UK DIVING INDUSTRY COMMITTEE

RISK BASED ASSESSMENT OF

CYLINDER INTERNAL EXAMINATION

PERIODICITY

The UK Diving Industry Committee is a stakeholder group set up to inform the industry of technical, safety and regulatory developments in UK diving.

This document is a risk assessment prepared for the Diving Industry Committee by the British Sub-Aqua Club as a National Governing Body, and agreed by consensus, to provide clear direction as to acceptable intervals for the internal examination of cylinders.

The risk assessment is managed and reviewed annually by the Diving Industry Committee.

The content of this document is in-line with UK Regulations and advice from the Health and Safety Executive.

Stakeholders involved in the consensus are:

Version control

Version	Date	Comments
V1	4 Sep 17	Original issue
V2	19 Sep 18	Logo changes, additional of aluminium alloy information and revision of Police Annex.
V3	16 Nov 18	Updated to include BS EN ISO 18119 date following publication on 31 October 2018

Record of review (to be at least annually)

Version	Review date	Comments
V1	6 Sep 17	Original reviewed and accepted at DIC
V2	19 Sep 18	Reviewed and accepted at DIC

1 Introduction

The requirements for the periodic examination and testing of seamless steel and seamless aluminium-alloy gas cylinders are specified in:

BS EN ISO 18119:2018 Gas cylinders – Seamless steel and seamless aluminium-alloy gas cylinders and tubes – Periodic inspection and testing

Within the standard there is an informative annex (*i.e.* guidance rather than a mandate) that recommends the periodicity of inspection and test. For compressed gas cylinders used for and containing:

- Self-contained breathing air, O_2, etc.
- Gases for underwater breathing apparatus

The standard recommends:

'*Local regulations will specify the interval of periodic inspection and test. In the absence of any local regulation as a guide, an internal examination every year with a periodic inspection test as 5 yearly intervals should be carried out. However, if on completion of a risk assessment and the specific use of a cylinder indicates that there is a low risk of internal degradation then the interval for carrying out an internal examination can be increased to a maximum of 2.5 years.'*

This document presents a generic risk assessment, conducted by the whole of the UK diving industry, to provide clear direction as to acceptable intervals for the internal examination of cylinders.

The different sectors of the UK diving industry have their own specific risks and requirements. These are covered in sector specific annexes.

2 Hazard identification

Two hazards have been identified in respect of the periodicity of cylinder internal examination:

- Internal degradation of cylinder walls (*e.g.* due to corrosion or cracking).

  If the intervals between internal examinations are too far apart, and significant degradation is not detected, there is a risk that cylinders may fail catastrophically.

- Damage to cylinder threads and valve and/or incorrect valve fitted to cylinder during the internal examination process.
  If threads are damaged or if mismatched valves are fitted to cylinders there is a risk that valves may be catastrophically ejected from cylinders. If the intervals between internal examinations are short, cylinders will be inspected more often during their service lives, and the likelihood of thread damage or the fitting of mismatched cylinder valves during the inspection process will be increased.

This assessment has only covered the first hazard which is mitigated by the examination process.

As noted above, an increase in the frequency of internal examinations is likely to increase the number of cylinder valve ejection events. The diving industry must balance this risk against the risk of failing to detect significant internal degradation of cylinder walls when setting periodicities for the internal examination of diving cylinders.

3 Initial assumptions

The following has been assumed in the development of this risk assessment:

- The superseded BS EN 1968:2002 and BS EN 1802:2002 standards which specified a period of 2.5 years between internal inspections have been applied in the last decade.
- The IMCA (International Marine Contractors Association) guidance for the periods for internal examination of offshore diving industry cylinders, stated in their document D018 'Code of practice for the initial and periodic examination, testing and certification of diving plant and equipment' has been applied.
- The internal examinations that have been conducted have fulfilled their purpose and removed damaged cylinders from circulation. Cylinders post inspection are considered as fit for purpose. Thus failure at inspection is not factored into this assessment of risk between examinations.
- Any incidents or failures that have occurred with cylinders that were outside of the current designated inspection period have been discounted. These cylinders should have been identified and removed from circulation at the appropriate inspection interval.
- The numbers of cylinders being used is based on best estimate numbers. These could be revised with better data.

4 Number of cylinders affected

Diving cylinders are used by commercial diving organisations, dive shops, schools and centres, clubs, scientific institutes, emergency services and the MoD. The number of cylinders in this group is estimated at 40,000.

From recreational membership data and knowledge of diving organisations' activities it is estimated that there may be 30,000 cylinder owning divers in the UK. As an average these divers are likely to own at least two cylinders – assuming multiple cylinders for day/weekend dives, bail-out and side mounts and multiple re-breather cylinders.

Thus the risk of the hazards occurring is associated with nominally 100,000 cylinders.

5 Known incidents

IMCA Safety Flashes record commercial diving incidents. Although several cylinder valve ejections have occurred in the last decade no catastrophic bursting failures have occurred.

The BSAC incident database has one recorded incident in the last decade:

- 2016: Gas leaking from cylinder wall. Subsequent examination identified internal corrosion and approx. 250 ml of seawater in cylinder.

The HSE have reported to the UK diving industry five additional incidents with excessive cylinder internal corrosion since June 2006 (*i.e.* in last decade). These were with four 3 litre cylinders and a 7 litre cylinder (*i.e.* cylinders used for bail-out or not continuously breathed underwater).

Only one of these has been reported as a catastrophic failure: (http://www.hse.gov.uk/diving/cylinder-care.htm).

These data are supported by a freedom of information request on the HSE which identified a total of ten cylinder incidents during the period 2006 to 2011. Of these five cylinders were outside of the required inspection period. Of the remaining five incidents only one was a catastrophic bursting failure:
https://www.whatdotheyknow.com/request/analysis_behind_changes_to_scuba

The HSE have also reported in 2017 serious harm caused by catastrophic failure of an aluminium alloy cylinder involved in diving operation; this cylinder was not used underwater:
http://www.hse.gov.uk/safetybulletins/aluminium-cylinders.htm

It is interesting to note that no bursting failures with cylinders used underwater have been recorded in the last six years.

Thus, other than periodic examination results, for cylinders within the recommended 2.5 year interval, only one catastrophic failure in six serious events.

6 Current incident rates

Thus considering the last decade the incident rate would be per annum:

6×10^{-6} (*i.e.* 6 ÷ 10 ÷ 100,000)

The catastrophic failure rate would be per annum:

1×10^{-6} (*i.e.* 1 ÷ 10 ÷ 100,000)

Considering a worst outcome of any accident being a fatality, this is likely to change the risk by another order of magnitude less than the incident rate (*i.e.* 1×10^{-7} rather than 1×10^{-6}).

7 Broadly acceptable risk

Within the UK the currently acceptable risk rates for fatal incidents are as per the HSE document Reducing Risks Protecting People (R2P2):
http://www.hse.gov.uk/risk/theory/r2p2.htm

Within R2P2 the broadly acceptable risk for fatalities in the UK is defined as 1 x 10^{-6}, Figure 1.

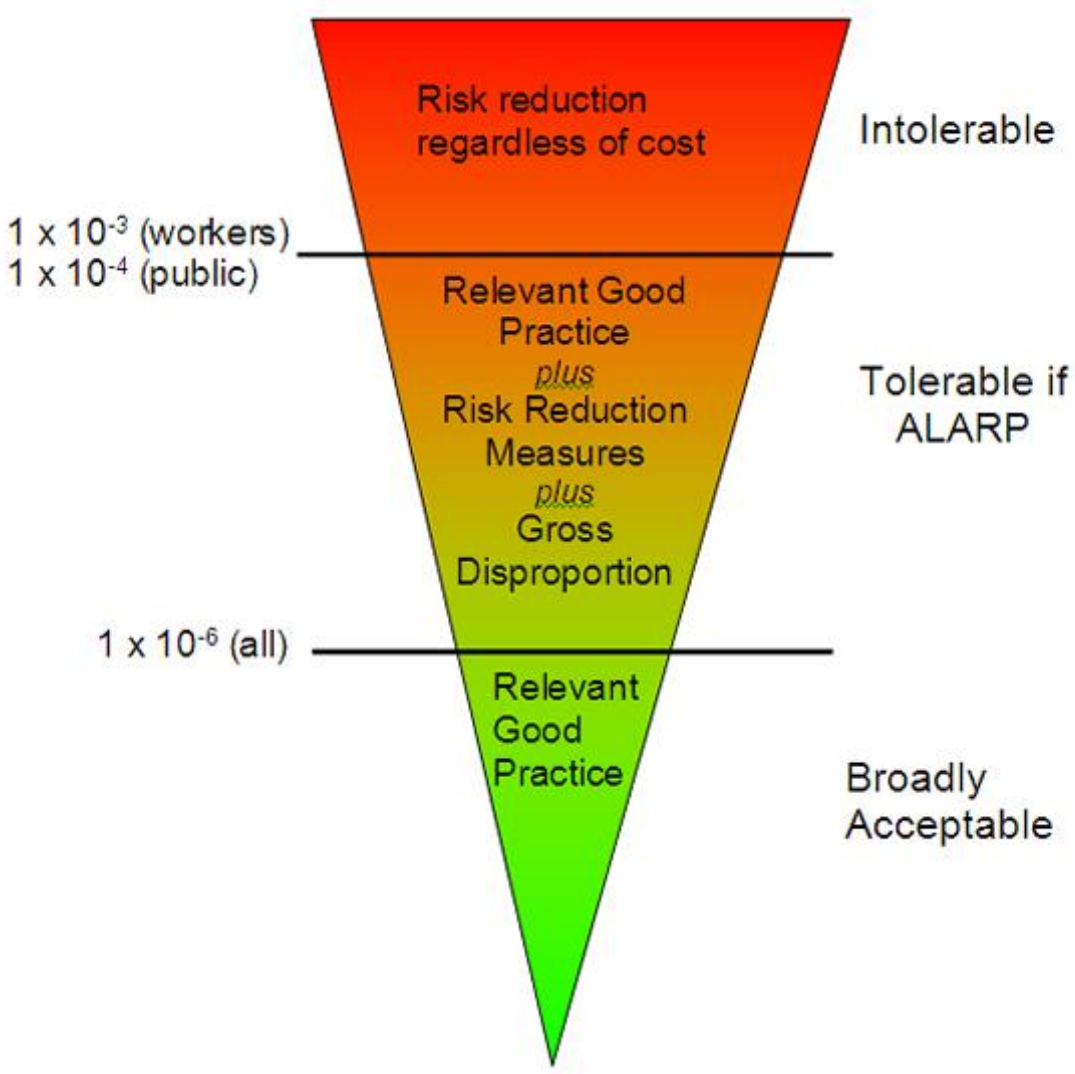

Figure 1: HSE R2P2 broadly acceptable fatal incident rates

8 Risk matrix

Based on the broadly acceptable fatal incidents rates the following risk assessment matrix has been identified (Tables 1, 2 and 3):

Likelihood category	Qualitative Definition
Frequent	Likely to occur repeatedly during one year
Probable	Likely to occur from time to time during one year
Occasional	Likely to occur once or more during one year
Remote	Unlikely, but may exceptionally occur during one year
Improbable	Very unlikely to occur during one year
Incredible	Extremely unlikely that the event will occur at all during one year

Table 1: Qualitative likelihood categories (L)

Severity category	Definition
Catastrophic	Multiple deaths
Critical	Up to a single death; and/or multiple severe injuries or severe occupational illnesses
Major	A single severe injury or occupational illness (requiring more than 3 days off work); and/or multiple minor/marginal injuries or minor/marginal occupational illnesses
Marginal	A single injury (requiring more than 3 days off work).
Negligible	At most a single minor injury or minor occupational illness not requiring time off work.

Table 2: Severity categories (S)

Severity	Likelihood (per year)					
	Frequent[a]	Probable	Occasional	Remote	Improbable	Incredible
	$< 10^{-1}$ [b]	$< 10^{-2}$ and $\geq 10^{-3}$	$< 10^{-3}$ and $\geq 10^{-4}$	$< 10^{-4}$ and $\geq 10^{-5}$	$< 10^{-5}$ and $\geq 10^{-6}$	$< 10^{-6}$
Catastrophic	Unacceptable risk	Unacceptable risk	Unacceptable risk	Unacceptable risk	Tolerable	Acceptable risk
Critical	Unacceptable risk	Unacceptable risk	Unacceptable risk	Tolerable	Tolerable	Acceptable risk
Major	Unacceptable risk	Unacceptable risk	Tolerable	Tolerable	Acceptable risk	Acceptable risk
Marginal	Unacceptable risk	Tolerable	Tolerable	Acceptable risk	Acceptable risk	Acceptable risk
Negligible	Tolerable	Tolerable	Acceptable risk	Acceptable risk	Acceptable risk	Acceptable risk

[a] Quantitative likelihood category

[b] Likelihood of dangerous failure per year

Table 3: Risk criteria (R)

9 Risk mitigation

Risks may be mitigated by both regulation and education.

Periodic examinations and testing are conducted at risk based intervals. Other than specific industry sector requirements (See annexes) the previously specified interval of 2.5 years between internal examinations is applied.

Periodic and internal examinations are conducted by competent persons, within organisations whose procedures are subject to third party independent audit, to at least the requirements of BS EN ISO 18119.2018.

At each periodic and internal examination, cylinders manufactured from aluminium alloys AA6082 (also known as HE30) and AA6351 are to be tested with an eddy-current device approved by the manufacturer of the cylinder. If the aluminium alloy cylinder is equipped with a thread adaptor, the adaptor must be removed prior to examination and eddy-current testing.

The filling of cylinders is to be conducted in accordance with BS EN ISO 24431:2016, Gas cylinders - Seamless, welded and composite cylinders for compressed and liquefied gases (excluding acetylene) - Inspection at time of filling (note: this is a new standard, *i.e.* 2016 which should reduce the risk associated with cylinder filling). Particularly:

- Section 5.2.3 Interior condition, which requires 'Before filling, the presence of liquid that could have caused internal corrosion shall be established.'
- Annex A which requires cylinders presented for filling without a residual pressure to be internally examined.

HSE industry 'guidance' on the risks associated with the filling and use of diving cylinders is applied:

- HSE Diving information sheets: http://www.hse.gov.uk/pubns/diveindx.htm#diving-info-sheets
- HSE diving cylinder specific safety information: Diving cylinders – the danger of internal corrosion http://www.hse.gov.uk/diving/cylinder-care.htm
- HSE Health and Safety bulletin ED 1-2018: Cylinders manufactured from aluminium alloys HE30/AA6082 and AA6351 and used primarily for gases for underwater breathing apparatus http://www.hse.gov.uk/safetybulletins/aluminium-cylinders.htm

The International Marine Contactors Association (IMCA) recommends in its publication IMCA D018 *Code of practice for the initial and periodic examination, testing and certification of diving plant and equipment* that commercial diving bail-out cylinders, *i.e.* those not continuously breathed underwater and at risk from salt water ingress, are internally inspected every 6 months (*i.e.* within any periodicity recommended in current or proposed testing standards).

Cylinders are only to be filled with gases that comply with EN 12021.

All sectors of the UK diving industry should recommend and repeatedly emphasise the following as good practice:

- Any cylinder known to have been repeatedly filled with gas having a higher moisture content than permitted by EN 12021 should be internally examined.
- Cylinders should not be emptied underwater such that there is no residual internal pressure above ambient.
- Any cylinder that has lost all gas pressure above ambient when under water, whereby water may have entered the cylinder, should be internally examined.
- Do not charge cylinders that have been emptied underwater (*e.g.* marker buoy, suit inflation or buoyancy compensator cylinders) by 'decanting' from another diving cylinder.
- All charging hoses should be 'blown through' before use.
- Cylinder valves should be 'blown through' before use or charging.
- Cylinders should be kept or stored with a residual pressure of at least 2 bar.
- Any empty cylinder should be left with the valve closed.
- Cylinder valves should be dried and capped to prevent moisture ingress when a regulator is not connected.

Informative Notes:

Cylinders that contain gases with a higher oxygen content than air *(i.e.* > 21 %) could be at an increased risk if internal corrosion was to occur. This due to the higher oxygen content allowing a more rapid rate of oxidisation (*i.e.* corrosion).

Cylinders that may during normal use lose all gas pressure above ambient when under water, such as side-mount, bail-out, marker buoy, buoyancy compensator and suit inflation cylinders are at a greater risk of water ingress and internal corrosion.

Thus, diligent application of the risk mitigation must specifically be applied to these cylinders.

Fitting a cylinder with a Residual Pressure Valve (RPV) is a standard compressed gas industry method of preventing contamination and water ingress. RPV have been considered for Respiratory Protective Equipment (RPE), including diving apparatus, as mitigation against the risk of cylinder internal corrosion. However, as they are a potential single point failure which could prevent the supply of breathing gas, and may also be a restriction to the flow of the breathing gas they are not considered appropriate for use with, or as a risk mitigation for, diving cylinders.

10 Risk assessment

The following generic risk assessment, using the information presented above, is applicable to the whole UK industry using existing intervals between internal examinations.

Serial	Hazard	Outcome	Mitigation	Risk		
				L	S	R
1	Internal degradation of cylinder walls (e.g. due to corrosion)	Catastrophic failure of cylinder resulting in personal injury	As per Section 9 and sector specific annexes	Improbable	Major	Acceptable risk
2	Internal degradation of cylinder walls (e.g. due to corrosion)	Catastrophic failure of cylinder resulting in Single fatality	As per Section 9 and sector specific annexes	Incredible	Critical	Acceptable risk
3	Internal degradation of cylinder walls (e.g. due to corrosion)	Catastrophic failure of cylinder resulting in Multiple fatalities	As per Section 9 and sector specific annexes	Incredible	Catastrophic	Acceptable risk

11 Conclusion

The risks associated with the current intervals used for cylinder testing and internal examination are broadly acceptable.

Without further mitigation or action, the current intervals used for cylinder testing and internal examination are acceptable.

Annex - Commercial offshore

Sponsor: International Marine Contractors Association (IMCA)

The commercial offshore diving industry have been using the following intervals for inspection and testing of diving cylinders (IMCA guidance D018):

- Periodic inspection and test every 4 years
- Internal examination every 2 years

Cylinders used for bail-out and suit/buoyancy control device (BCD) inflation that are at an increased risk of water ingress, are internally examined every 6 months.

Cylinders either individually or supplied in bundles and used only on the surface to provide gas to a diver via an umbilical have been inspected and tested every 10 years.

These inspection periods have not resulted in a catastrophic failure in the past decade and are part of the broadly acceptable risk presented in the generic risk assessment.

Annex - Commercial inshore

Sponsor: Association of Diving Contractors (ADC)

The commercial inshore diving industry have been using the following intervals for inspection and testing of diving cylinders:

- Periodic inspection and test every 5 years
- Internal examination every 2.5 years

Cylinders used for bail-out and suit/buoyancy control device (BCD) inflation that are at an increased risk of water ingress, are internally examined every 6 months.

Cylinders either individually or supplied in bundles and used only on the surface to provide gas to a diver via an umbilical have been inspected and tested every 10 years.

These inspection periods have not resulted in a catastrophic failure in the past decade and are part of the broadly acceptable risk presented in the generic risk assessment.

Annex - Media

Sponsor: BBC

The Media diving industry have been using the following intervals for inspection and testing of diving cylinders:

- Periodic inspection and test every 5 years
- Internal examination every 2.5 years

These periods are within the broadly acceptable risk presented in the generic risk assessment.

Annex - Scientific, archaeological and aquarium

Sponsor: Scientific Diving Supervisory Committee (SDSC)

The scientific, archaeological and aquarium diving industry have been using the following intervals for inspection and testing of diving cylinders:

- Periodic inspection and test every 5 years
- Internal examination every 2.5 years

Cylinders used for specific operations that are at an increased risk of water ingress are internally examined every 6 months.

Cylinders either individually or supplied in bundles and used only on the surface to provide gas to a diver via an umbilical have been inspected and tested every 10 years.

These inspection periods have not resulted in a catastrophic failure in the past decade and are part of the broadly acceptable risk presented in the generic risk assessment.

Annex - Defence

Sponsor: Ministry of Defence (MoD)

The Ministry of Defence and the emergency services have been using the following intervals for inspection and testing of diving cylinders:

- Periodic inspection and test every 5 years
- Internal examination every 2.5 years

Cylinders used for specific operations that are at an increased risk of water ingress are internally examined every 6 months.

Cylinders either individually or supplied in bundles and used only on the surface to provide gas to a diver via an umbilical have been inspected and tested every 10 years.

These inspection periods have not resulted in a catastrophic failure in the past decade and are part of the broadly acceptable risk presented in the generic risk assessment.

Annex - Police

Sponsor: Association of Chief Police Officers (ACPO)

The Police have been using the following intervals for inspection and testing of diving cylinders:

- Periodic inspection and test every 5 years
- Internal examination every 2.5 years

Cylinders either individually or supplied in bundles and used only on the surface to provide gas to a diver via an umbilical have been inspected and tested every 10 years.

These periods are within the broadly acceptable risk presented in the generic risk assessment.

Annex – Recreational

Sponsor: British Sub Aqua Club (BSAC) and Scottish Sub-Aqua Club (SSAC) as National Governing Bodies for the sport

The recreational diving industry have been using the following intervals for inspection and testing of diving cylinders:

- Periodic inspection and test every 5 years
- Internal examination every 2.5 years

These periods are within the broadly acceptable risk presented in the generic risk assessment.