix B). If it is assumed that gas with DME concentration of 0.06ppm exists in the rebreather at the maximum dive depth of 97.5 meters, the surface equivalent value would be (10.7ata/1ata) x 0.06ppm, or 0.64ppm. This leads to the 0.02ppm diving mixture limit (for comparison with the measured value of 0.06ppm) indicated by Captain (MD) Knafelc's memo in Appendix C. Here, the exposure limit for the dive mix is determined by (1ata/10.7ata) x 0.15ppm, or 0.014ppm, rounded to 0.02ppm since 0.15ppm is the most conservative surface exposure limit found. Either approach indicates the DME exceeds the Duracell exposure limit.

It should be noted that the Safety Data Sheets for Eveready and other lithium battery venders indicate that no OSHA Personal Exposure Limit for DME is established, and that Ultra Life Batteries, Inc. indicates limit TWAs of 1ppm for pregnant women and 5ppm otherwise. It should also be noted that the battery test which produced DME concentration above the Duracell limit did not replicate the actual temperature, humidity, carbon dioxide scrubber interaction, oscillatory flow, etc. of the rebreather system.

3.2.3 Short Circuited Battery Test

The internal battery safety features that limit heat and pressure no doubt perform well at one atmosphere, as evidenced by successful mass production and distribution to the general public for many years. However, performance in hyperbaric conditions was unknown, and a simple test was conducted to investigate behavior.

The same battery used in the simulated dive to 97.5 meters was returned to the clean 7.6 liter collection chamber. Bare copper wire and a glass insulator were used inside the chamber to eliminate potential offgassing from heated insulation, and a circuit was prepared to short the battery with an external low resistance shunt. Figure 2 shows the battery mounted under the chamber cap. The battery attitude was approximately horizontal during the test. Short circuit resistance was 0.2 ohms. The chamber was pressurized at less than 25 psi per minute to produce a helium-oxygen mixture at 50 psig with oxygen partial pressure of 1.3ata. This simulated a diver depth of 34 meters (113 feet) with a high ppO_2 recirculator setting.

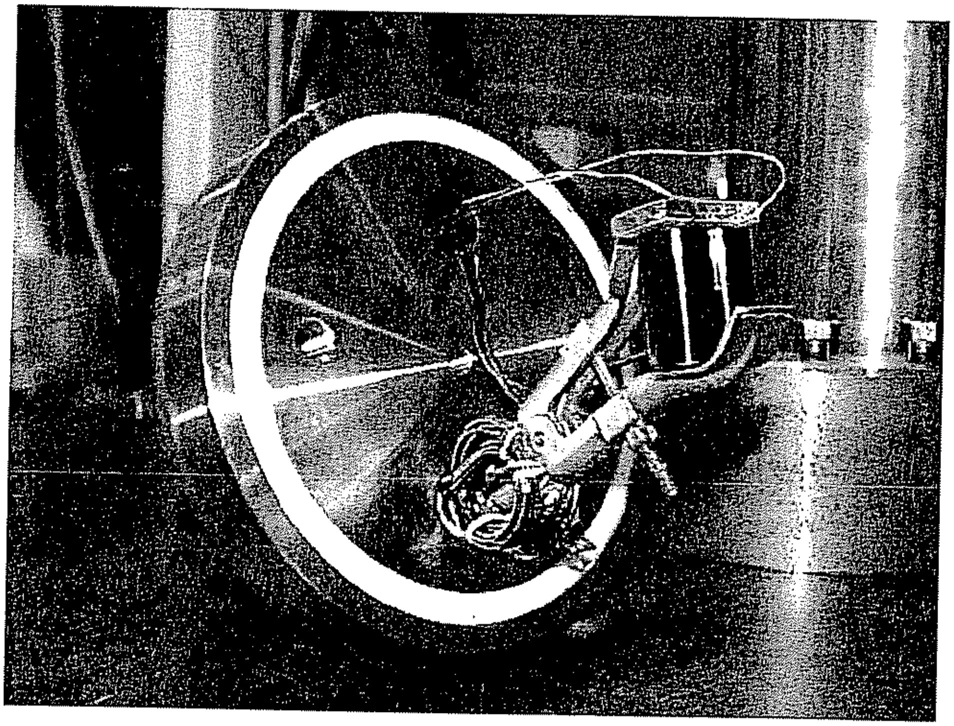


Figure 2. Short Circuit Battery Test

Shunt voltage was recorded at 35 millisecond intervals for conversion to current as the battery short circuit was closed. As shown in Figure 3a, in less than forty seconds the safety features of the battery limited current from an initial recording of 11 amps to under 0.4 amps. In less than sixty seconds current stabilized at under 0.1 amps where it remained until the short circuit was opened after a total of twenty minutes. Battery voltage at the beginning and end of this event was 6.1 and 5.7 volts respectively.

The battery was held in the chamber under pressure for five minutes, and the shorting procedure repeated. The battery shut down more rapidly than the first event, as shown in Figure 3b. After stabilizing the current remained under 0.1 amps for ten minutes when the short circuit was opened. Battery voltage at the start and end of the second event was 5.85 and 5.7 volts respectively.

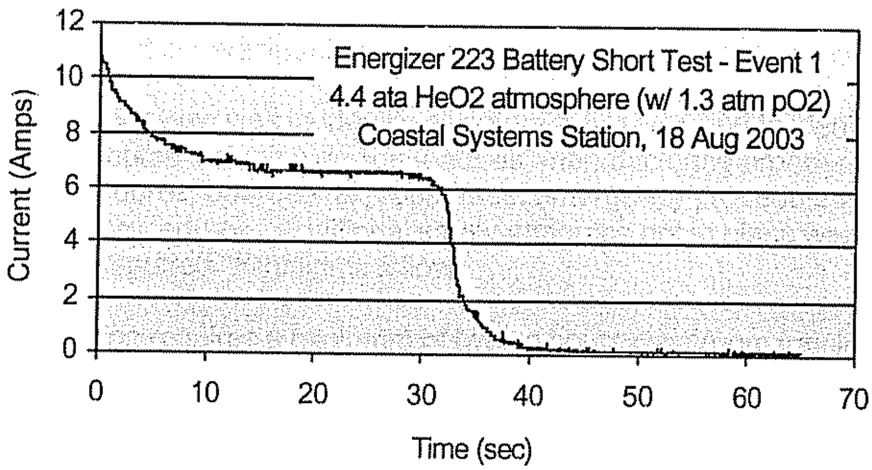


Figure 3a.

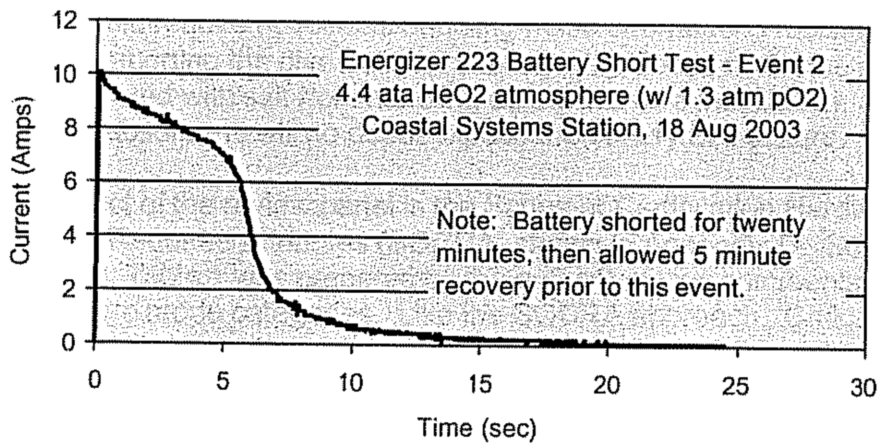


Figure 3b.

Collection chamber gas had an ether odor like gas from the simulated dive to 97.5 meters, but much, much stronger. Results of gas analysis are shown in report #20030818JC01 of Appendix C. Measured levels must be multiplied by 4.4ata/1ata to compare with the surface allowed limits. Total hydrocarbons and DME concentrations were well above acceptable limits. Both increased dramatically over the simulated normal operating mode, implying that the battery safety vent opened when the battery was shorted.

3.3 SAFETY ANALYSIS

A team was assembled to include detailed knowledge of the Inspiration rebreather, and independent experience in safety analysis of diving life support equipment. A list of participants and meeting overview are in Appendix D.

The goal of this review was to identify all potential hazards and to identify all mitigating attributes including design features, manufacturing processes, training pre-dive procedures, operational procedures, emergency procedures, and maintenance procedures. Additional safety attributes not in place were discussed as required. Highlights follow.

Inspiration diving requires a minimum of twelve hours classroom training, which includes pre and post dive analysis, and eight immersions with a minimum total dive time of 500 minutes. An average 'serious' Inspiration diver logs from 50 to 150 diving hours per year. While the maximum controlled oxygen setting is 1.3 ata, this may be exceeded if the operator overrides with the manual add vale, and has reset or disregards the controller warning. A maximum recreational oxygen limit of 1.6 ata is given in the Inspiration manual.

The rebreather system is configured to minimize the possibility of complete submergence of the batteries. They are located at the top of the CO_2 scrubber canister (diver upright) and downstream of the scrubber with its water barrier filter. This would require noticeable bubbling noise or breathing resistance that would require aborting the dive before batteries were flooded. On the other hand condensate, mixed with salt from handling during pre-dive installation, and perhaps CO_2 absorbent, will no doubt expose the battery to moisture.

A direct product of the review panel is the Scope of Certification Hardware Criticality and Required Attributes (SOCRA) shown in Appendix D. Subsequent to the meeting, Table 1 was prepared by the author to focus comments on individual failure mode categories. Like the SOCRA approach, 'Critical' and 'Support' in Table 1 refer to single event and multiple event failures that cause injury or death.

In addition to the battery review, it was noted that the PVC insulation used for cabling would not be allowed in a USN breathing loop due to toxicity/flammability hazard without substantiating evidence of safety and a specific approval.

TABLE 1
EVEREADY EL223 LITHIUM/MANGANESE DIOXIDE 6V BATTERY
INSTALLED IN THE INSPIRATION REBREATHER

FAILURE MODE	COMMENTS	FAILURE CATAGORY	SAFETY COMMENTS
Loss of Power	Two redundant batteries are used. Batteries are mass produced with good reliability.	Support	Ensure proper model battery is used.
Offgassing			
a. Normal Operation	Breathing loop slightly contaminated due to decompression and/or power generation. Contamination may be mitigated by humidity and/or CO_2 scrubber.	Critical	Conduct additional tests to determine level of contamination in fully simulated breathing loop. Validate vendor QA procedures and control use to battery configuration tested. (1)
b. Short Circuit	If battery is shorted high contamination is a product. Flooded recirculator does not short circuit battery.	Critical	Validate that rebreather design and procedures make short circuit probability acceptable. (1)
Flammability			
a. Ignition Source	Internal battery safety features appear to prohibit ignition from breathing loop flood, dive pressures and short-circuiting.	Critical	Conduct additional tests with moisture during compression and flooding at depth. Validate vendor QA of battery configuration tested. (1)
b. Fuel Source	One test indicated normal use poses little or no hazard. However, heating or mechanical damage will release flammable gases.	Support	Conduct additional tests to determine level of flammability due to normal decompression or heating. (1)

(1) Redesign to remove batteries from the breathing loop eliminates the need for additional battery testing and QA validation

4.0 CONCLUSIONS AND RECOMMENDATIONS

Within the scope of review completed for this report, it appears the Inspiration is a durable rebreather, with well produced interchangeable parts and supported with controlled training. However, this review focused on batteries and electrical cabling, and raised concern with level of diver safety.

Battery offgassing of 1,2 Dimethoxyethane (also known as DME, or ethyleneglycol dimethyl ether) during normal operation appears to be above at least one industry eight-hour exposure limit. Internal battery safety features appear to be robust and functional even in hyperbaric conditions, limiting heat from an electrical short circuit and the potential for ignition of a fire. However, the internal battery vent allows toxic levels of DME and total hydrocarbons to be released from the battery if it is shorted. The PVC insulated electrical cabling poses a hazard if heated or burned and is not generally permitted in USN enclosed breathing spaces. These battery and cabling issues, without further evidence of safety, would disallow USN diving life support equipment certification.

The following recommendations are provided for consideration to improve the margin of safety for the Inspiration rebreather.

1. Develop a design revision that moves the batteries out of the breathing gas loop. This eliminates all critical battery hazards.
2. Validate through analysis and testing that the probability of heating PVC insulated wire to the point of toxic gas generation is extremely remote, or replace with a preferred insulation such as Teflon.
3. If batteries are not removed from the breathing gas loop;
   a) Remove, "or direct equivalent" from the user Instruction Manual and control battery models specified to those with sufficient safety assurance testing.
   b) Add a visual battery inspection and sniff test to pre dive procedures that requires replacement of batteries with detectable odor, evidence of mechanical abuse, or are otherwise suspect.
   c) Conduct additional analysis and testing of specific batteries to verify safe operation under diving conditions without toxic offgassing, or combustion. This would require multiple trial testing to support adequate confidence levels. Limit authorized use to batteries so verified.
   d) Implement a configuration control process to ensure that batteries used in dives are of identical construction to those used in safety assurance testing.

These recommendations are based on information available at the time of writing, limited investigation of wetted battery behavior at one atmosphere ambient pressure, and dry battery behavior in hyperbaric conditions. Testing in a full rebreather simulation may significantly alter results.

5.0 REFRENCES

1. Parker, Martin, Inspiration Closed Circuit Rebreather User Instruction Manual, Ambient Pressure Diving, Feb 2001.

2. Energizer Battery Company, www.energizer.com

3. Arnold, B., Phone conversation and email to Energizer Engineering Division via Technical Support, 30 July 2003, 03 Sept 2003.

4. Naval Ordnance Center, Technical Manual for Batteries, Navy Lithium Safety Program, Responsibilities and Procedures, S9310-AQ-SAF-010, 27 Feb 1998. (Revision in process not expected to impact this report)

5. Naval Sea Systems Command, US Navy Diving and Manned Hyperbaric Systems Safety Certification Manual, SS5L1-AA-MAN D10, Change 2/I, Jan 1998.

6. Naval Sea Systems Command, Department of Defense Handbook, Preparation of Electronic Equipment Specifications, MIL-HDBK 2036, 01 Nov 1999.

7. Naval Sea Systems Command, US Navy Diving Manual, SS521-AG-PRO-010, 20 Jan 1999.

8. Naval Sea Systems Command, System Certification Procedures and Criteria manual for Deep Submergence Systems, SS800-AG-MAN-010/P9290, 03 Nov 1998.

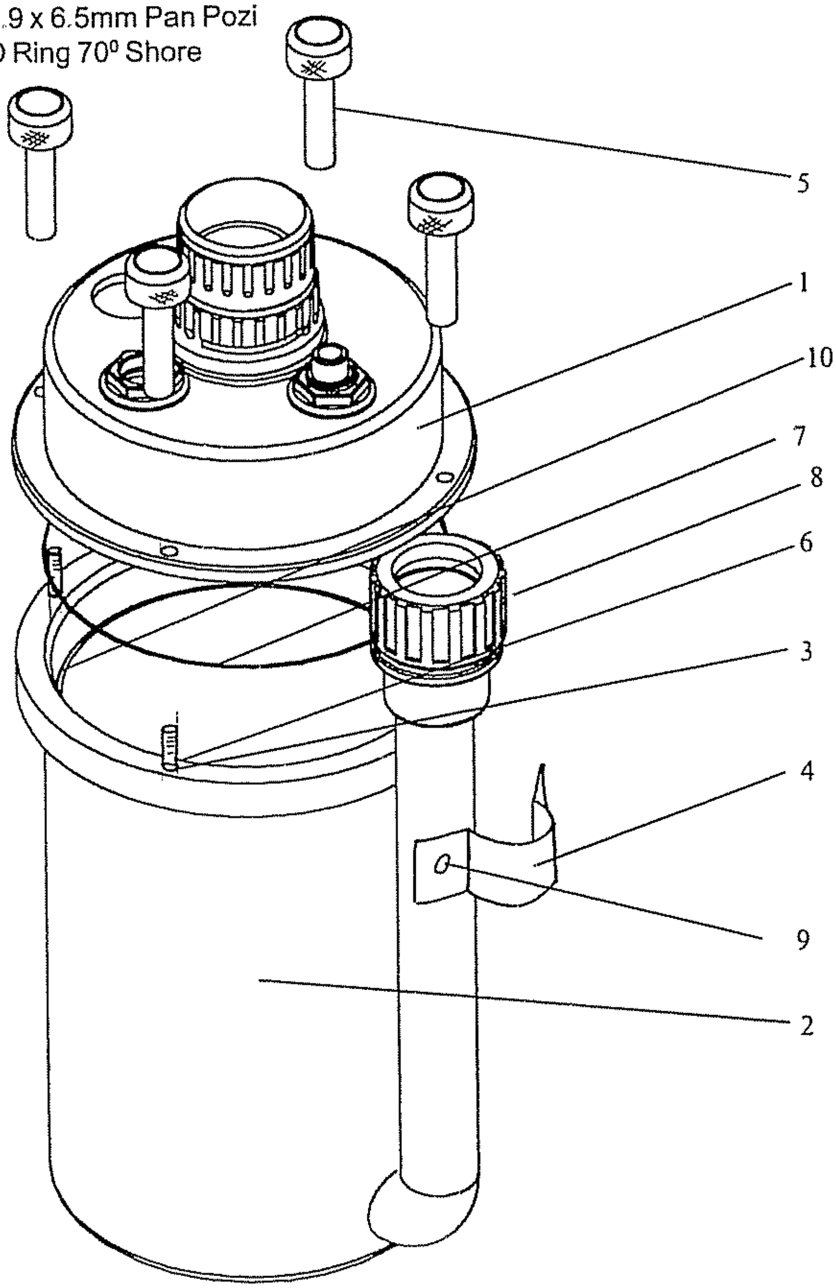
APPENDIX A
REBREATHER DATA

- Canister Assembly Drawing (a)
- Inspiration Battery Identification (a)
- Inspiration Electronics Schematic (b)
- Electrical Cabling Mechanical Data (b)
- Inspiration Current Requirements (b)

(a) Inspiration Closed Circuit Rebreather User Instruction Manual
(b) Email from Silent Diving Systems

Cannister Assembly

ITEM	REFERENCE	DESCRIPTION
1	RB06/01	Lid Assembly
2	RB06/02	Base Assembly
3	RB06/04	Brass Insert
4	RB06/05	Tube Clamp
5	RB06/06	Canister Lid Securing Nut
6	RB06/07	35mm Grub Screw
7	BS.162N70	O Ring 70⁰ Shore
8	RB12/05	Canister side tube nut
9	SC102	2.9 x 6.5mm Pan Pozi
10	BS.256N70	O Ring 70⁰ Shore



Ambient Pressure Diving,
Water-Ma-Trout Industrial Estate,
Helston, Cornwall, TR13 0LW. ENGLAND.

Tel : +44 (0) 1326 563834
Fax : +44 (0) 1326 573605

Assembly	Date	Issue No.
RB06	11/11/2000	1

closing the mouthpiece, holding the mouthpiece overhead and shaking it, water is still apparent, it may be entering around the outside of the mouthpiece. Also confirm the mouthpiece is fully open. As the mouthpiece is opened and closed, an O ring seal which is used to seal the inner tube against the outer, will be seen. If the mouthpiece valve is only partially open, an O ring will be visible when viewed through the mouthpiece and water will be allowed to enter the loop from the water vent. Finally, ensure the mouthpiece ty-rap is secure. Incorrect tensioning during replacement could result in a leak.

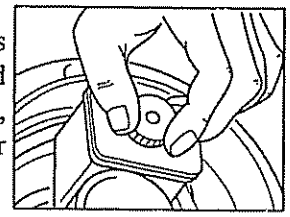
1.15 System Integrity - Indications

Know your ppO_2 at all times! Learn how to evaluate the information provided by the oxygen controllers - Section 3.5 to 3.5.6, Sections 6, 7 and 9.

Listen out for the solenoid. It should be operating in short bursts. If you think it has been open longer than normal or it has not been heard for a long while - it is time to take a look at the ppO_2 display.

Compare the cell readings. While breathing, the cell readings change. Bearing in mind that these oxygen cell readings are shown in real time, the ability to see all three sensors simultaneously is a great diagnostic aid. If one is failing to react as quickly as the others, there may be water on the cell's sensor face. The modifications made to the sensors prevent large quantities of moisture reaching the face and affecting the internal circuitry. It is, therefore, essential to use only oxygen cells supplied by Ambient Pressure Diving.

1.16 Batteries



Each oxygen controller has its own battery and circuitry. However, both batteries share the same battery box door, so it is imperative to ensure this door is fastened properly. The 6 volt Lithium batteries - Energizer EL223AP.CRP2 or direct equivalent, are readily available and last for approximately 35 hours when used for the Master controller and approximately 70 hours when used for the Slave.

The controller does not power down when not in use. **It is, therefore, very important to ensure that both controllers are switched off after use to preserve battery life.**

1.17 Surface Swimming

When swimming forward, face down, on the surface, only partially inflate the BC. Over inflation will cause increased body angle and extra drag. Deflate the BC and adopt a horizontal, head down, streamlined swimming position.

1.18 Surface Buoyancy and Trim

By rotating the counterlung's pressure relief valve to the high pressure setting, and with the mouthpiece closed the counterlungs can be inflated and used for additional surface buoyancy. The volume of gas admitted to the BC must be regulated to ensure an upright floating position.

1.19 Quick Post-Dive Checks

Check the exhale counterlung for residual water by unscrewing the oxygen inflator, see Section 4.6. If water is present, drain and check the downstream side of the first water trap. If water is present, remove the scrubber and check the Sofnolime at the bottom of the scrubber. If it is soaked replace the Sofnolime before the next dive.

It is important to keep the unit upright if water is suspected to have entered the scrubber. This prevents the Sofnolime and water from damaging the oxygen sensors.

APPENDIX B
LITHIUM MANGANESE DIOXIDE
BATTERY DATA

- Energizer Engineering Data Sheet
- Energizer Product Safety Data Sheet
- Duracell Material Safety Data Sheet

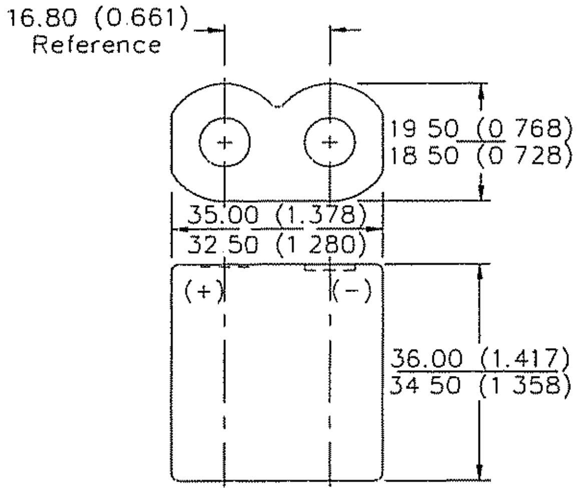
Energizer ENGINEERING DATASHEET

EVEREADY BATTERY CO.
Internet: www energizer com

1-800-383-7323 / USA
1-800-383-7323 / CANADA
+ 44 (0) 208 920 2306 / EUROPE

ENERGIZER NO. 223 (EL223)

Industry Standard Dimensions in mm (inches)

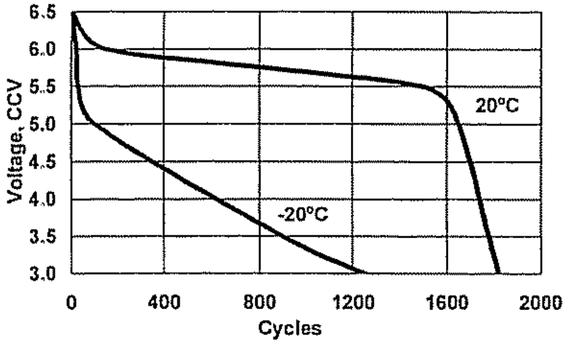


THIS BATTERY HAS UNDERWRITERS LABORATORIES COMPONENT RECOGNITION

Chemical System: Lithium
Lithium/Manganese Dioxide (Li/MnO_2)

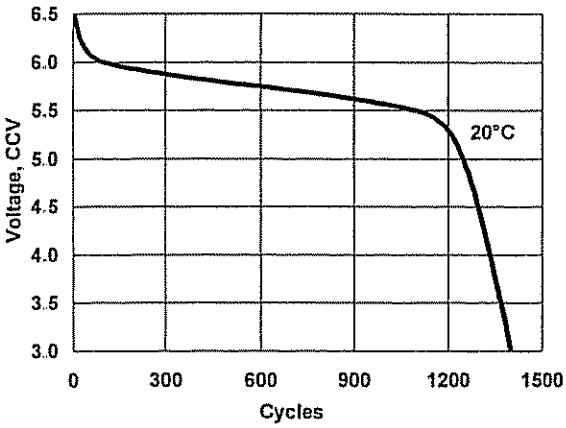
Designation: ANSI / NEDA-5024LC. IEC-CP-P2
Battery Voltage: 6 0 Volts
Average Weight: 37.0 grams (1 3 oz.)
Volume: 23 8 cubic centimeters (1 4 cubic inch)
Average Capacity: 1400 mAh to 4 0 volts
(Rated Capacity at 200 ohms at 21°C)
Maximum Reverse Charge Current: 2 microampere
Max Discharge: 1500 mA continuous - 3500 mA pulse
Cells: Two 2/3A

Typical Discharge Characteristics
Schedule: 3 sec ON / 27 sec OFF
Typical Drain: 900 milliamperes



This battery Contains a Positive Temperature Coefficient (PTC) Device to Limit Current Flow

Typical Discharge Characteristics
Schedule: 3 sec ON / 7 sec OFF
Typical Drain: 1200 milliampere



Simulated Application Test
Estimated Average Service at 21°C (70°F)

Schedule:	Typical Drains (mA)	Load (ohms)	Cutoff Voltage 4.0 V Hours	3.1 V Cycles	2.6 V Cycles
24 hours/ day	-	200	54 1	-	-
24 hours/ day	1000	-	1 4	-	-
3 sec ON / 7 sec OFF	900	-	-	-	1425
3 sec ON / 27 sec OFF	1200	-	-	1800	-

Important Notice

This data sheet contains information specific to batteries manufactured at the time of its publication.
Contents herein do not constitute a warranty.

Form No. EBC - 4205E

PRODUCT SAFETY DATA SHEET

The information contained within is provided for your information only This battery is an article pursuant to 29 CFR 1910.1200 and, as such, is not subject to the OSHA Hazard Communication Standard requirement for preparation of a material safety data sheet The information and recommendations set forth herein are made in good faith and are believed to be accurate as of the date of preparation However, EVEREADY BATTERY COMPANY, INC., MAKES NO WARRANTY, EITHER EXPRESS OR IMPLIED, WITH RESPECT TO THIS INFORMATION AND DISCLAIMS ALL LIABILITY FROM RELIANCE ON IT

PRODUCT SAFETY DATA SHEET

PRODUCT NAME: EVEREADY Battery

TRADE NAME: ENERGIZER, Lithium-Manganese Dioxide Battery

CHEMICAL SYSTEM: Lithium-Manganese Dioxide

Type No.:

Volts: 3 0/cell

Approximate Weight:

Designed for Recharge: No

SECTION I - MANUFACTURER INFORMATION

Manufactured for:
Eveready Battery Company, Inc
25225 Detroit Road
Westlake, OH 44145

Telephone Numbers for Information:
(440) 835-7368
(800) 383-7323 (USA)

Date Prepared: October 17, 2001

SECTION II - HAZARDOUS INGREDIENTS

IMPORTANT NOTE: The battery should not be opened or burned Exposure to the ingredients contained within or their combustion products could be harmful

MATERIAL OR INGREDIENT	PEL (OSHA)	TLV (ACGIH)	%/wt.
Carbon Black (CAS# 1333-86-4)	3 5 mg/m^3 TWA	3.5 mg/m^3 TWA	0-1
1,2-Dimethoxyethane (CAS# 110-71-4)	None established	None established	0-6
1,3-Dioxolane (CAS# 646-06-0)	None established	None established	0-8
Graphite (CAS# 7782-42-5)	15 mg/m^3 TWA (total dust) 5 mg/m^3 TWA (respirable fraction)	2 mg/m^3 TWA (respirable fraction)	0-3
Lithium or Lithium Alloy (CAS# 7439-93-2)	None established	None established	1-6
Lithium Perchlorate (CAS# 7791-03-9)	None established	None established	0-3

MATERIAL OR INGREDIENT	PEL (OSHA)	TLV (ACGIH)	%/wt.
Lithium Trifluoromethanesulfonate (CAS# 33454-82-9)	None established	None established	0-3
Lithium Trifluoromethanesulfonimide (CAS# 90076-65-6)	None established	None established	0-3
Manganese Dioxide (CAS# 1313-13-9)	5 mg/m^3 Ceiling (as Mn)	0 2 mg/m^3 TWA (as Mn)	12-42
Propylene Carbonate (CAS# 108-32-7)	None established	None established	0-8

SECTION III - FIRE AND EXPLOSION HAZARD DATA

In case of fire where lithium batteries are present, apply a smothering agent such as METL-X, sand, dry ground dolomite, or soda ash, or flood the area with water. A smothering agent will extinguish burning lithium batteries. Water may not extinguish burning batteries but will cool the adjacent batteries and control the spread of fire. Burning batteries will burn themselves out. Virtually all fires involving lithium batteries can be controlled with water. When water is used, however, hydrogen gas may evolve. In a confined space, hydrogen gas can form an explosive mixture. In this situation, smothering agents are recommended.

Fire fighters should wear self-contained breathing apparatus. Burning lithium-manganese dioxide batteries produce toxic and corrosive lithium hydroxide fumes.

SECTION IV - HEALTH HAZARD DATA

Under normal conditions of use, the battery is hermetically sealed.

Ingestion: Swallowing a battery can be harmful.

Contents of an open battery can cause serious chemical burns of mouth, esophagus, and gastrointestinal tract.

If battery or open battery is ingested, do not induce vomiting or give food or drink. Seek medical attention immediately. CALL NATIONAL BATTERY INGESTION HOTLINE for advice and follow-up (202-625-3333) collect, day or night.

Inhalation: Contents of an open battery can cause respiratory irritation. Provide fresh air and seek medical attention.

Skin Absorption: Dimethoxyethane, dioxolane, and lithium trifluoromethanesulfonate may be absorbed through the skin, causing localized inflammation.

Skin Contact: Contents of an open battery can cause skin irritation and/or chemical burns. Remove contaminated clothing and wash skin with soap and water. If a chemical burn occurs or if irritation persists, seek medical attention.

Eye Contact: Contents of an open battery can cause severe irritation and chemical burns. Immediately flush eyes thoroughly with water for at least 15 minutes, lifting upper and lower lids, until no evidence of the chemical remains. Seek medical attention.

Note: Carbon black is listed as a possible carcinogen by International Agency for Research on Cancer (IARC).

SECTION V - PRECAUTIONS FOR SAFE HANDLING AND USE

Storage: Store in a cool, well ventilated area. Elevated temperatures can result in shortened battery life.

Mechanical Containment: Containment of this battery in a manner that obstructs or defeats the safety vent or electrical disconnect mechanisms designed into this battery can result in fire and/or explosion and cause personal injury and device damage. This battery is not designed to be potted, enclosed in hermetic overpackaging, or sealed by any means that prevents free operation of the designed safety mechanisms.

Handling: Accidental short circuit for a few seconds will not seriously affect the battery. Prolonged short circuit will cause the battery to lose energy, and can cause the safety release vent to open. Sources of short circuits include jumbled batteries in bulk containers, metal jewelry, metal covered tables or metal belts used for assembly of batteries into devices.

If soldering or welding to the battery is required, consult your Eveready Battery Company representative for proper precautions to prevent seal damage or short circuit.

Charging: This battery is manufactured in a charged state. It is not designed for recharging. Recharging can cause battery leakage or, in some cases, high pressure rupture. Inadvertent charging can occur if a battery is installed backwards.

Labeling: If the Eveready label or package warnings are not visible, it is important to provide a package and/or device label stating:

WARNING: FIRE, EXPLOSION, and BURN HAZARD DO NOT OPEN BATTERY, DISPOSE OF IN FIRE, HEAT ABOVE 100°C (212°F), EXPOSE CONTENTS TO WATER, RECHARGE, PUT IN BACKWARDS, MIX WITH USED OR OTHER BATTERY TYPES - MAY EXPLODE OR LEAK AND CAUSE PERSONAL INJURY

GENERAL EXCEPTION: At a minimum use Eveready label or package warnings

SPECIFIC EXCEPTIONS: For the L522 battery only, the appropriate warning is:

WARNING: FIRE, EXPLOSION, and BURN HAZARD DO NOT OPEN BATTERY, DISPOSE OF IN FIRE, HEAT ABOVE 75°C (167°F), EXPOSE CONTENTS TO WATER, RECHARGE, PUT IN BACKWARDS, MIX WITH USED OR OTHER BATTERY TYPES - MAY EXPLODE OR LEAK AND CAUSE PERSONAL INJURY

Where accidental ingestion of small batteries is possible, the label and/or immediate packaging should also include:

WARNING: (1) KEEP AWAY FROM SMALL CHILDREN IF SWALLOWED, PROMPTLY SEE DOCTOR; HAVE DOCTOR PHONE (202) 625-3333 COLLECT In addition to the appropriate warning copy shown above

Some photo lithium batteries use the following warning:
BATTERY CAN EXPLODE OR CAUSE BURNS IF DISSASSEMBLED, RECHARGED, OR EXPOSED TO WATER, FIRE, OR HIGH TEMPERATURE

Disposal: Dispose in accordance with all applicable federal, state and local regulations

SECTION VI - SPECIAL PROTECTION INFORMATION

Ventilation Requirements: Not necessary under normal conditions

Respiratory Protection: Not necessary under normal conditions

Eye Protection: Not necessary under normal conditions Wear safety glasses with side shields if handling an open or leaking battery.

Gloves: Not necessary under normal conditions Use neoprene or natural rubber gloves if handling an open or leaking battery.

SECTION VII - REGULATORY INFORMATION

The transportation of lithium batteries in the types and sizes manufactured or sold by Eveready Battery Company is not regulated by the U S Department of Transportation or the major international regulatory bodies However, to maintain this unregulated status, the batteries must be packaged in a manner as to prevent short circuits and be packed in strong outside packaging

SARA/TITLE III - As an article, this battery and its contents are not subject to the requirements of the Emergency Planning and Community Right-To-Know Act

Gillette Medical
Evaluation
Laboratories

37 A Street
Needham, MA 02492
Tel 781.292.8151

MATERIAL SAFETY DATA SHEET

NAME: DURACELL LITHIUM MANGANESE DIOXIDE BATTERIES

CAS NO: Not applicable **Effective Date:** 9/4/01 **Rev:** 4

A. — IDENTIFICATION

Ingredient	%
Manganese Dioxide (1313-13-9)	30-45
1,2-Dimethoxyethane (110-71-4)	5-10
Propylene Carbonate (108-32-7)	1-10
Lithium (7439-93-2)	1-5
Carbon Black (1333-86-4)	1-5
Lithium Trifluoromethane Sulfonate (33454-82-9)	1-5
Ethylene Carbonate (96-49-1)	0-5

Formula: Mixture Mixture

Molecular Weight: NA

Synonyms: Lithium Manganese Dioxide Cells: DL2/3A; DL123A(3V); DL223A(6V); DL245 (6V); DL323A; DL1025; (3V); DL1216; DLCR2; PL123 ; CR-V3P (3V) and batteries comprised of DL2/3A cells.

B. — PHYSICAL DATA

Boiling Point	Melting Point	Freezing Point
NA °F NA °C	NA °F NA °C	NA °F NA °C
Specific Gravity (H_2O=1)	Vapor Density (air=1)	Vapor Pressure @ ____ °F
NA	NA	NA mm Hg
Evaporation (Ether =1)	Saturation in Air (by volume@ ____ °F)	Autoignition Temperature ____ °F ____ °C
NA	NA	NA
% Volatiles	Solubility in Water	
NA	NA	pH NA

Appearance/Color: Small cylindrical batteries. Contents dark in color.

Flash Point and Test Method(s): 1,2-Dimethoxyethane 42.8 °F, 6°C (Closed Cup)

Flammable Limits in Air (% by volume): Lower NA % Upper NA %

C. — REACTIVITY

Stability	[X] stable	[ ] unstable	Polymerization	[ ] may occur	[X] will not occur

Conditions to Avoid (Stability): Do not heat, crush, disassemble, short circuit or recharge.

Conditions to Avoid (Polymerization): Not applicable

Incompatible Materials: Contents incompatible with strong oxidizing agents.

Hazardous Decomposition Products: Thermal degradation may produce hazardous fumes of manganese and lithium; hydrofluoric acid; oxides of carbon and sulfur and other toxic by-products.

*** IF MULTIPLE INGREDIENTS, INCLUDE CAS NUMBERS FOR EACH NA=NOT AVAILABLE**

Footnotes
Not applicable

D. — HEALTH HAZARD DATA

Occupational Exposure Limits PEL's, TLV's, etc.)

8-Hour TWAs: Manganese Dioxide (as Mn) - 5 mg/m^3 (Ceiling) (OSHA); 0.2 mg/m^3 (ACGIH/Duracell)

1,2-Dimethoxyethane - 0.15 ppm (Duracell)

Carbon Black - 3.5 mg/m^3 (OSHA/ACGIH)

Lithium Trifluoromethane Sulfonate - 0.1 mg/m^3 (3M recommendation)

These levels are not anticipated under normal consumer use conditions.

Warning Signals

Not applicable

Routes/Effects of Exposure

These chemicals and metals are contained in a sealed can. For consumer use, adequate hazard warnings are included on both the package and on the battery. Potential for exposure should not exist unless the battery leaks, is exposed to high temperature or is mechanically, physically, or electrically abused.

1. Inhalation — Not anticipated. Respiratory (and eye) irritation may occur if fumes are released due to heat or an abundance of leaking batteries.
2. Ingestion — Irritation to the internal/external mouth area may occur following exposure to a leaking battery.
3. Skin
   a. Contact
   Irritation may occur following exposure to a leaking battery.
   b. Absorption
   Not anticipated.
4. Eye Contact — Irritation may occur following exposure to a leaking battery.
5. Other — Not applicable

E. — ENVIRONMENTAL IMPACT

1. Applicable Regulations — All ingredients listed in TSCA inventory.
2. DOT Hazard Class - Not applicable
3. DOT Shipping Name - Not applicable

Battery products offered by DURACELL for sale are designed to be safe under intended use conditions. DURACELL Lithium batteries are produced in conformity with International Electrotechnical Commission (IEC) standards and specifications.

While lithium batteries are regulated by IATA and ICAO, the type of lithium batteries offered for sale by DURACELL are exempted per provision A45 of the IATA Dangerous Goods Regulations and provision A45 of the ICAO Technical Instructions For The Safe Transport Of Dangerous Goods By Air. Per section A45 of the IATA and ICAO regulations, DURACELL consumer lithium batteries, which are of the solid cathode type, with less than 1g lithium per cell and less than 2g lithium per battery, are not subject to regulation. Thus, as long as these batteries are properly packaged in a manner to prevent short circuits and have strong outer packaging, they are not considered hazardous and are acceptable for air transport.

Environmental Effects

These batteries pass the U. S. EPA's Toxicity Characteristic Leaching Procedure and therefore, may be disposed of with normal waste

F. — EXPOSURE CONTROL METHODS

Engineering Controls

General ventilation under normal use conditions.

Eye Protection

None under normal use conditions. Wear safety glasses when handling leaking batteries.

Skin Protection

None under normal use conditions. Use butyl gloves when handling leaking batteries.

Respiratory Protection

None under normal use conditions.

Other

Keep batteries away from small children.

G. — WORK PRACTICES

Handling and Storage

Store at room temperature. Avoid mechanical or electrical abuse. **DO NOT** short or install incorrectly. Batteries may explode, pyrolize or vent if disassembled, crushed, recharged or exposed to high temperatures. Install batteries in accordance with equipment instructions. Replace all batteries in equipment at the same time. Do not carry batteries loose in pocket or bag.

Normal Clean Up

Not applicable

Waste Disposal Methods

No special precautions are required for small quantities. Large quantities of open batteries should be treated as hazardous waste. Dispose of in accordance with federal, state and local regulations. Do not incinerate, since batteries may explode at excessive temperatures.

H. — EMERGENCY PROCEDURES

Steps to be taken if material is released to the environment or spilled in the work area

Notify safety personnel of large spills. Evacuate the area and allow vapors to dissipate. Increase ventilation. Avoid eye or skin contact. **DO NOT** inhale vapors. Clean-up personnel should wear appropriate protective gear. Remove spilled liquid with absorbent and contain for disposal.

Fire and Explosion Hazard	Extinguishing Media
Batteries may burst and release hazardous decomposition products when exposed to a fire situation. See Sec. C.	As for surrounding area. Dry chemical, alcohol foam, water or carbon dioxide. For incipient fires, carbon dioxide extinguishers are more effective than water.

Firefighting Procedures

Cool fire-exposed batteries and adjacent structures with water spray from a distance. Use self-contained breathing apparatus and full protective gear.

I. — FIRST AID AND MEDICAL EMERGENCY PROCEDURES

Eyes

Not anticipated. If battery is leaking and material contacts eyes, flush with copious amounts of clear, tepid water for 30 minutes. Contact a physician at once.

Skin

Not anticipated. If battery is leaking, irrigate exposed skin with copious amounts of clear, tepid water for at least 15 minutes. If irritation, injury or pain persists, consult a physician.

Inhalation

Not anticipated. If battery is leaking, contents may be irritating to respiratory passages. Remove to fresh air. Contact physician if irritation persists.

Ingestion

Not anticipated. Rinse the mouth and surrounding area with clear, tepid water for at least 15 minutes. Consult a physician immediately for treatment and to rule out involvement of the esophagus and other tissues.

Notes to Physician

1) Potential leakage of dimethoxyethane, propylene carbonate and lithium trifluoromethane sulfonate.
2) Dimethoxyethane rapidly evaporates.
3) Under certain misuse conditions and by abusively opening the battery, exposed lithium can react with water or moisture in the air causing potential thermal burns or fire.

Replaces #1892: change address, add CR-V3P in Section A.

APPENDIX C
INVESTIGATION OF BATTERY OPERATION

- LITHIUM BATTERY OFFGASSING TEST
  (simulated dive, and short circuit)
- MEMORANDUM, EVEREADY EL223 LITHIUM
  BATTERY
  - Enclosure 1: Offgassing Report #20030815JC01,
    Heliox Dive to 320 fsw
  - Enclosure 2: Offgassing Report #20030818JC01
    Shorted Battery

LITHIUM BATTERY OFFGASSING TEST

CSS E50, 14 Aug 2003

1. **Purpose**: Determine if the Energizer 223 6v battery offgasses harmful products under hyperbaric conditions during; a) normal operating conditions, and b) shorted.

2. **Procedure**: Simulate a heliox dive to 320 fsw with 30 minutes bottom time and follow USN 0.7 ppO_2 decompression to the minimum depth that provides sufficient pressure for gas sampling (100 fsw). Hold at 100 fsw for a time representative of on-gas time during diver decompression with recirculator (54 min.), and sample gas adjacent to battery. Expose the battery to heliox with 1.3 ppO_2 at 110 fsw, short the battery, and obtain a second gas sample.

2.1 Wire the battery for operation in a 7.6 liter collection cylinder rated to 1900 psi, via an appropriate through–hull connector, with variable resistive load externally connected in series. Use bare copper 18GA (or heavier) wires from battery to bulkhead. Check Load Profiles A and B with a calibrated ammeter, and verify current data acquisition calibration. Seal the battery in cylinder.

2.2 Flush the cylinder with helium, then pressurize from zero to 10.3 +/-0.5 psig with oxygen. Establish Load Profile A in the battery loop and pressurize the cylinder to 142+/-5 psig at approximately 25 psi/min with helium.

2.3 Establish Load Profile B and hold at 142 psi for 26 minutes. Decompress the cylinder in accordance with in the following table.

2.4 At the end of the 44psi hold for 54 minutes, depressurize and analyze the 'Normal' gas sample at no more than approximately 13 psi/min.

2.5 Remove the variable resistive load, and prepare a low resistance shunt for shorting the battery, with current data acquisition. Measure and record shorting circuit resistance.

2.6 Flush the cylinder with helium, then pressurize from zero to 19.1 +/-0.5 psig with oxygen. Compress to 50+/-5psig with helium. ✓ @ 1050 8/18/03

2.7 Short the battery with the shunt and record current behavior. Hold for one hour, or for twenty minutes after the battery current stabilizes. ✓ @

- 1220 HRS 6 mA max to ~ zero

2.8 Depressurize and analyze the 'Shorted' gas sample at no more than approximately 13 psi/min. Inspect and photograph battery.

- 1240 HRS OPEN SWITCH 5.7V → 5.85
- 1245 HRS CLOSE SWITCH 8 mA max
- 1255 HRS OPEN SWITCH 5.6V → 5.7

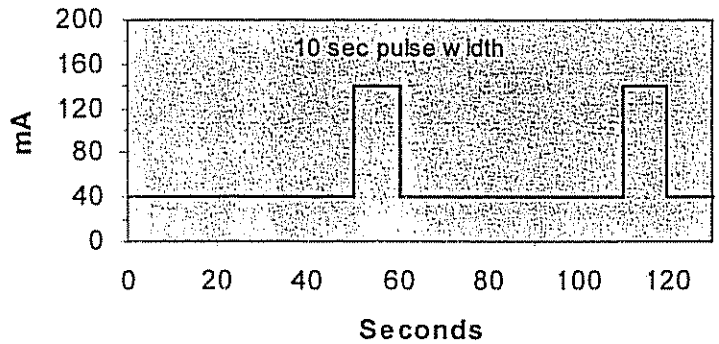
Test Cylinder Volume: 7.6 liters

Pressure Gauge: Range O_2 0-30 psi / He 0-300 psi Cal Due Date 6/23/04 (0.1 psi div) / 6/24/04 (1 psi div)

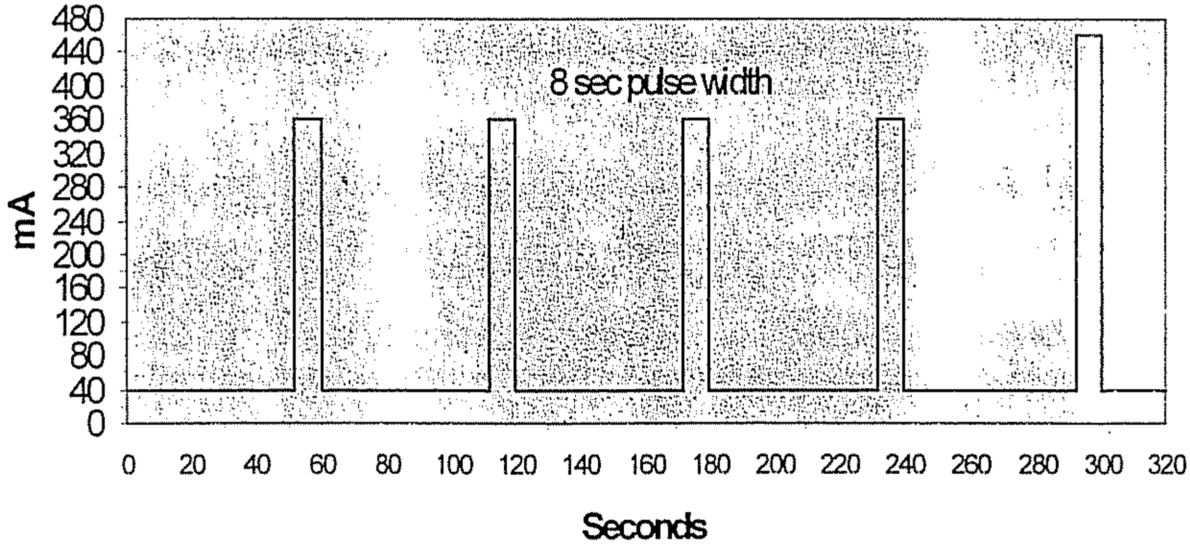
Multimeter: Cal Due Date 7/25/05 DACS: Cal Due Date 12/26/03

Ambient Temperature: ~23 °C

Normal Test Battery Voltage: Start 6.51 (1) volts Stop 5.8 volts 8/15/03 @



LOAD PROFILE A Descent; 40 mA steady, pulsing to 140 mA when backlight activated.



LOAD PROFILE B Bottom and Ascent; 40 mA steady, pulsing to 360 mA adding O2 for 2.0 lpm O2 consumption, and 460 mA for O2 add with backlight on at 5 min intervals.

(1) New battery O.C. voltage at days start. Ran Load A ~ 10 min and Load B ~ 45 min at 10.3 psig He-O_2 (.7pp O_2 atm) before starting dive simulation

IN CAN

At 10.3 psig for ~55 m

Pre ~~batt~~ run at Profile A&B ~55 min

DEPTH (fsw)	TARGET PSIG	TARGET TRAVEL (min:sec)	TARGET HOLD (min)	TARGET LOAD PROFILE	ACTUAL PSIG	ACTUAL TRAVEL (min:sec)	ACTUAL HOLD (min)	ACTUAL LOAD PROFILE	CHRON
0	0	5:20	N/A	A	0	5:20	N/A	A	0847 HR
320	142	4:20	26	B	142	4:20	26	B	31:20
190	84	0:20	1		84	:20	1		35:40 / 36:40
180	80	0:20	4		80	:20	4		41
170	75	0:20	4		75	:20	4		46:20
160	71	0:20	9		71	:20	9		55:40
150	67	0:20	9		67	:20	9		64 /4
140	62	0:20	9		62	:20	9		13:20
130	58	0:20	9		58	:20	9		22:4
120	53	0:20	10		53	:20	10		32:0
110	49	0:20	9		49	:20	9		42:2
100	44	3:20	54		44	~20:00(2)	44		36:20 / 96:2
0	0		N/A						

TARGET ELAPSED TIME: 160 min ACTUAL ELAPSED TIME: (2) 156:20 + ~20 = ~176 xfer to chem lab for analysis

Shorting Circuit (shunt and wiring) resistance: 0.2 ohms

Shorted Test Battery Voltage: Start 6.11 volts Stop 5.7v - cycle 1 / 5.7v - cycle 2 volts

8/18/03 1030 HRS

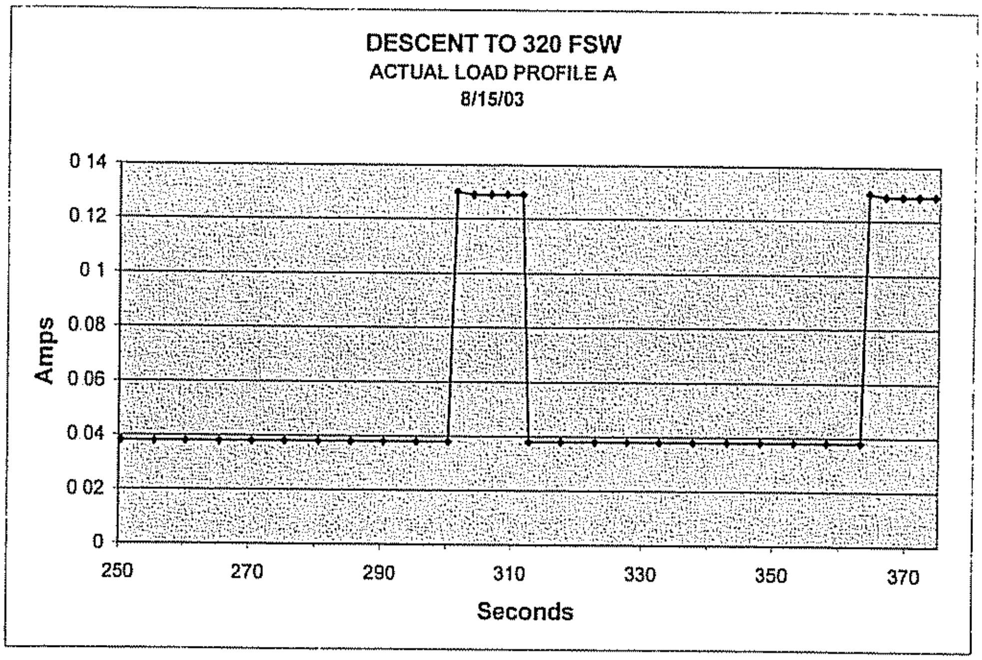
ATTACH:

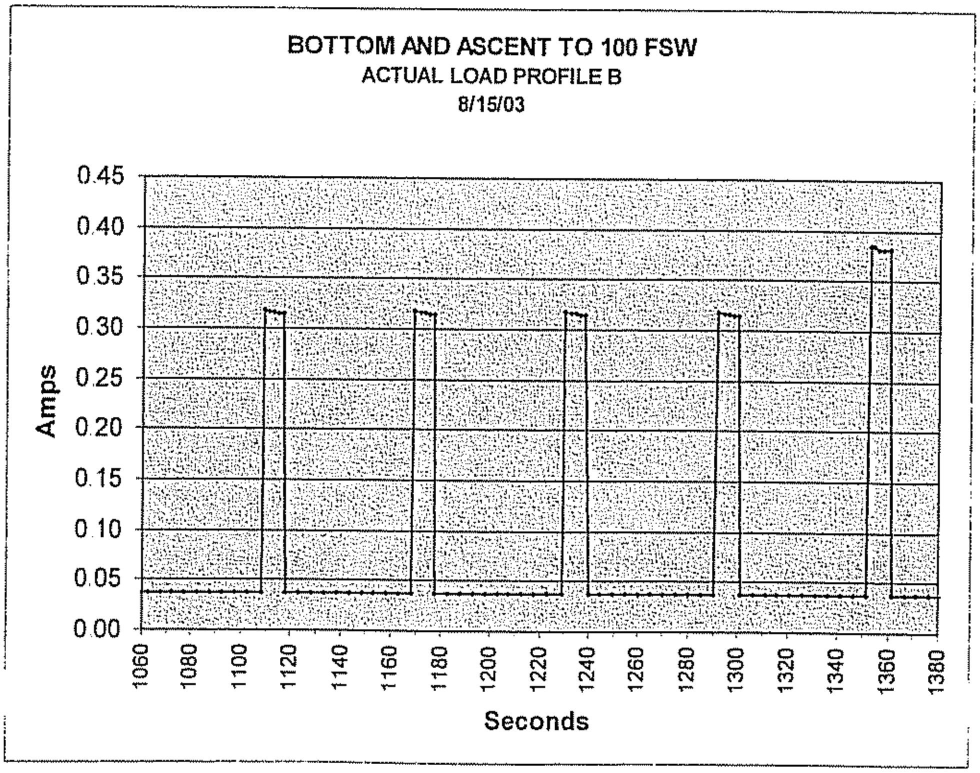
1. Shorted battery current behavior and final battery photo.
2. Normal sample offgas analysis.
3. Shorted sample offgas analysis.

Test Conducted by: [signature] Date: 8/18/03

Test Witnessed by: [signature] Date: 18 AUG 2003

LITHIUM BATTERY OFFGASSING TEST
CSS E50





21 AUG 2003

From: Diving Medical Officer for CSS Code E50
To: Dr. John Camperman, CSS Code E50E

Subj: EVEREADY EL223 LITHIUM BATTERY

Encl: (1) P9290 Offgassing Report, Coastal Systems Station, dtd 19Aug03
(2) P9290 Offgassing Report, shorted battery test, Coastal Systems Station, dtd 19Aug03

1. Enclosures (1) and (2) were reviewed for the health and safety considerations with regard to potential atmospheric contaminants from a lithium battery. The gas samples were taken during a simulated 320 FSW heliox dive. The gas sampled collected during normal operation found a total hydrocarbon level of 3.3 ppm, oxygen at 9.9%, and a carbon dioxide level of 13 ppm. All other targeted compounds were below the absolute measured levels. Further analysis of the hydrocarbons found **1,2-dimethoxyethane at 0.06 ppm**, butane-1,1,3,4-tetrachloro-1,2,2,3,4,4-hexaflouro at 0.41 ppm, and butane-1,2,3,4-tetrachloro-1,1,2,3,4,4-hexafluoro at 0.06 ppm. The analyses of the gas sample obtained when the battery was shorted were: total hydrocarbons at 12.1 ppm, oxygen at 28.6%, carbon dioxide at 40 ppm, and a failure for odor and aerosols. All other targeted compounds were below the absolute measured levels. Further analysis of the hydrocarbons found **1,2-dimethoxyethane at 2.0 ppm**, butane-1,1,3,4-tetrachloro-1,2,2,3,4,4-hexaflouro at 0.55 ppm, butane-1,2,3,4-tetrachloro-1,1,2,3,4,4-hexafluoro at 0.10 ppm, heptane-2,4-dimethyl at 0.01 ppm, and freon 113 at 0.15 ppm.

2. During the testing of the battery during normal operation some observers noted a smell from the battery; whereas, the odor was very offensive when the battery was shorted. The gaseous contaminant most likely causing the odor is 1,2-dimethoxyethane. This compound is harmful by inhalation. Though there is no federal guidance on the allowable exposure limit, Duracell sets an exposure limit of 0.15 ppm. Based upon this limit and correcting for depth as per U. S. Navy protocol for setting allowable limits for hyperbaric applications, **the maximum allowable level for 1,2-dimethoxyethane is 0.02 ppm**. The levels of 1,2-dimethoxyethane found in this battery exceed the allowable limit for U. S. Navy applications, even during normal operations.

3. Based upon the known inhalation hazard of 1,2-dimethoxyethane found in this lithium battery, the use of a lithium battery within the breathing loop of an underwater breathing apparatus (UBA) is unacceptable. Depending upon the sensitivity of the individual to this compound, a diver may experience an adverse reaction when breathing from the UBA during normal operations. In the event of a battery short, the diver's reaction may be catastrophic, resulting in serious injury or death.

M E Knafelc MD, PhD
M. E. KNAFELC
CAPT, MC, USN

Test Facility: Coastal Systems Station Gas Analysis Lab, Bldg.#414 6703 W. Hwy. 98 Panama City, FL 32407 850-235-5505	**P9290 Offgassing Report** **Analysis Date:** 08/15/03 **Report Date:** 08/19/03	**Report To:** John Camperman, Code E50E Coastal Systems Station Panama City, Fl 32407

Sample Description: Offgassing Analysis of Eveready EL223 Lithium battery, 6 volt. Cure/MFG Date: Shelf Life to 2010.

Sample Weight: 36.6 g.	**Room Temperature:** 70°F

The above sample was placed in a 7,600 cubic-centimeter offgassing chamber which had been precleaned to ensure a zero hydrocarbon background. The chamber was then charged to simulate a heliox dive to 320 FSW before an analysis for specific and total hydrocarbons. Gas analysis was performed at a cylinder pressure of 44 psig. Refer to the attached Lithium Battery Offgassing Test procedure. The analysis yielded the following results: (CSS E50, 14 AUG 03)

Standard Components

COMPONENT	ABSOLUTE MEASURED LEVEL	NORMALIZED LEVEL (Ref-8)	ANALYSIS METHOD	REPORTING LIMIT (Ref-9)	SURFACE ALLOWED LIMIT (ref.)
Total Hydrocarbons	3.3 PPM	2.97E-3 PPM/G/L	THA-FID	5.0 PPM	25 PPM **(1,3)**
Total Halogens	<0.5 PPM	Not Detected	HA	2.0 PPM	10 PPM **(3,6)**
Hydrogen	<300 PPM	Not Detected	DT	2000 PPM	10,000 PPM **(3)**
Oxygen	9.9%	8.91E-3 %/G/L	GC-TCD	N/A	N/A
Carbon Dioxide	13 PPM	1.17E-2 PPM/G/L	CO2-IR	200 PPM	1,000 PPM **(4)**
Carbon Monoxide	<0.5 PPM	Not Detected	CO-IR	2.0 PPM	10 PPM **(3)**
Odor & Aerosols Before Test	pass	pass	Nose (smell)	not detected	not detected **(3)**
Odor & Aerosols After Test	pass	pass	Nose (smell)	not detected	not detected **(3)**
Mercury	<0.001 mg/m3	Not Detected	GFMA	0.002 mg/m3	0.01 mg/m3 **(3)**
Butyl Cellusolve	<0.1 PPM	Not Detected	GC-MSD	0.4 PPM	2 PPM **(3)**

Enclosure (1)

Standard Components

COMPONENT	ABSOLUTE MEASURED LEVEL	NORMALIZED LEVEL (Ref-8)	ANALYSIS METHOD	REPORTING LIMIT (Ref-9)	SURFACE ALLOWED LIMIT (ref.)
1,1,1-Trichloroethane	<0.01 PPM	Not Detected	GC-ECD	0.5 PPM	2.5 PPM **(3)**
t-1,2-Dichloroethylene	<0.05 PPM	Not Detected	GC-ECD	0.05 PPM	0.1 PPM **(3)**
Trichloro ethylene	<0.01 PPM	Not Detected	GC-ECD	0.02 PPM	0.1 PPM **(3)**
Vinylidine Chloride	<0.01 PPM	Not Detected	GC-ECD	0.03 PPM	0.15 PPM **(3)**
Acrolein	<0.002 PPM	Not Detected	GC-MSD	0.002 PPM	0.01 PPM **(3)**
Benzene	<0.01 PPM	Not Detected	GC-FID	0.02 PPM	0.1 PPM **(3)**
Methanol	<0.2 PPM	Not Detected	GC-FID	1.4 PPM	7 PPM **(2)**
Xylenes	<0.1 PPM	Not Detected	GC-FID	2.0 PPM	10 PPM **(3)**
Ammonia	<0.2 PPM	Not Detected	DT	2.0 PPM	10 PPM **(3)**
Chlorine	<0.05 PPM	Not Detected	DT	0.05 PPM	0.1 PPM **(3)**
Formaldehyde	<0.03 PPM	Not Detected	DT	0.03 PPM	0.04 PPM **(3)**
Hydrogen Sulfide	<0.2 PPM	Not Detected	DT	0.2 PPM	1.0 PPM **(3)**
Sulfur Dioxide	<0.25 PPM	Not Detected	DT	0.25 PPM	1.0 PPM **(3)**

Other Components

Note: The estimated absolute measured level for other components is based upon the Library search report generated from the Mass Spectrometer. The area percent obtained from the report is compared with the total hydrocarbon level to calculate the estimated concentration level of each compound; expressed as PPM per molecule.

COMPONENT	ESTIMATED ABSOLUTE MEASURED LEVEL	NORMALIZED LEVEL (Ref-8)	ANALYSIS METHOD	REPORTING LIMIT (Ref-9)	SURFACE ALLOWED LIMIT (Ref-5,7)
1,2-Dimethoxy ethane	0.06 PPM	5.40E-5 PPM/G/L	GC-MSD	N/A	none specified(5)
Butane-1,1,3,4-tetrachloro-1,2,2,3,4,4-hexafluoro	0.41 PPM	3.69E-4 PPM/G/L	GC-MSD	N/A	none specified(5)
Butane-1,2,3,4-tetrachloro-1,1,2,3,4,4-hexafluoro	0.06 PPM	5.40E-5 PPM/G/L	GC-MSD	N/A	none specified(5)

Test results are only applicable to the sample identified in the sample description. The sample did not show excessive offgasing at the man-rated environment limits shown. Test chamber volume, pressure, and amount of material used must be considered when evaluating results for use in other enclosures.

Ref-1: Expressed as methane equivalents.
Ref-2: Table F-3, P9290 Rev A.
Ref-3: Table F-4, P9290 Rev A.
Ref-4: Limits taken from Navy Dive Manual; Rev. 4, Table 4-1.
Ref-5: OSHA Final Rule limits.
Ref-6: Expressed as chloromethane equivalents.
Ref-7: Section F6-C of P9290 Rev A(pg F-20). Limit is equal to one-tenth the lowest allowable exposure limit established by OSHA or ACGIH.
Ref-8: The normalized level for pieces is PPM/g/L (PPM/SA/V). Complete assemblies like computers are normalized as PPM/L.
Ref-9: Section F5.4-C of P9290 Rev A(pg F-19). The reporting limit is the lowest concentration (sensitivity) to which each component must be analyzed. The reporting limit should be not less than 1/5 the SEV corrected allowable exposure limit. Where the SEV corrected allowable exposure limit is less than or equal to the instrument sensitivity, the reporting limit shall be specified as instrument detectability. The minimum instrument detectability shall be equal to the SEV corrected allowable exposure limit, or if greater, a value acceptable to cognizant medical department personnel.

Hugh B Orr 8-19-03
Hugh Ben Orr, Date
Analyst/Lab Manager

Reviewed by
Marie E Knafelc MD, PhD
20 Aug 03
Marie E. Knafelc
CAPT/MC/USN
Diving Medical Officer

COASTAL SYSTEMS STATION GAS ANALYSIS LAB	CERTIFICATION OF CALIBRATION	PAGE 1 OF 4 QA_Sheet.doc

EQUIPMENT USED AND CERTIFICATION OF CALIBRATION

Date of Analysis: 15 August 2003 Reports #20030815JC01

1). **(DT) Detector tubes.**

A). The detector tubes are calibrated and certified at the factory.

B). The pumps are leak checked once prior to the days analysis.

TYPE	MANUFACTURER (M) MATHESON (S) SENSIDYNE	Tube#	LOT#	EXP. DATE
Ammonia	Sensidyne	105SD	426102	APR 2005
[illegible]	Sensidyne	[illegible]	[illegible]	[illegible]
[illegible]	Sensidyne	[illegible]	[illegible]	[illegible]
[illegible]	Sensidyne	[illegible]	[illegible]10072	[illegible]
[illegible]	Sensidyne	137[illegible]	[illegible]	[illegible]
Hydrogen Sulfide	Sensidyne	120[illegible]	[illegible]	JAN 2004
Nitrogen Dioxide	Sensidyne	117[illegible]	106072	DEC 2004
Sulfur Dioxide	Sensidyne	103SE	123112	

2). **(THA-FID) Total Hydrocarbon Analyzer.** Next Cal. Date:09/12/2003

Rosemount Analytical Model #400A, S/N:1001597

Calibration Gas: Cylinder # LL49325.

3). **(CO-IR) Carbon Monoxide Analyzer.** Next Cal. Date: 09/12/2003

Beckman Model #865, S/N: 0103715

Calibration Gas: Cylinder # CC143468.

4). **(GC-ECD) HP 6890 Gas Chromatograph.**

Last Cal. Date: 06/25/2003, Next Cal. Date: 08/25/2003

Chromatograph Model #6890, S/N: US00010085

HP6890 Integrator Model #3396C, S/N: CN00007256

Calibration Gas: Cylinder #FF22008, FF20813, FF20881, FF22060.

5). **(GFMA) Gold Film Mercury Analyzer.**

Model#411, S/N: 411-1308, Next Cal. Date: 02/12/2004

6). **(GC-TCD) Gow-Mac Chromatograph.**

Gow-Mac Model #69-580-TCD, S/N:390507

Next Cal. Date: Once daily for each group of samples.

Calibration Gas: Cyl # CC143468.

7). **(GC-FID) HP 5890 Gas Chromatograph.**

Last Cal. Date: 06/25/2003, Next Cal. Date: 08/25/2003

Chromatograph Model #5890E, S/N: 3336A55655

HP Integrator Model #3396B, S/N: 3028A20869

Calibration Gas: Cyl# LL49325,FF22008, FF22072, FF20813,FF20881, FF22071, CC162928, FF22060, FF22007, FF19229.

8). **(GC/MSD)HP 5971A GC/MSD with Dynatherm ACEM 900 Single Tube Desorption System.**

Dynatherm Concentrator, Model #ACEM900, S/N: 19483.

Chromatograph, HP Model #5890, S/N: 2950A27550.

HP Mass Selective Detector, Model #5971A, S/N:2950A00761.

A). Next Cal. Date: N/A for Qualitative Analysis

B). Quantitative Analysis of 2-Butoxyethanol.

Next Cal. Date: 08/18/2003.

Standard concentration: [illegible].059 g/l in Methanol.

Cal. Standard Expiration Date: 10/04/2003.

2-Butoxyethanol raw material Lot # [illegible].

C). Quantitative Analysis of Acrolein.

Next Cal. Date: 08/18/2003.

Calibration Gas: CC162928.

9). **(SOA) Servomix Oxygen Analyzer.**
Servo Mix Type: 00244701, S/N: 1944.
Next Cal. Date: Once daily for every group of analysis.
Calibration Gas: Cyl# CC143468, Cyl# A582.

10). **(HA) Total Halogenated Hydrocarbon Analyzer.**
Yokogawa Model # H-25C, S/N: H25C-N-N-5N-E
Next Cal. Date: 09/12/2003
Calibration Gas: Cyl#LL16176.

11). **Calibration gases.**

A). Cylinder #LL49325, Expiration Date: 08/01/2005
25.2 PPM Methane in air, accuracy +/-2%.

[illegible] #CC1[illegible]458 Expiration Date: [illegible]/2[illegible]
[illegible] C[illegible], [illegible] 900[illegible] [illegible] 550 PPM [illegible] PPM [illegible]
[illegible] N[illegible]rogen, accuracy +/-2%%.

C). Cylinder #FF22060, Expiration Date: 09/11/2003
10.1 PPM Acetone, 10.0 PPM Acetylene, 10.0 PPM Freon 12, 10.0 PPM Freon 114,
10.1 PPM Toluene, 10.1 PPM 1,1,1-Trichloroethane, 10.1 PPM Freon 113,
3.03 PPM 1,2,4-Trimethylbenzene, 3.03 PPM 1,3,5-Trimethylbenzene, 10.1 PPM M-Xylene,
10.1 PPM O-Xylene, Bal. Nitrogen, accuracy +/-1%.

D). Cylinder #FF22008, Expiration Date: 09/11/2004
1.01 PPM Chloroform, 0.507 PPM Trichloroethylene,
1.02 PPM 1,1-Dichloroethene, 0.507 PPM t-1,2-Dichloroethylene,
Bal. Nitrogen, accuracy +/-1%.

E). Cylinder #FF22007, Expiration Date: 09/11/2003
10.1 PPM Ethanol, 10.1 PPM Ethylene, 10.1 PPM Isopropanol,
10.1 PPM Methanol, 10.1 PPM Methyl Ethyl Ketone,
10.1 PPM Methyl Isobutyl Ketone, 10.1 PPM p-Xylene,
Bal. Nitrogen, accuracy +/-1%.

F). Cylinder #FF22072, Expiration Date: 04/22/2005
10.1 PPM Ethane, Bal. Nitrogen, accuracy +/-1%.

G). Cylinder # LL16176, Expiration Date:08/27/2004.
10.4 PPM Chloromethane, Bal. Air, accuracy +/-2%.

H). Cylinder#FF20813, Expiration Date:10/16/2004
10.03 PPM Freon 11, Bal. Nitrogen, accuracy: +/-1%

I). Cylinder#FF22071, Expiration Date: 10/16/2004
0.504 PPM Benzene, Bal. Nitrogen, accuracy +/-1%.

J). Cylinder#LL16186, Expiration Date: 01/[illegible]/2005
50.1 PPM Carbon Dioxide, Bal. Air, accuracy +/-2%.

K). Cylinder#A582, Expiration Date: N/A
Research Purity Oxygen, 99.999%.

L). Cylinder#FF20881, Expiration Date: 04/22/2005
10.2 PPM Methylene Chloride, Bal. Nitrogen, accuracy +/-1%.

M). Cylinder#CC162928, Expiration Date: [illegible] 24 2004
[illegible].344 PPM Acrolein, Bal. Nitrogen, accuracy + -10%

N). Cylinder#FF19229, Expiration Date:02/[illegible]/2004
1.03 PPM Vinyl Chloride, Bal. Nitrogen, accuracy: +/-1%

[illegible]). **Sierra Instruments Flow Controllers.**
Model 810C-DR-13, S/N: 53913, Next Cal. Date:[illegible] 28/2003
Model 810C-DR-13, S/N: 53914, Next Cal. Date:[illegible] 28/2003

13). **Alltech Digital Flow Check Meter**
S/N: 03704, Next Cal. Date: 10-17-2003.
S/N: 11030, Next Cal. Date: 05-21-2004.

14). **Cole-Parmer/Ashcroft Test gauge**
0-200 psig, accuracy 0.25% of scale.
Cat#68033-07, S/N: 57443.
Next Cal. Date: 06-27-2004.

15). **Cole-Parmer/Ashcroft Test gauge**
0-100 psig, accuracy 0.25% of scale.
[illegible], S/N [illegible] 42.
[illegible] 2004

16). Omega Thermometer.
Model #650-JF-A-DSS, S/N:6601, Next Cal. Date: 7-03-[illegible].
Model #650-JF-X-DSS, S/N: 4688, Next Cal. Date: 7-03-2005.
Model #MDSS18-TC, S/N: 2310424, Next Cal. Date: 5-07-2005.

17). **Mettler PC8000 Scale.**
Model #PC8000, S/N:A25511.
Next Cal. Date: 01/03/2004.

18). **Mettler AE240 Scale.**
Model #AE240, S/N: G31930
Next Cal. Date: 01/07/2004.

19). **Mettler ID1 Multirange Scale**
Model #KC120, S/N: 1905526
Next Cal. Date: 01/03/2004.

20). **(AMA) Ametek Moisture Monitor**
Model# 303B, S/N: 303B8027
Next Cal. Date: 6/30/2004.

21). **(OMP) Cole-Parmer Flow Meter**
Model #P11/1, S/N:192107
Next Cal. Date: 06/27/2004.

22). **(CO2-IR) Carbon Dioxide Analyzer.** Next Cal. Date: 09/12/2003
Beckman Model #865, S/N: 102535
Calibration Gas: Cylinder # CC143468, [illegible]6186.

Test Uncertainty

1). The test uncertainty will provide the client with a reasonable indication of the accuracy o testing and analysis performed by the laboratory.

2). Test uncertainty will include the uncertainties due to test method repeatability, reference materials and standards, and any additional uncertainties that are identified to effect th accuracy of the test results.

3). The following table gives the test uncertainties associated with this test report.

COASTAL SYSTEMS STATION GAS ANALYSIS LAB	CERTIFICATION OF CALIBRATION	PAGE 4 OF 4 QA_Sheet.doc

TEST UNCERTAINTY		
ANALYSIS METHOD	**DATE**	**% TEST UNCERTAINTY**
GC-TCD		
Oxygen	08/15/2003	21% O2 +/-2.7%
Argon	08/15/2003	0.9% Ar +/-2.0%
Nitrogen	08/15/2003	78.1% N2 +/-2.8%
SOA	05/12/2003	21% O2 +/-2.3%
CMP	05/06/2003	4.87 mg/m^3 +/-9%
GC/MSD		
2-Butoxyethanol	06/13/2003	0.324 PPM +/-3.5%
[illegible]	[illegible] 2003	[illegible] PPM +/-10.4%
[illegible]-FID	[illegible] 2003	[illegible] PPM +/-2.0
CO-IR	08/12/2003	15.2 PPM +/-2.[illegible]%
HA	08/12/2003	10.4 PPM +/-2.9%
CO2-IR		
CO2-HIGH LEVEL CAL	08/12/2003	353 PPM +/-2.4%
CO2-LOW LEVEL	08/12/2003	50.1 PPM +/-3.1%
GC-ECD		
1% Mix Accuracy	06/25/2003	CONC. CAL GAS </=6.8%
GC-FID		
1% Mix Accuracy	06/25/2003	CONC. CAL GAS </=9.8%
2% Mix Accuracy	06/25/2003	CONC. CAL GAS </=2.5%
AMA	N/A	10.0%
DT	N/A	25.0%
GFMA	N/A	15.0%
QA SHEET UNCERTAINTY.XLS		

I certify that the above data is correct.

Hugh B Orr — 8-12-03

Hugh Ben Orr,
Analyst/Lab Manager.

Date

Test Facility: Coastal Systems Station Gas Analysis Lab, Bldg.#414 6703 W. Hwy. 98 Panama City, FL 32407 850-235-5505	**P9290 Offgassing Report** **Analysis Date:** 08/18/03 **Report Date:** 08/19/03	**Report To:** John Camperman, Code E50E Coastal Systems Station Panama City, Fl 32407

Sample Description: Offgassing Analysis of Eveready EL223 Lithium battery, 6 volt. Cure/MFG Date: Shelf Life to 2010. Shorted battery test.

Sample Weight: 36.6 g.	**Room Temperature:** 70°F

The above sample was placed in a 7,600 cubic-centimeter offgassing chamber which had been precleaned to ensure a zero hydrocarbon background. ~~The chamber was then charged to simulate a heliox dive to 320 FSW before an analysis for specific and total hydrocarbons~~. Gas analysis was performed at a cylinder pressure of 50 psig. Refer to the attached Lithium Battery Offgassing Test procedure. The analysis yielded the following results:
(CSS E50, 14 AUG 03)

Standard Components

COMPONENT	ABSOLUTE MEASURED LEVEL	NORMALIZED LEVEL (Ref-8)	ANALYSIS METHOD	REPORTING LIMIT (Ref-9)	SURFACE ALLOWED LIMIT (ref.)
Total Hydrocarbons	12.1 PPM	9.88E-3 PPM/G/L	THA-FID	5.0 PPM	25 PPM**(1,3)**
Total Halogens	<0.5 PPM	Not Detected	HA	2.0 PPM	10 PPM**(3,6)**
Hydrogen	<300 PPM	Not Detected	DT	2000 PPM	10,000 PPM**(3)**
Oxygen	28.6%	2.34E-6 %/G/L	GC-TCD	N/A	N/A
Carbon Dioxide	40 PPM	3.27E-2 PPM/G/L	CO2-IR	200 PPM	1,000 PPM**(4)**
Carbon Monoxide	<0.5 PPM	Not Detected	CO-IR	2.0 PPM	10 PPM**(3)**
Odor & Aerosols Before Test	pass	pass	Nose (smell)	not detected	not detected**(3)**
Odor & Aerosols After Test	fail	fail	Nose (smell)	not detected	not detected**(3)**
Mercury	<0.001 mg/m3	Not Detected	GFMA	0.002 mg/m3	0.01 mg/m3**(3)**
Butyl Cellusolve	<0.1 PPM	Not Detected	GC-MSD	0.4 PPM	2 PPM**(3)**

Enclosure (2)

Standard Components

COMPONENT	ABSOLUTE MEASURED LEVEL	NORMALIZED LEVEL (Ref-8)	ANALYSIS METHOD	REPORTING LIMIT (Ref-9)	SURFACE ALLOWED LIMIT (ref.)
1,1,1-Trichloroethane	<0.01 PPM	Not Detected	GC-ECD	0.5 PPM	2.5 PPM(3)
t-1,2-Dichloroethylene	<0.05 PPM	Not Detected	GC-ECD	0.05 PPM	0.1 PPM(3)
Trichloro ethylene	<0.01 PPM	Not Detected	GC-ECD	0.02 PPM	0.1 PPM(3)
Vinylidine Chloride	<0.01 PPM	Not Detected	GC-ECD	0.03 PPM	0.15 PPM(3)
Acrolein	<0.002 PPM	Not Detected	GC-MSD	0.002 PPM	0.01 PPM(3)
Benzene	<0.01 PPM	Not Detected	GC-FID	0.02 PPM	0.1 PPM(3)
Methanol	<0.2 PPM	Not Detected	GC-FID	1.4 PPM	7 PPM(2)
Xylenes	<0.1 PPM	Not Detected	GC-FID	2.0 PPM	10 PPM(3)
Ammonia	<0.2 PPM	Not Detected	DT	2.0 PPM	10 PPM(3)
Chlorine	<0.05 PPM	Not Detected	DT	0.05 PPM	0.1 PPM(3)
Formaldehyde	<0.03 PPM	Not Detected	DT	0.03 PPM	0.04 PPM(3)
Hydrogen Sulfide	<0.2 PPM	Not Detected	DT	0.2 PPM	1.0 PPM(3)
Sulfur Dioxide	<0.25 PPM	Not Detected	DT	0.25 PPM	1.0 PPM(3)

Other Components

Note: The estimated absolute measured level for other components is based upon the Library search report generated from the Mass Spectrometer. The area percent obtained from the report is compared with the total hydrocarbon level to calculate the estimated concentration level of each compound; expressed as PPM per molecule.

COMPONENT	ESTIMATED ABSOLUTE MEASURED LEVEL	NORMALIZED LEVEL (Ref-8)	ANALYSIS METHOD	REPORTING LIMIT (Ref-9)	SURFACE ALLOWED LIMIT (Ref-5,7)
1,2-Dimethoxy ethane	2.0 PPM	1.63E-3 PPM/G/L	GC-MSD	N/A	none specified(5)
Butane-1,1,3,4-tetrachloro-1,2,2,3,4,4-hexafluoro	0.55 PPM	4.49E-4 PPM/G/L	GC-MSD	N/A	none specified(5)
Butane-1,2,3,4-tetrachloro-1,1,2,3,4,4-hexafluoro	0.10 PPM	8.17E-5 PPM/G/L	GC-MSD	N/A	none specified(5)

COMPONENT	ESTIMATED ABSOLUTE MEASURED LEVEL	NORMALIZED LEVEL (Ref-8)	ANALYSIS METHOD	REPORTING LIMIT (Ref-9)	SURFACE ALLOWED LIMIT (Ref-5,7)
Heptane-2,4-dimethyl	0.01 PPM	8.17E-6 PPM/G/L	GC-MSD	N/A	not specified(5)
Freon 113	0.15 PPM	1.23E-4 PPM/G/L	GC-MSD	20 PPM	100 PPM(7)

Test results are only applicable to the sample identified in the sample description. The sample showed excessive offgasing at the man-rated environment limits shown. Test chamber volume, pressure, and amount of material used must be considered when evaluating results for use in other enclosures.

Ref-1: Expressed as methane equivalents.
Ref-2: Table F-3, P9290 Rev A.
Ref-3: Table F-4, P9290 Rev A.
Ref-4: Limits taken from Navy Dive Manual; Rev. 4, Table 4-1.
Ref-5: OSHA Final Rule limits.
Ref-6: Expressed as chloromethane equivalents.
Ref-7: Section F6-C of P9290 Rev A(pg F-20). Limit is equal to one-tenth the lowest allowable exposure limit established by OSHA or ACGIH.
Ref-8: The normalized level for pieces is PPM/g/L (PPM/SA/V). Complete assemblies like computers are normalized as PPM/L.
Ref-9: Section F5.4-C of P9290 Rev A(pg F-19). The reporting limit is the lowest concentration (sensitivity) to which each component must be analyzed. The reporting limit should be not less than 1/5 the SEV corrected allowable exposure limit. Where the SEV corrected allowable exposure limit is less than or equal to the instrument sensitivity, the reporting limit shall be specified as instrument detectability. The minimum instrument detectability shall be equal to the SEV corrected allowable exposure limit, or if greater, a value acceptable to cognizant medical department personnel.

Reviewed by:
Marie E Knafelc MD, PhD
Marie E. Knafelc
CAPT/MC/USN
Diving Medical Officer
20 Aug 03

Hugh B Orr 8-19-03
Hugh Ben Orr, Date
Analyst/Lab Manager

APPENDIX D
BATTERY & CABLING SAFETY REVIEW

- Safety Review Panel 26, 27 August 2003
- Scope of Certification Hardware Criticality and Required Attributes
- Scope of Certification Hardware Criticality Guide

INSPIRATION REBREATHER
BATTERY SAFETY REVIEW 26, 27 AUG 03

PARTICIPANTS

Silent Diving Systems, LLC:	Mike Fowler, Cliff Simoneau
NOAA Undersea Research Program:	Eugene Smith
USN Coastal Systems Station:	John Camperman, Wes Hughson, Kirk VanZandt
USN, CSS E50 Diving Medical Officer:	Capt. Marie Knafelc

26 AUG

0900-1200 SDS briefing on Inspiration system hardware, operation, and training procedures.

1300-1500 CSS briefing on battery safety investigation and offgas analysis for simulated dive to 320 feet, and for shorted battery. Discussion followed.

1500-1600 SDS briefing on Ambient Pressure Diving Ltd. production capabilities, and on Evolution and Trojan recirculators.

27 AUG

0900-1030 Captain M. Knafelc (MD.) described potential hazards from 1,2 Dimethoxyethane in diver breathing gas. Discussion followed.

1030-1300 Developed Scope of Certification Hardware Criticality and Required Attributes sheet for the Inspiration battery. This involved noting all potential hazards and attributes required to mitigate them.

SCOPE OF CERTIFICATION
HARDWARE CRITICALITY AND REQUIRED ATTRIBUTES

ITEM DESCRIPTION Energizer 6v Lithium manganese Dioxide Battery		PART (DWG) NO. EL223	REV
NEXT HIGHER ASSY PN Canister Lid Assembly RB06 / 01	DATE 09/16/03	SIGNATURE	

FUNCTIONAL DESCRIPTION
One battery provides power to the rebreather controller/displays, oxygen sensors, oxygen solenoid, and alarm. A second identical battery provides redundant backup. Batteries are in the breathing gas loop.

HAZARD ANALYSIS, ENGINEERING JUDGMENT, OR EXPERIENCE

	Inspection	Testing
Original issue -	(*)	(*)
Premission -	(x)	(x)
Predive -	( )	(x)
Planned Maintenance -	(x)	(x)
Depot Overhaul -	(x)	(x)

Inspection: Visual
Testing: Voltage

*Manufacturer QA expected but not verified.

Power Failure: The redundant battery makes this failure mode a multiple path failure. Controller warnings, training, and emergency procedures require terminating the dive when one battery fails.
Toxic Offgassing: Single path failure. A test indicated odor and unacceptable atmospheric contamination during normal operation on deep dives. A test indicated that contamination is highly unacceptable if the battery is short-circuited.
Flammability: Single path failure. Internal battery safety features are designed to limit heat in the event of battery short-circuit. A test in 1.3ata oxygen at 4.4ata total pressure confirmed this function. The battery box contacts are spring loaded to prevent arcing. Planned maintenance requires replacement of the battery box assembly.
General: More than 100,000 dive hours have been conducted using more than 6,000 batteries since December 1996. The rebreather vendors know of no cases of toxic gas or oxygen fire. Redesign to move the batteries out of the breathing gas loop would eliminate the single path failures above. Additional toxic offgassing and flammability tests are warranted for batteries in the breathing gas loop. Safety attributes assigned below assume testing confirms battery safety in a breathing loop.

SERIOUS INJURY OR LOSS-OF-LIFE THREAT RESULTING FROM:
Component Failure - SINGLE (x) MULTIPLE ( ) NOT APPLICABLE ( )

CATEGORY OF CRITICALITY

1. CRITICAL (x) 2. SUPPORT ( ) 3. LIMITED ( ) 4. NON-SOC ( )

SAFETY ATTRIBUTES ASSIGNED
07, 15

NON-SAFETY ATTRIBUTES ASSIGNED
17

COASTAL SYSTEMS STATION CODE E52

SCOPE OF CERTIFICATION HARDWARE CRITICALITY GUIDE
COASTAL SYSTEMS STATION, DEEP SUBMERGENCE SYSTEMS BRANCH
JULY 2003

GUIDELINES FOR ESTABLISHING CRITICALITY LEVELS AND ATTRIBUTES

1. Identify level of criticality for the item without regard for probability of failure (assume it could fail even if the probability is remote).

2. Identify required safety attributes for the item with consideration of criticality level and safety factors/experience/use, etc.

3. Safety attributes are related to the failure mode that required the level of criticality assigned. Non-safety attributes are not related to safety but may be required for part interchangeability, longevity, appearance, etc.

4. Required attributes are always called out at level where objective quality evidence (OQE) is to be maintained., This often means that an attribute is actually satisfied at an upper assembly versus part or subassembly level.

5. Documentation used as OQE for required attributes may be from vendors or subcontractors provided it is traceable to the final components. OQE that exceeds the requirements of an attribute may be used to fill a required attribute (i.e., chemicals and physicals may be used in lieu of a generic acid spot test) if approved by quality assurance personnel.

6. The drawing revision letter shown for each component is that of the latest revision that affected certification attributes. Revision letters for drawing revisions not affecting certification attributes are not updated in this document.

SCOPE OF CERTIFICATION CATEGORIES

System components (assemblies, subassemblies, and parts) are assigned to scope of certification (SOC) hardware criticality categories based on the hazard analysis, engineering judgment, and experience of cognizant engineers responsible for component design and system safety.

1. SOC CRITICAL. Components are designated SOC CRITICAL if a single failure of the component during normal operation would result in serious injury or loss of life. A designation of SOC CRITICAL invokes the most stringent controls for material accountability, testing, maintenance, and repair according to the attributes listed in the matrices.

2. SOC SUPPORT. Components are designated SOC SUPPORT if a multiple component failure during normal operation would have to occur in order to jeopardize personnel safety. A designation of SOC SUPPORT invokes work and process control to assure accountability during construction, maintenance, and repair according to the attributes listed in the matrices.

3. SOC LIMITED. Components (not designated SOC CRITICAL or SOC SUPPORT) are designated SOC LIMITED if they require controls to assure cleanliness and toxic/flammable material identification and qualification.

4. NON-SOC. Components in the system that do not affect safety and therefore are not in the scope of certification, are designated NON-SOC. NON-SOC items by virtue of being part of the system require quality assurance controls to provide for system reliability, but these controls are not required to assure personnel safety.

HARDWARE SAFETY ATTRIBUTE DEFINITIONS
(exerpts)

TESTING ATTRIBUTES:

07 BATCH TESTING. OQE documentation showing that all applicable tests have been performed on each item in the sample and that the items meet all contract/ purchase order and/or drawing specifications. Actual test data for each item in the lot is not required. Documentation shall show quantity tested, tests accomplished, pass/fail criteria, date tested, and shall be initialed by personnel performing the test.

FABRICATION AND FINAL ASSEMBLY ATTRIBUTES:

15 PACKAGING AND LABELING. The inspector shall visually check the items in the shipment to ensure that they are properly packaged and labeled in accordance with the contract/purchase order and/or drawing specifications. This attribute applies only to items that are ready for Fleet issue and not to incoming shipments unless otherwise stated in the contract/purchase order.

17 SHELF LIFE. The inspector shall ensure that items in the shipment are still within the stated shelf life of the item in accordance with any applicable specifications.