HAZARD AND OPERABILITY STUDY (HAZOP) REPORT

Subject: Rebreather hoses including all hose attachments and counter lungs.

Site:	St.Petersburg, Russia Design Centre
Date:	17 January 2007, 1st part., with follow on review in Sweden July 2009 and FS certification closure review April 2010
Time:	10:00 -19:00
Project:	O.R. Rebreathers
Participants and Contributors:	YB , JH, JAH, JNO, SO, KS, AD, MY, AB, AK, SM, VD, PK, VK, BS, OL, JS, JB, KS
Study leader:	Vladimir Komarov , follow up review led by AD

General review:

Terms of reference and scope of the study are SCR hoses including attachment and counter lungs according to the project document Green Book GreenB_ORTONOR_070105.pdf and Agenda of HAZOP Study of 17.01.2007, and FMECA Volumes 1 to 4 inclusive.

The hoses comprised of gas hoses to/from counter lungs to/from mouthpiece. The cable tie caps are also part of the scope and being under consideration.

The cable ties were changed from twin cable ties to stainless steel jubilee clip as a consequence of the previous design and safety review. The meeting asked to see how the jubilee clip fails, to see whether the clip failed in a safe manner. For this purpose, a clip was tightened on a port. The grub screw failed without any failure of the overall function. The hose was then pulled until failure occurred. The port was then disassembled and it could be seen that the clamp had not torn the hose: pictures below – the failure point was the small cuts the forming tool makes on each ring, extending around the ring.

The meeting noted that the requirement for EN14143:2003 was for 25kg pull resistance, and the present design achieved 50kg. The design target is 100kg: the meeting found that 100kg was beyond the plausible tension on the hose but 50kg was not, so 100kg should remain the design target. The follow up review used a custom EPDM, and 100kg was achieved reliably for the hose. At pulls beyond 50kg, it is possible for the port it is attached to release the port as a normal male – female disconnect, without damage. If there is excessive strain on the area around the hoses, the vacuum moulded versions of the rebreather case, used in the SRB models, has a weak point CNC'd into the port area that is designed to split to keep the breathing loop intact: this is a failure evident feature intended to prevent hidden failures of the counterlung nut.

The MSDS for the exact EPDM used for the hoses was circulated to the meeting. This was a detailed document which the meeting found satisfactory in depth, but identified Thiram in the original EPDM compound as an off-gas product. Thiram is a formaldehyde with known long term health hazards: see http://ptcl.chem.ox.ac.uk/MSDS/TH/thiram.html

Follow Up Action Taken: Contacted manufacturer to find a solution that does not use Thiram. Custom EPDM was produced for Deep Life that is Thiram free, and all hoses were refabricated from this compound and retested. Only the Thiram free EPDM is used: all previous stock was rejected.

The overall approach taken to the breathing hoses is to make them as short as possible, with 400% stretch achieved by convoluting the material: the stretch available from non-convoluted materials is generally limited to 200% though a 300% stretch from solid silicone rod is noted.

The meeting compared the kinking characteristics with hoses from other rebreathers. The samples of the design put forward to the meeting were the only ones that did not kink with a 180 change in direction. The meeting agreed that kinking was a safety hazard, as it greatly increases the work of breathing.

The findings in the FMECA Vol 4 regarding the EN14143:2003 10% and 30% extension limits creating a safety hazard, were accepted.
Follow Up Action Taken: KS undertook to raise this with the international EN14143 committee, of which he is a member, to seek to have the standard changed. AD undertook to provide the supporting data. EN 14143 committee issued a Minute clarifying the requirement and that the hose was acceptable, and clarified that the reason for the requirement for maximum hose stretch in the standard was to prevent hoses stretching out of reach: the committee had not hitherto considered apparatus with very short hoses such as the O.R. rebreathers. The O.R. hoses cannot stretch out of reach of the diver so the safety requirement is met.

Fig 1:: Hose with jubilee clip, after tensioning the clip until the grub screw failed, then tensioning the hose until the hose failed. Hose failure point is at the same point observed in the tests reported in the FMECA Vol 4

Fig 2:: Hose under tension showing cracks caused by forming tool during manufacture, from which failures extend around the hose.

The counterlung material is PU, with no plasticiser, Bayer Chemical #PU 65D. The MSDS was examined.
The counterlung reinforcing rings are Polyurethane Vibrathane 5008. The MSDS was examined.
The hard plastic parts where fabricated in Akema Kynar 700, ASA, Polypropylene and polycarbonate before choosing ASA. All four materials are tough, UV resistant and chemically inert in:

- Acids (including hot)
- Halogens (Chlorine, bromine, iodine, fluorine)
- Chlorinated & brominated chemicals
- Oxidants (peroxides, ozone,)
- Alcohols and aliphatic hydrocarbons
- Mid bases (pH under 12)
- Crude oil

Following extensive evaluation, ASA was chosen for its dimensional stability. PC and many acetyls, including POM and Delrin, pose a risk of toxic offgasing so were rejected on that basis. Kynar and PP proved to be dimensionally unstable during moulding processes. Nylons were not sufficient hard wearing on edges and seal areas, in the presence of sand and marine detritus.

The HAZOP keywords combinations:

Primarily keywords:	Secondary keywords:
Tear; Flow; Pressure; Temperature; Contamination; Offgas; Puncture; Absence (of component); Misassemble.	No; Under; Over; Reverse; Other; Flooding.

During the HAZOP study sessions all the combinations of primarily and secondary keywords were considered. Action worksheets have been filled out (attached).

Observations and Recommendations:

1. The initial HAZOP resulted in an improved custom EPDM material being developed for the hoses to reduce the effect of tearing, punctures or cuts, and avoid Thiram.
2. Maintenance procedure for hoses includes a check for puncture or cut before use. This is presently in the pre-dive positive and negative pressure checks, which are satisfactory.
3. The hose demonstrated to the meeting met the non-kinking requirement.
4. The monitoring system should detect cuts or punctures using the pre-dive check sequence, with positive and negative pressure checks.
5. The present design uses spiral hoses to limit possible water traps and contamination. Use of spiral hose was accepted by the meeting as mitigating these hazards.
6. The hoses have 400% stretch, enabling the RB to use as short hoses as possible and avoid hoses crossing the diver's field of vision.
7. If hose covers are used, the covers for the hoses should be oversized to allow the stretched hose to be protected. The meeting noted that the present design does this.
8. Close attention was paid to the mushroom design, including molding and choosing of right supplier. There is extensive information on the mushroom designs in FMECA V4.
9. The meeting reviewed the recommended cleaning solutions for hoses to avoid any contamination and accepted these from the documentation provided.
10. The training manual includes a strict cleaning procedure for hoses and internal surfaces within the rebreather using Virkon, which is compatible with the rebreather materials.
11. The colour coded silicone covers for joints and caps was considered a good design feature.
12. The HAZOP meeting considered that the training manual should contain a section setting down the operational procedure when lowering the rebreather to the seabed in a basket, or raising it, to avoid under or over-pressure: this was subsequently revised by tests showing the rebreather can withstand without leaks 2 bar under pressure and 600mbar over pressure – the OPV Exhaust

Valve releases at 35mbar overpressure, and there is a helmet underpressure valve set to 60mbar. These cracking pressures are sufficient to protect the rebreather should it be pressurised or depressurised in a basket or interlock with the gas switched off or exhausted.

13. A Design Verification report confirmed the working pressure of the under pressure valve and that this operates in both gas and water environments.
14. Operational procedures include a check for all three OVP/UPV/ADV before the dive.
15. Operational procedures include a requirement for acclimatization of RB before use if stored in a very hot or cold location: the electronics does this temperature check automatically as an additional monitor.
16. Action implemented to remove materials that use Thiram, a softener used in the EPDM hose, which can off-gas.
17. Operational procedures include a requirement of limited access to the diving equipment, with warnings that it should not be tampered with or used by untrained persons.
18. The Operational procedures underline a strong necessity of proper training for all personal working with the RB.
19. The units presented to the meeting used different colours for inhale and exhale parts of the loop, for hose covers, mushroom spiders and mushroom valves. This was considered a good feature.
20. The design of the rebreather was considered and the meeting heard from the design team members that each part was unique and that careful attention had been given to each part to prevent being misassembled, for example, mushrooms the wrong way around. The parts examined by the meeting supported that assertion, including those parts that may be disconnected without tools.
21. During the review of these minutes, a member of the client group raised a question of whether it might be possible for the 400% stretch hoses to extend fully on over pressure thus adding to the overall loop volume - whether this was a significant factor?
    This situation was considered carefully by the Deep Life team and the conclusion is as follows:
    a. Increases in loop volume were considered, as they allow the PPO2 to fall due to a fall in internal pressure. The hoses stretch 150mm on each side, with 36mm bore. This is a total of 0.3litres. The dead volume of the rebreather is 6 litres, so if the counterlungs are empty and the diver's lungs are empty, then the reduction in PPO2 is 5%. This means if the PPO2 is borderline at 0.209, then it can fall to 0.199. This does not represent any health hazard.
    b. The amount of hose stretch is constant between the different hoses. That is, the diver needs to move his head by 150mm, so there is 150mm of hose that needs to be expanded. When the hose is long with a 30% stretch with a 10N (1kg) load, then it provides 150mm of extra volume. When the hose is short, with a 400% stretch to provide 150mm of extra volume, the increase in loop volume is the same. Therefore there is no safety hazard from increasing the stretch in the hoses.

Enclosure: HAZOP Action worksheets – 4 pages.

HAZOP Study leader: V. Komarov