Air Quality in Compressed Air Supply Systems

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INTRODUCTION

In most hyperbaric facilities, compressed air is used as a breathing gas (for air breaks or in case the chamber environment is contaminated). Air may also be used to compress the hyperbaric chamber (in multiplace or monoplace chamber facilities). Whenever compressed air is used, the hyperbaric facility must ensure the quality/purity of the air is appropriate for its intended use. This typically involves periodic sampling and/or continuous monitoring. Internationally, hyperbaric facilities have very diverse air quality standards. In most cases, these standards were developed for other applications or industries – not specifically for clinical hyperbaric medicine. Consequently, the air quality standard applied to your hyperbaric facility may not be perfectly suited to your operational requirements. It is important to understand air quality standards and what effect certain contaminants will have in the hyperbaric environment.

OBJECTIVES

On completion of this activity, the reader should be able to:

- Understand how air quality standards are derived
- Identify the inherent risks with contaminants
- Identify additional contaminants that should be considered in hyperbaric facilities

BACKGROUND

Over the past 50 or more years, a range of gas analyzers and analysis techniques have been developed. These have been systematically tempered through scientific advances, practical assessments and regulatory efforts. Recent decades have brought improvements in compression and filtration techniques as well as advances and improved availability of analytical instruments. Access to global information has improved; and we now have an extended history of gas related incidents and accidents that have been examined and assessed. Medical investigative work has been performed to determine the human impact of common contaminants in breathing air; and this has provided rationale behind carbon dioxide (CO_2) and carbon monoxide (CO) maximum levels in stored breathing gases. Other notable toxic or debilitating substances have found their way into breathing systems, including sulphur dioxide (SO_2), nitrous oxide (N_2O), nitrogen dioxide (NO_2), nitrous fumes (NO_x), methane (CH_4), and non-volatile hydrocarbons. Although a rare occurrence,

compounds such as xylene, toluene and various halogenated solvents (sometimes used to clean piping systems) have been found. Limits on these substances (based primarily on health effects) are published in occupational health regulations and specifications.

In order to discuss how this knowledge and experience applies to hyperbaric facilities, it is important to understand the history of hyperbaric air quality standards. The technical realm of hyperbaric medicine has traditionally been driven by two main influences: (1) commercial and military diving practices; and (2) clinical and hospital engineering standards. Most hyperbaric air quality standards are based on occupational health or diving related applications; whereas clinical hyperbaric facilities deal with medical devices. The majority of our new standards and guidance documents have attempted to introduce technical specifications based on actual hyperbaric practice requirements, but there are some areas where the older, traditional methodologies have been incorporated without much change. Examples of contaminants that may not be properly addressed by current standards include oil and water (in either vapour or condensed liquid form). These contaminants, together with other biological hazards, require some discussion in order to consider suitable limits in hyperbaric facilities. We need to understand the effects of the various contaminants on our clinical hyperbaric environment in order to determine realistic air quality requirements.

PRACTICAL CONSIDERATIONS

When establishing hyperbaric air specifications for contaminants, consideration of available analytical techniques is necessary to ensure that analysis can be done in practice. We must use a technique that provides accuracy and resolution appropriate to our application; but consider that analyses requiring elaborate, expensive, or remote testing methods are not practical.

The EIGA document (see reference 1) provides guidance as to how analyses need to be done. Assuming the commonly-used, commercially available testing methods, Table 1 below demonstrates the basic instruments, their relative accuracy levels, and the lowest level of contaminant that they are able to detect. The most commonly used method (i.e. the detector tube) has lower accuracy, while higher accuracy is achieved using electronic (sensor-based) or laboratory-based instruments. Some examples of these higher accuracy techniques are shown, but the list is not comprehensive.

Table 1: Practical methods for air analysis

		Manual Detection	Electronic Detection
CO_2	Type of Detector	Detector tube	Infrared sensor
	Accuracy	± 15%	±2%
	Lowest Detection Limit	100 ppm$_v$	50 ppm$_v$
CO	Type of Detector	Detector tube	Electro-chemical sensor
	Accuracy	±15%	±5%
	Lowest Detection Limit	5 ppm$_v$	0 ppm$_v$
H_2O	Type of Detector	Detector tube	Dew-point meter
	Accuracy	±20%	±0.2°
	Lowest Detection Limit	5 mg/m^3	±10 ppm$_v$[c]
Oil	Type of Detector	Detector tube	Gravimetric analysis
	Accuracy	N/A[a]	±0.2%[b]
	Lowest Detection Limit	0.1 mg/m^3	0.01mg/m^3

Notes to Table 1:

a   Oil-detection by detector tube or equivalent provides a simple pass or fail outcome only.
b   On-line oil detection requires highly sophisticated equipment, impractical to use in a production plant. Gravimetric analysis in a testing laboratory provides greater accuracy for oil contaminant detection, but is not an on-line or real-time method.
c   The limits of detection expressed in ppm$_v$ for a dew point meter reduce with temperature. The value shown is a rough indication that applies at the typical dew point temperatures that are required.

There are a range of other toxic and debilitating compounds that have been detected in breathing air. However, it is impractical to demand analysis of all these compounds except where a risk assessment clearly shows there to be a likely hazard in a specific location or situation. Theoretical concerns about microbiological contaminants (e.g. pollen, mould, fungus, bacteria, virus) or "organic compound" contamination (e.g. paint, solvent, cleansers, disinfectants, aerosol sprays, pesticide, xylene, formaldehyde) have been raised by some practitioners. In general, breathing gas supplied to a hyperbaric environment is not likely to be exposed to microbiological contamination. In addition, compressed gases have pO$_2$ values that are toxic to most known pathogens. Microbiological contamination is thus unlikely in "unused" air (i.e. air that has not yet gone into the chamber or breathing

gas system). Organic compounds should be assessed by risk analysis and if a hazardous situation is likely to exist, there are analytical instruments commercially available to provide monitoring for these compounds.

ISSUES WITH HYPERBARIC AIR

Hyperbaric air quality has traditionally been addressed as two separate issues: (1) air used to pressurise the hyperbaric environment, which has been heavily influenced by the diving industry and the limiting practicalities of dedicated air compression plants; and (2) air provided to chamber occupants, primarily for therapeutic purposes (i.e. "air breaks").

Because there will be at least one human being inside any hyperbaric chamber, there is a cross-over between quality of air before and after entering the chamber. The focus here is on unused air to be introduced into the chamber either for pressurisation and ventilation, or as a therapeutic (or emergency) breathing gas.

The situation is complicated when breathing air needs to be provided through the built-in breathing systems of a multiplace chamber. It may be needed for air breaks, in the event of a fire, or contaminated chamber atmosphere. In these cases, the breathing system will be used for both oxygen and air. This introduces a fire hazard in the oxygen piping if the air quality does not meet oxygen compatible standards. Applying the same concerns to monoplace chambers, the chamber may be pressurized using either oxygen or air.

Our approach needs to accommodate all of these variations: (1) air for the compression of a multiplace chamber may contain a higher amount of oil vapour; (2) air used in an emergency situation in the multiplace chamber needs to be free from oil; and (3) air for use in the monoplace chamber, whether for pressurization or for air breaks only, will always be regarded as a medical drug; it thus needs to meet the requirements for medical air.

QUALITY OF AIR

The three primary reasons for considering the assessment of air quality in clinical hyperbaric facilities (listed in a normally accepted order of concern) include: (1) the risk to human health; (2) the risk of fire; and (3) the risk of equipment failure.

Contaminants can be divided into three levels that represent the likelihood of occurrence, namely: (1) those most commonly found in compressed air (CO2, CO, H2O, condensed oil, particles and odour); (2) those found in certain operational areas (volatile hydrocarbons and organic compounds, such as CH4); and (3) relatively rare but reported toxic substances (e.g. vapours from cleaning products and halogenated solvents, emissions from motor vehicles, SO2, and NOx fumes).

The production process for compressed air can introduce oil (vaporised or condensed), particulates, and some amounts of CO2 and CO. All the other contaminants, including larger amounts of CO2 and CO, must be present in the ambient environment (where the compressor intakes are located) in order to be present in the final product. As a general rule, occupational health practices require that we analyse environmental conditions in the vicinity where there are potential hazards. However, it remains an accepted fact that

we do not monitor or analyse the air that we breathe unless we have reason to be concerned.

Compressors used to produce air for chamber compression or for breathing air will require a thorough risk analysis prior to selection and purchase. Installation of the compressors, the compressed air lines, and all interface connections will require compliance with the applicable codes and standards governing the installation of gas systems. Site selection of the compressor air intake should also receive a careful risk analysis with consideration given to weather conditions, potential local toxic fumes, and exhaust from buildings or internal combustion engines. Lubricating oils for "oil-free" or "oil-lubricated" breathing air compressors are selected on the basis of their high temperature stability, inertness, and acceptability to human exposure. This mitigates some of the health concerns.

These considerations are mentioned to provide a degree of pragmatism in any debate on the quality of air produced for hyperbaric facilities. In the ideal world, where all the correct selection criteria are applied, and where a thorough risk analysis is made of the operating area, these requirements for analysis and quality control could be reduced by design. Additionally, planned sampling could be limited to where changes or maintenance activities are known to have taken place. However, the reality is that exposures to contaminants in compressed air have occurred due to a loss of controls, external influences and incidents, and where equipment has been neglected.

Finally, while it is possible to provide a consensus and even a mandate on maximum exposure limits for all potential hazardous contaminants, the practicalities of on-line, real-time analysis, affordable measuring instruments, and the accuracy achievable in the field, have in the end a large determining influence on what can and should be required. A discussion on air quality to derive safe, realistic, achievable and sustainable standards therefore needs to be done in the context of the imperfect world and with a sensible dose of realism.

MAIN CONTAMINANTS AND DETECTION

Group 1: Contaminants always potentially present in compressed air

Compound:	**Carbon dioxide (CO_2)**
Sources:	Ambient environment; internal combustion and cooking processes; human and animal respiration; microbial breakdown of organic matter; conversion of CO to CO_2 in compressor filters; or motor vehicle exhaust systems.
Human safety:	Elevated levels cause increased rate of breathing; increase in chamber depth increases respiratory risk; patients with high PaO_2 are at greater risk of oxygen-induced seizures with elevated $PaCO_2$; elevated levels lead to (in order of increasing severity) minor perceptive changes, discomfort, dizziness, stupor, unconsciousness, and even death.
Fire safety:	No concerns
Equipment:	No concerns
Detection:	1. Field detection through detector tube or on-line infra-red sensor.
	2. Laboratory measurement using GC-M-FID[a].
Compound:	**Carbon monoxide (CO)**
Sources:	Ambient environment; internal combustion processes; furnaces; gas burners; cigarette or cigar smoke; or overheated compressor oils.
Human safety:	Decreases the carrying capacity of haemoglobin resulting in a decreased amount of oxygen available to the tissues leading to hypoxia. A highly toxic contaminant with environmental levels magnified by increased chamber pressure.
Fire safety:	No concerns
Equipment:	No concerns
Detection:	1. Field detection through detector tube or on-line electrochemical sensor cell.
	2. Laboratory detection using GC-M-FID[a].
Compound:	**Moisture (H_2O)**
Sources:	Ambient environment (humidity); drying process (laundry); some combustion and other processes.
Human safety:	Elevated levels of moisture are desirable (comfort & reduced dehydration), whereas dry air inhibits growth of bacteria.
Fire safety:	Very dry conditions enhance production of static electricity.
Equipment:	1. Excessive moisture may cause regulators to freeze as adiabatic cooling takes place during pressure reduction. Regulators may fail open, causing downstream over-pressurisation of piping and equipment.
	2. Excessive moisture enhances corrosion and oxidation (rust) of air storage vessels.
	3. Excessive moisture causes filtration elements & chemicals to saturate, resulting in reduced filtration efficiency and effectiveness, and elevated pressure drops. Excessive moisture can interact with some ultra-fine carbon filtration units generating strong chemical odours, resulting in nausea and respiratory irritation.
Detection:	1. Field detection through detector tube or dew point meter (electronic hygrometer).
	2. Laboratory detection using GC-MS[b].
Compound:	**Oil (condensed)**
Sources:	Compressor lubricating oil (introduced internally); ambient evaporated oil from compressor oil leaks & surrounding equipment; motor vehicle exhaust fumes; pollens (introduced through the compressor intake); or contaminated air pipes between the air processing plant and the chamber.

Human safety:	Larger condensed particles removed by body's clearance mechanisms; smaller particles are retained and may be hazardous depending on type and amount (symptoms include inflammation or even rupturing of alveoli) [3].
Fire safety:	Significant fire concerns, regardless of type of condensed oil.
Equipment:	No concerns at the levels usually controlled for. The maximum level of 5 mg/m^3 equates to a dew point temperature of -64°C, or 6 ppm$_v$; significantly lower than the lowest required levels for H_2O.
Detection:	1. Field detection through detector tube (Impactor[c]).
	2. Laboratory detection using gravimetric analysis or GC-MS[b].
Compound:	**Particles**
Sources:	Ambient environment (micro-particles of dust & pollens); breakdown products in compressors; piping systems & filtration media; or post-construction debris in pipes and controls.
Human safety:	Particles smaller than 10 microns (μm) have the potential to cause shortness of breath, especially in patients with respiratory conditions (e.g. asthma & bronchitis), and a reduction in the ability to resist infection.
Fire safety:	Large concentrations of particulates can serve as a source of ignitable fuel.
Equipment:	Larger particles are known causes of failure in pressure regulators, may cause valves not to seal when closed, and may erode valve seats, discs and seals.
Detection:	1. Field detection is not a practical option; however, filtration is highly effective where properly located and sized.
	2. Laboratory detection using gravimetric analysis. Particle size assessed using microscopy.
Compound:	**Odour**
Sources:	Ambient environment and cleaning compounds used on air supply systems.
Human safety:	Generally related to comfort levels only. Odours from volatile, toxic or otherwise harmful substances indicate potential safety issues related to these contaminants.
Fire safety:	No concerns from odour. Contaminants with fire risks (oils, VOC, etc.) are discussed under the relevant contaminant sections.
Equipment:	No concerns

Detection:	1. Field detection – subjectively through the human sense of smell.
	2. Laboratory detection for odours using an olfactometer. Identified odours measured using GC-MS[b].

Notes:

a. GC-M-FID: Gas Chromatography - Methaniser - Flame Ionization Detection
b. GC-MS: Gas Chromatography - Mass Spectrometry
c. Impactor is a Dräger Safety product enabling field detection of all oil types with reproducible results expressed in the ranges: <0.1 mg/m^3, 0.1 to 0.5 mg/m^3 and >1.0 mg/m^3.

Group 2: Contaminants present in specific areas

This group may be significantly larger than discussed here, but the following analysis indicates where potential hazards may exist for clinical hyperbaric facilities. Volatile hydrocarbons include organic compounds. However, methane is the most commonly occurring of these compounds and is separated from the analysis. Some standards require that all hydrocarbons be grouped as a total hydrocarbon (THC) limit. This grouping does not allow for easy identification of potential sources.

Contaminant:	**Volatile hydrocarbons and Volatile Organic Compounds (VOC)** – include but are not limited to toluene, xylene, benzene, ethane, styrene and acetone.
Sources:	Ambient environment as a result of exposure to building materials; plastic materials; industrial chemicals & cleaning compounds; adhesives; furniture; flooring; heating & combustion processes. Overheating compressors reported as a potential source.
Human safety:	Generally hazardous in terms of carcinogens, neurological & narcotic effects, organ damage & general distress. Initial symptoms include fatigue, headaches, confusion, numbness, cardiac irritation & depression.
Fire safety:	Significant fire concerns in terms of low ignition temperature and low flashpoint fuels.
Equipment:	No significant concerns at the expected levels.
Detection:	1. Field detection – odour usually detected through the human sense of smell.
	2. Identified compounds measured using detector tubes or GC-MS[a].
Compound:	**Methane (CH_4)**
Sources:	Ambient environment; especially prominent in certain geological areas as well as near decaying or fermenting organic matter, landfills, or domestic animals (cattle). CH_4 may permeate buildings and enter the compressor intake.
Human safety:	Not toxic (may be an asphyxiant where oxygen is reduced to below 16%)

Fire safety: Significant fire concerns with CH_4 being a highly flammable fuel.

Equipment: No concerns

Detection: 1. Field detection through detector tube or on-line using infra-red sensors.
                 2. Laboratory detection using GC-M-FID[b].

 Notes:

a. GC-MS: Gas Chromatography - Mass Spectrometry
b. GC-M-FID: Gas Chromatography - Methaniser - Flame Ionization Detection

Group 3: Rare but reported contaminants

This group is too diverse and extensive to discuss in a similar fashion to the previous two groups. Typical contaminants include vapours from cleaning products or solvents not covered under Group 2 above, as well as environmental compounds including hydrogen sulphide (H2S), SO2, NO, N2O NO2, NOx fumes, ozone, lead compounds, asbestos and many others. Each of these has specific deleterious effects on humans, but no significant fire or equipment issues – at least not in the concentrations expected in the air. Nitrogen oxide products, loosely referred to as NOx, are associated with decreases in lung function, increased severity of respiratory problems, chronic inflammation and irreversible structural changes, amongst other related respiratory conditions and complications.

Most occupational health and safety regulations for any public enterprise provide regulations, limits and guidelines for identification and exclusion of the type of contaminants mentioned above. In terms of this discussion, we will exclude several of these from the requirements for acceptable air quality and accept that they will be controlled by occupation hazard identification and risk assessment (HIRA) practices.

PRACTICAL LIMITS

The following limits have been extracted from the literature (see References and Relevant literature at the end) based on the effect on human physiology, fire risks and risks to equipment. Consistent units of measure have been used throughout the table as far as possible for easy of reading, but are not necessarily the units used by some measurement devices. All human exposure limits are expressed as the surface equivalent value (SEV) and for the purposes of a discussion in clinical hyperbaric facilities, a maximum pressure of 6 ATA is assumed. Limits tabulated are generally stated as the "no-effect level", that is the dose with no known toxic or debilitating effects. The exact conditions under which air quality analysis should be done are not discussed, but from a practical perspective, any analysis should be done such that the worst case can be detected. This will ensure that the actual air delivery conditions to the chamber, occupants or sensitive equipment are likely to be less severe.

Table 2: Contaminant safe limits

	Human exposure	Fire risk	Equipment risk	Detection limit[a]	Achievable limit[b]
CO_2	5000 ppm_v for $pO_2 \geq 3$ ATA 15000 ppm_v for $pO_2 \leq 1.6$ ATA	Nil	Nil	100 ppm_v	< 350 ppm_v Normal air contains ±300+ ppm_v
CO	60 ppm_v[c]	Nil	Nil	1 ppm_v	≤ 5 ppm_v
H_2O	RH[d]: ≤ 50% – 60% Based on control of bacterial growth	RH[d] > 30% Dew point > 3°C	HP: Lowest ambient less 44°C LP: Lowest ambient less 6°C	Dew point -64°C based on 5 mg/m^3	-48°C or ≤ 35 mg/m^3
Oil	≤ 5 mg/m^3	≤ 0.1 mg/m^3	None at ≤ 5 mg/m^3	0.1 mg/m^3	≤ 0.5[e] mg/m^3
Particles	≤ 50 mg/m^3 No particles ≤ 10 μm	≤ 5 mg/m^3	No limits determined	0.01 mg Size 0.5 μm	0.5 mg/m^3 for particles > 5 μm
Odor	None	None detected	Nil	None	None
VOC	≤ 5 ppm_v	LEL[f] ≤ 1 % Limit 1000 ppm_v	Nil	5 ppm_v	≤ 5 ppm_v
CH_4	≤ 5% (5×10^4 ppm_v)	LEL[f] ≤ 5 % Limit 5000 ppm_v	Nil	10 ppm_v	≤ 25 ppm_v
H_2S	≤ 50 ppm_v	Nil	>> Human limit	1 ppm_v	≤ 1 ppm_v
SO_2	≤ 5 ppm_v	Nil	Nil	1 ppm_v	≤ 1 ppm_v
NOx[g]	≤ 10 ppm_v	Nil	Nil	0.5 ppm_v	≤ 2 ppm_v

 Notes to Table 2:

a. Limit applicable to what can be detected in the field – using detector tubes or basic on-line analysers.
b. Limit that can be realistically achieved based on current filtration, catalytic and elimination methods.
c. A SEV value of 60 ppm_v at 6 ATA arises from a value of 10 ppm_v at 1 ATA.
d. RH: Relative humidity at normal temperature and pressure (20°C and 101.325 kPa).
e. Some equipment suppliers state the limit contained in EN 12021 ref. [1]. Using available and economically viable equipment, a limit of ≤ 0.1 mg/m^3 is realistically achievable.
f. LEL: Lower explosive limit – fire codes usually recommend a limit of ≤ 10% of LEL. 10% of 1% LEL = 0.1% or 1000 ppm_v.
g. NOx represents all nitrogen oxide compounds.

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PROPOSAL

Based on the limited but focused literature survey, a discussion of limits in terms of what can be achieved in practice, and applying a clinical hyperbaric-specific risk assessment, the following proposal is submitted:

Air quality requirements for clinical hyperbaric facilities.

Table 3: Proposed Contaminant Limits for Compressed Air

Group 1[a]: Contaminants always potentially present should be limited to:					
Element	Application	Proposed Limits	Existing Guidelines		
			CGA E[4]	CGA N[b]	RAG[5]
CO_2	Compressed air	1000 ppm$_v$	1000 ppm$_v$	500 ppm$_v$	500 ppm$_v$
	Hyperbaric chamber	0.5% SEV (5000 ppm$_v$ at 1 ATA) where SEV = level at 1 ATA divided by total pressure (ATA)			
CO	Compressed air	5 ppm$_v$	10 ppm$_v$	10 ppm$_v$	10 ppm$_v$
H_2O	Compressed air	(i) Produced < 15 bar: 402 mg/m^3 (500 ppm$_v$; -27°C) (ii) Stored at 40 - 200 bar: 50 mg/m^3 (62 ppm$_v$) (iii) Stored above 200 bar: 35 mg/m^3 (44 ppm$_v$) (iv) Supplied to cylinders: 25 mg/m^3 (31 ppm$_v$)	24 ppm$_v$[c]	None	500 ppm$_v$
	Hyperbaric chamber	RH: Ideally 50% – 60%	None	None	None
Oil	Pressurisation air[d] Breathing air	0.5 mg/m^3 0.1 mg/m^3	5 mg/m^3	None	0.5 mg/m^3 0.1 mg/m^3
Particles	Compressed air	0.5 mg/m^3 for particles > 5 µm	NS	NS	0.5 mg/m^{3e}
Odor	Compressed air	None	None	NS	None
Group 2[f]: Contaminants present in specific areas should be limited to:					
VOC	Compressed air Hyperbaric chamber	≤ 5 ppm$_v$ LEL ≤ 0.1% (1000 ppm$_v$)	[25 ppm$_v$][g]	NS	RA
CH_4	Compressed air Hyperbaric chamber	≤ 25 ppm$_v$ LEL ≤ 0.5% (5000 ppm$_v$)	[25 ppm$_v$][g]	NS NS	25 ppm$_v$ 25 ppm$_v$
Group 3[f]: Rare but reported contaminants should be limited to:					
H_2S	Compressed air	≤ 1 ppm$_v$	NS	5 ppm$_v$	RA
SO_2	Compressed air	≤ 1 ppm$_v$	NS	NS	RA
NOx[h]	Compressed air	≤ 2 ppm$_v$	NS	2.5 ppm$_v$	RA

Notes to Table 3:

NS   Not stated.
RA   Risk Assessment needed.
SEV   The equivalent level at the surface for an acceptable limit for CO_2 to be determined at treatment pressure. SEV = acceptable limit at 1 ATA divided by the treatment pressure in ATA.
a   These contaminants should be monitored regularly (every 3 months) by means of either on-site or laboratory analysis.

b   CGA Grade N has the same specification as USP air.

c   Dew point (atmospheric) to be ±6°C below lowest likely temperature or -54°C for exposure of air in cold regions (24 ppm_v).

d   It is deemed preferable that all air meet the higher limit of 0.1 mg/m^3.

e   The concentration of particles is to be less than 0.5 mg/m^3 for particles greater than 5 micron in size.

f   A RA survey should be used to determine the likelihood of any of these or other potentially toxic elements being present in the environment during the air compression process.

g   VOC and CH_4 are combined as one total limit.

h   NOx includes all nitrogen oxides.

CONCLUDING REMARKS

The information presented in this paper has been extracted from available literature and combined with personal experiences in this industry. Medical effects stated are as presented in the scientific media and have not been based on any current human-based research.

It is not considered practical to base contaminant limits (or associated gas analysis) only on incidents or accidents (unless these accidents occur with significant frequency). On the other hand, the lack of reported accidents should not allow for the removal of, or reduction in a specific limit. Basic risk theory (where the actual risk is the product of severity, likelihood, and frequency of an accident) is a more suitable means of making decisions. In each and every case, there is a place for specific risk assessment in order to accommodate individual and unique operational situations or requirements.

Where local or other mandated regulations apply, these should always take precedence. It is likely these local rules are based on actual environmental conditions. Where the limits and requirements proposed in this article exceed local rules, then it would be prudent to adopt the more conservative levels.

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