Guidance note

Low oxygen atmospheres and the risk control of associated health hazards

Protecting people, property, business and the environment

FPA Fire Protection Association

InFiReS

FPA guidance documents

Lists of other publications on loss control are available at www.thefpa.co.uk and from the FPA at London Road, Moreton-in-Marsh, Gloucestershire GL56 0RH. Copies of publications can be purchased from the FPA at that address or by calling 01608 812500 or e-mailing sales@thefpa.co.uk.

Technical contact:

Adair Lewis
FPA, London Road, Moreton-in-Marsh, Gloucestershire
GL56 0RH
E-mail: alewis@thefpa.co.uk

First published by
The Fire Protection Association
London Road
Moreton in Marsh
Gloucestershire GL56 0RH
Tel: 01608 812500, Fax: 01608 812501

E-mail: fpa@thefpa.co.uk, Website: www.thefpa.co.uk

Copies of this document may be obtained from the publications department of the FPA, at the above address.

Printed by Modern Colour Solutions 1.0/02.06

Contents

Executive summary 3
1. Scope 3
2. Introduction 3
3. Terminology and definitions 4
4. Atmospheric composition 4
5. The physiology of oxygen uptake 4
6. Physical performance in low oxygen atmospheres 6
   6.1 Cognitive performance in low oxygen environments 6
7. Health hazards in low oxygen environments 6
8. Acclimatisation 7
9. Toxic gases in low oxygen atmospheres 8
   9.1 Carbon monoxide 8
   9.2 Carbon dioxide 8
10. Hazards and risk assessment 8
   10.1 Overview 8
   10.2 The worker's state of health 9
   10.3 Assessment of the physical and mental demands of the occupational role 9
   10.4 Heterogeneity of oxygen and depletion of oxygen in confined spaces 9
   10.5 Long-term exposure to low oxygen atmospheres 9
   10.6 Toxic gases 9
   10.7 Monitoring oxygen levels 10
   10.8 Liability risks arising from detrimental effects on employee health 10
   10.9 Pre-existing health conditions 10
11. Health assessment 11
12. Summary 12
13. Reference 12

EXECUTIVE SUMMARY

The principal considerations associated with controlling hazards to health associated with low oxygen atmospheres are:

- Short-term and long-term exposures to low oxygen atmospheres have different associated hazards.
- The relationship between exposure to low oxygen atmosphere and the associated risk is not linear – a small fall in oxygen concentration can bring a disproportionately large increase in risk.
- If an employee is exposed to or expected to work in a low oxygen environment, then it is essential to carry out a detailed assessment of the health of the individual in relation to the tasks which are required to be performed.
- If an employer requires employees to work in low oxygen atmospheres, it is possible that the employer may be exposed to liability risks if the workforce and the working conditions are not properly managed.

1. Scope

The purpose of this document is to provide an understanding of the health and safety risks resulting from exposure to a low oxygen environment. The intended audience for the document is insurance surveyors, risk managers and health and safety practitioners.

The document is based on, and makes extensive reference to, the FPA report *Hazards to Health Associated with Low Oxygen Atmospheres*. References to the appropriate section or sections of that report (the FPA Report) are provided in square brackets.

The document provides guidance on the risks presented by exposures to low oxygen atmospheres (both long-term and short-term inadvertent). Short-term exposures to a low oxygen environment could occur due to an uncontrolled asphyxiant gas release. Long-term exposures to a low oxygen environment include those associated with diving, tunnelling, aviation and the use of systems where the oxygen level is reduced for other reasons. Occupational or leisure activities at high altitudes also result in exposures to low oxygen environments, which may be of short-term or long-term duration. The effects of low oxygen atmospheres on the toxicity of other gases will also be considered.

2. Introduction

The evidence reviewed in the FPA Report showed that the relationship between the concentration of oxygen in the atmosphere and its impact on health is not linear; progressive, equal reductions in oxygen concentration produce increasing biological effects and risks to health. In particular, the minimum level of oxygen required for permanent survival for an individual is approximately half that of a normal atmosphere at sea level, so the impact of reducing oxygen concentrations should be considered over this range, rather than between 0% and the concentration in the atmosphere (20.9%).

Physical activity places additional demands for oxygen, which may be up to 7 times higher than the demand at rest [Section 2.2.7], consequently the physical demands of an activity or occupation must be assessed as part of an overall risk assessment.

Although moderately reduced levels of oxygen do not in themselves pose an immediate health risk, they do have the potential to exacerbate existing health conditions and may increase the effective toxicity of toxic gases that may be present. For these reasons, it is important to view the risk assessment of the impact of a reduced oxygen atmosphere in the context of a broader risk assessment of other related hazards. Health conditions that act to reduce the body's efficiency in the uptake of oxygen will expose an individual to a higher degree of risk of suffering adverse health effects than in a healthy individual.

3. Terminology and definitions

Diffusion: A passive process whereby there is a net movement of molecules from a region of higher concentration to a region of lower concentration.

Haemoglobin: The molecule present in red blood cells responsible for the transport of oxygen. It consists of a protein part, globin, and a pigment part heme that contains 4 atoms of iron, each of which may be combined with a molecule of oxygen.

HSE: Health and Safety Executive

Hypoxia: A general low level of oxygen availability. In the case of physiology it describes a deficiency of oxygen at the tissue level or in the blood.

Metabolic rate: The rate at which heat is produced by the body, a by-product of expending energy during exercise or while at rest (the base metabolic rate).

Normbaric: Atmospheric pressure at sea level.

Oedema: An accumulation of fluid in the body, usually water.

Partial pressure: The partial pressure of a gas is the pressure it would exert if it occurred in isolation and may be calculated as the product of its concentration in the gas mixture and the total pressure of the gas mixture.

Pulmonary arteries: The arteries connecting the heart and lungs.

Respiration: The process by which oxygen is absorbed is referred to as respiration.

4. Atmospheric composition

Atmospheric air excluding water vapour is on average composed of 78.1% nitrogen, 20.9% oxygen, 0.934% argon and 0.0360% carbon dioxide. The composition of the atmosphere is constant with altitude, although the density of the air and therefore its pressure decreases with altitude. As a result, although the percentage of oxygen in the atmosphere at a given altitude is constant the partial pressure of oxygen, which determines its availability, is reduced.

The partial pressure of oxygen at a given altitude is often expressed as the percentage composition of oxygen in air at sea level that would give the same partial pressure as at the altitude under consideration [Section 2.1.1]. By expressing oxygen partial pressures thus, it becomes possible to make comparisons between oxygen availability at different altitudes and in artificial atmospheres in a way that is easy to understand and communicate.

Figure 1 illustrates the decrease in the partial pressure of oxygen with altitude. Atmospheric composition is discussed in more detail in section 2.1 of the FPA Report.

In a healthy individual at rest in a normal atmosphere at sea level the cells in the body tissues remove about 25% of the oxygen present in tissue capillary blood. The maximum altitude at which life can be sustained is around 5800m, equivalent to a 10% oxygen atmosphere at normal atmospheric pressure. Individuals who climb Everest without supplementary oxygen are exposed to significantly lower oxygen partial pressures than 10%. However, such individuals are highly acclimatised to the high-altitude low-oxygen environment and can only endure the altitude of Everest for a very short period of time. In addition, some studies have found evidence of impaired cognitive performance 12 months after such attempts.

A detailed discussion of the physiology of oxygen uptake and the respiration process, the process by which oxygen is taken up by the body, may be found in the FPA Report. Two main systems are involved in the process of respiration, the respiratory system, comprising the lungs and related organs, and the circulatory system, comprising the blood and related organs.

The ability of the body to take up sufficient oxygen depends on two main factors. The first is the efficiency of the respiratory system, a function of the rate of air circulation and the rate of diffusion of oxygen from the air to the blood in the pulmonary arteries, which is essentially limited by the laws of physics. The second factor is the ability of the blood to transport oxygen, which may be enhanced by acclimatisation [Section 3.5] to low oxygen environments; the process where physiological changes in the blood increase its oxygen transporting capacity.

5. The physiology of oxygen uptake

The pulmonary arteries take de-oxygenated blood to the lungs where it is oxygenated. Ninety-eight per cent of oxygen transport by the blood takes place by the binding of oxygen to haemoglobin in red blood cells. The affinity of haemoglobin for oxygen is related to the

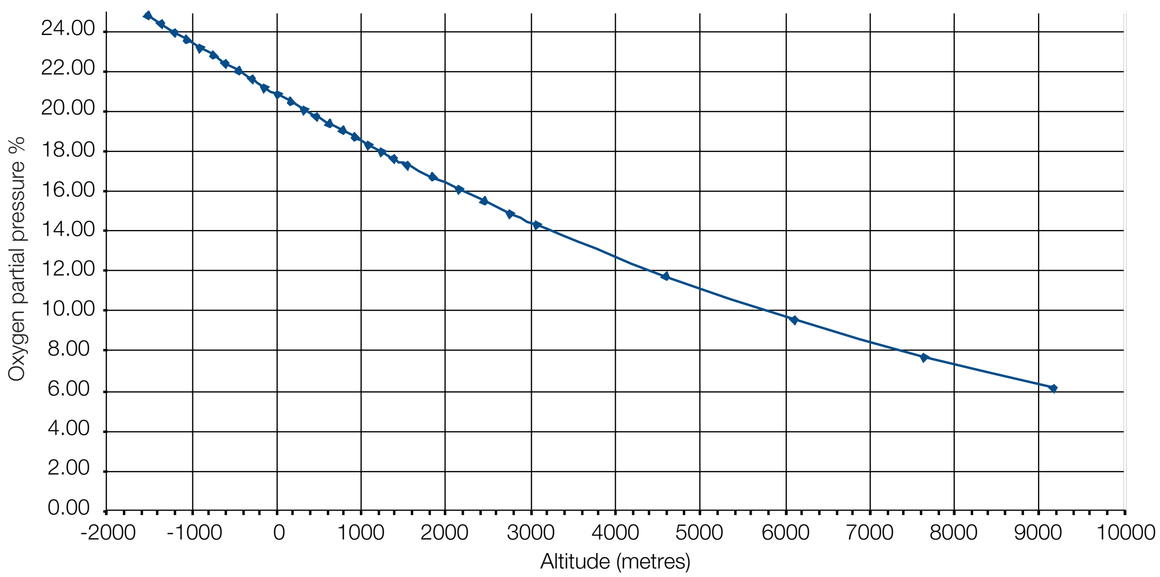

Figure 1: Oxygen partial pressure as effective % composition at sea level. Oxygen partial pressure expressed as the percentage of oxygen in a normal atmosphere at sea level that would have a partial pressure equivalent to that of oxygen at the altitude on the x-axis.

partial pressure of oxygen in the blood and follows a relationship which, when depicted, presents an s-shaped (sigmoid) graph (Figure 2) (and see [Section 2.2.2]). As the partial pressure of oxygen in the pulmonary arteries follows a linear relationship with the partial pressure of oxygen in the atmosphere [Section 2.2.1, last paragraph] it is possible to take the oxygen-haemoglobin saturation curve and re-label the x-axis as the oxygen partial pressure in the atmosphere. Modifying the graph in this way creates a risk curve relating oxygen-haemoglobin saturation to the partial pressure of oxygen in the atmosphere. This allows a direct link to be made between the availability of oxygen in the air and the oxygen available to the tissues, and the associated health implications.

At arterial oxygen partial pressures below 50mmHg, equivalent to about 10% oxygen composition in a sea level pressure atmosphere, there is insufficient oxygen in the blood to permit the part of the brain that controls breathing to function, and breathing stops. This oxygen partial pressure corresponds to an oxygen-haemoglobin saturation level of 85%. The risk curve is therefore of most interest when the haemoglobin saturation is between 85% and 100% and is illustrated in Figure 3. At the top of the curve, reducing the oxygen partial pressure has little effect on haemoglobin saturation, for example reducing the oxygen partial pressure from 20% to 15% results in the same % decrease in haemoglobin saturation as a reduction from in oxygen partial pressure from 15% to 13%.

Figure 3 shows expected haemoglobin saturation plotted against the atmospheric oxygen partial pressure expressed as the equivalent % oxygen composition in a normal atmosphere at sea level. The lowest oxygen-haemoglobin saturation of 85% corresponds to a

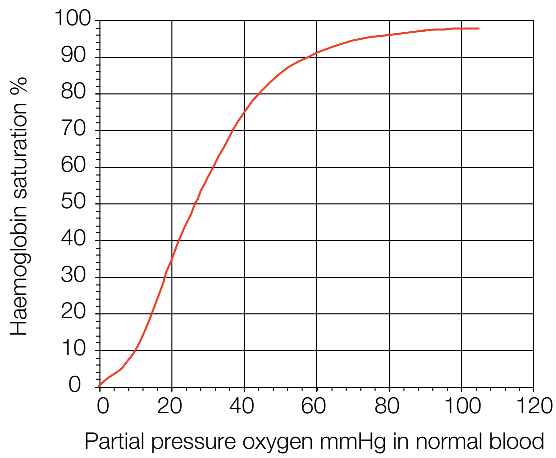

Figure 2: Oxygen-haemoglobin dissociation curve at normal body temperature showing the relationship between haemoglobin saturation and the arterial partial pressure of oxygen. As arterial oxygen partial pressure increases, more oxygen binds to haemoglobin.

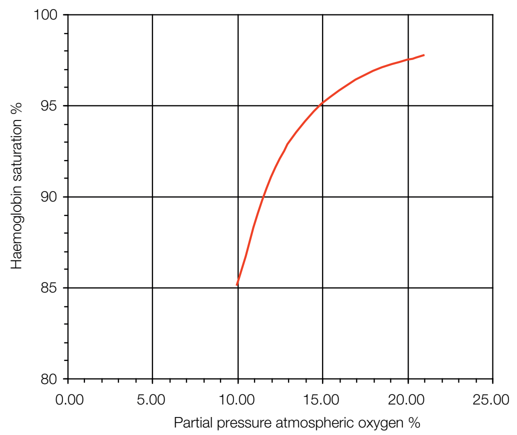

Figure 3: Oxygen-haemoglobin risk curve

partial pressure of oxygen in arterial blood of 50mmHg, below which pressure the respiratory control area in the brain becomes starved of oxygen and ceases to function.

6. Physical performance in low oxygen atmospheres

The rate of uptake of oxygen from the air depends on the metabolic rate, which is determined by the type of activity undertaken. At rest in a normal oxygen environment the tissues of the body utilise approximately 25% of the oxygen made available to them. Metabolic rates, and the rate of supply of oxygen required to meet them, vary by a factor of almost seven, from rest (lowest) to high intensity physical exertion (highest). Consequently at the highest metabolic rates the muscles use more oxygen than can be supplied by the blood and perform anaerobic respiration, producing lactic acid as a by-product. When metabolic activity is reduced to a lower level breathing continues at an elevated rate and the body uses oxygen to convert lactic acid to carbon dioxide and water.

A few occupations require individuals to perform very strenuous work. These include the emergency services, where individuals may be required to perform at their maximum work rate. The maximum work rate is determined by physical fitness, body size and age and is only sustainable for a few minutes. Under low oxygen conditions the maximum work rate and its duration attainable by an individual are lowered due to the reduced carrying capacity of haemoglobin. Oxygen-haemoglobin saturation decreases from 98% to 85% in response to a fall in atmospheric oxygen partial pressure from 21% to 10% (Figure 3). However, the ability of the respiratory system to replenish the oxygen used falls by a much greater amount than the percentage change in oxygen-haemoglobin saturation would imply, and it is this that causes breathlessness at high altitude rather than the carrying capacity of haemoglobin. The result is that individuals taking vigorous exercise at high altitude become exhausted more quickly and are unable to recover quickly due to the difficulty of replenishing the oxygen used during exercise.

6.1 Cognitive performance in low oxygen environments

Cognitive performance [Section 3.4] is not significantly impaired at oxygen concentrations at or above 15% unless the subject is suffering from acute mountain sickness. At 13% there is some impairment of cognitive ability. Different cognitive abilities vary in the amount in which they are impaired by low oxygen concentration.

Table 1 summarises the current state of knowledge; there is a considerable degree of uncertainty in the available evidence. There is some evidence, based on measurement of cognitive performance at low oxygen concentrations, to suggest that complex activity, such as that employed in making judgements, is the least affected by reduced oxygen concentrations. Exposees may be unaware of changes in their cognitive performance even when the changes are considerable. Changes in cognitive performance in environments where the oxygen concentration is greater than 13% are reversed upon completion of acclimatisation or on return to a normal atmosphere.

7. Health hazards in low oxygen environments

Altitude illness [Section 3.3] is the term used to describe the biological effects and medical conditions resulting

Table 1: Cognitive performance, impairment with altitude

Concentration of oxygen	15%-13%	13%-10.5%	< 10.5%
Cognitive Ability			
Spatial orientation	No impairment under normobaric conditions		
Visual reaction time	No impairment		
Motor speed and memory	Slight impairment of short term memory	No evidence of impairment at 12.8% or higher. Slight impairment at 4200m (12.4%)	Large degree of impairment
Grammatical reasoning			
Numerical performance	Impairment at 13%	Further deterioration with increasing altitude	High degree of impairment
Computer interaction	Slight impairment at 13%		High degree of impairment expected
Conceptual skills		Anecdotal evidence of improvement at altitudes in the range 4000-5000m (12.8% - 10.5%)	Less impairment than other types of cognitive ability
Judgement	cognitive abilities	Judgement is less affected by low oxygen availability than impairment at 6500m (9%)	Less impairment than other types of cognitive activity. Gross other

Table 2: Low oxygen illnesses

Risk	General non-specific symptoms	Acute mountain sickness	High altitude pulmonary oedema*	High altitude cerebral oedema*
Oxygen concentration				
21% - 17%	None	None	No risk	No risk
17%-15%		Low risk	Extremely rare (below 2500m)	Extremely rare
15%-13%	Increased breathlessness after moderate exercise. Dehydration	Medium risk increasing with decreasing oxygen concentration	Incidence of 0.0001% at 15% oxygen concentration.	Occurs above 3500m equivalent to an oxygen concentration of 13.5%.
< 13%	Decreased cerebral functioning	Very high risk	Incidence of 2% at an altitude of 4000m equivalent to anoxygen concentration of 12.8%.	Increasing likelihood
Risk Factors	Successfully treated heart and lung disease. High blood pressure. Diabetes. Individuals with any history of high altitude pulmonary oedema or high altitude cerebral oedema		Speed of ascent, Male sex, youth, vigorous exercise	Abrupt increase in cerebral blood flow immediately after ascent

* oedema = an accumulation of fluid (usually water) in the body.

Table 3: Detrimental effects of acclimatisation

Effect	Timespan	Duration	Health consequences
Appetite suppression	Short term	1-5 days, during the acclimatisation period	
Excessive ventilation.	Short term	varies	
De-hydration	exposure > 6 hours	1-5 days, during the acclimatisation period.	
Increased blood viscosity	exposure > 2-3 week	Blood viscosity returns to normal over 2-4 weeks.	The increased viscosity of the blood is linked to an increase in the risk of venous thromboembolism.
Inhibition of protein synthesis	Long term	varies	
Muscle wasting	Long term	varies	

from ascent to altitudes where the partial pressure of oxygen is reduced. The most common medical condition is acute mountain sickness and occurs at altitudes of 2500m and higher, particularly when the ascent is too rapid. This altitude is equivalent to a normobaric (atmospheric pressure equal to that at sea level) environment with an oxygen concentration around 15%. Incidence of acute mountain sickness in low oxygen normobaric environments is approximately half that found at an altitude corresponding to the same partial pressure of oxygen, where the atmospheric pressure is also reduced. The symptoms of acute mountain sickness include headache, insomnia, breathlessness, nausea and anorexia and develop over a period of 12-24 hours, peaking in the period 48-72 hours after exposure. Table 2 describes the various conditions occurring at different oxygen concentrations.

The condition of high altitude pulmonary oedema [Section 3.3.3] is potentially life threatening if not treated and may or may not be preceded by acute mountain sickness. The symptoms include a progressive increase in breathlessness, a productive cough producing white sputum and mild fever. The onset of symptoms is typically within 6-10 hours of exposure, but some cases have been reported after 1 hour. Individuals with high pulmonary artery blood pressure are more susceptible.

High altitude cerebral oedema [Section 3.3.4] is the most malignant form of altitude sickness and is fatal if left untreated. The symptoms are similar to those of hypothermia.

8. Acclimatisation

Altitude acclimatisation describes the physiological changes that take place as a result of exposure to altitude. In populations living permanently at high altitude there exist a number of physiological adaptations to the reduced oxygen availability, in particular an increase in haemoglobin levels compared to populations living at or near sea level. These physiological adaptations allow individuals at high altitude to maintain higher levels of physical activity than would be possible without them. Individuals travelling to high altitude regions undergo a number of physiological changes. Many of these changes occur slowly over several days and therefore only take place when an individual is living in a hypoxic (oxygen deficient) environment rather than being exposed to hypoxia for a few hours.

The detrimental effects of altitude acclimatisation at high altitudes are listed in Table 3.

The detrimental effects of altitude acclimatisation on muscle structure are thought to be the result of over-training, due to the body's inability to take in sufficient oxygen after vigorous exercise to metabolise the lactic acid produced by anaerobic (oxygen starved) activity.

Increased blood viscosity occurs as a consequence of the increased production of erythrocytes (red blood cells). Deep vein thrombosis (DVT) and pulmonary embolism are two manifestations of venous thromboembolism, which is the formation of a blood clot in the cardiovascular system. Unsurprisingly, given this list (Table 3), exposure to extreme high altitude has been shown to be detrimental to muscle structure and as a result, exercise performance.

Occupational exposure to an oxygen concentration of 15% for approximately 6 hours a day will cause some changes in the constitution of the blood, which could improve exercise performance [Section 3.5.1] and are unlikely to cause any significant detrimental effects to health in healthy individuals.

9. Toxic gases in low oxygen atmospheres

In general the toxicity of toxic gases should be anticipated to be greater in low oxygen environments, due to the additional stress they impose over and above that caused by the reduction in the partial pressure of oxygen. In addition, some of the toxic symptoms may be similar to the effects of low oxygen.

9.1 Carbon monoxide

Carbon monoxide is a colourless, odourless gas, which binds to haemoglobin 200 times more strongly than oxygen. Carbon monoxide poisoning results in rapid hypoxia (a low level of oxygen availability in the blood), due to the reduction of the oxygen-carrying capability of the blood. A partial pressure of carbon monoxide of 0.5mmHg, which is equivalent to 0.1% composition by volume, is capable of combining with half the haemoglobin molecules in the blood, resulting in a reduction in the available oxygen-carrying capacity of 50%. The reduction in oxygen-carrying capacity of the blood will be exacerbated in environments where the partial pressure of oxygen is lower than that at sea level. The symptoms of carbon monoxide poisoning are listed in Table 4.

Table 4: Carbon monoxide concentrations and their symptoms

CO concentration in air	Inhalation time and toxic symptoms developed
50 ppm	Safe exposure level as specified by the Health and Safety Executive
200 ppm	Slight headache within 2-3 hours
400 ppm	Frontal headache within 1-2 hours, becoming widespread in 3 hours
800 ppm	Dizziness, nausea, convulsions within 45 minutes, insensible in 2 hours

The (HSE) standard for carbon monoxide is 50ppm and should provide a sufficient margin of tolerance so as to present a safe level in environments where the oxygen partial pressure is 15.2kPa (15%) or higher. However, a lower standard may be necessary in environments where the oxygen partial pressure falls below 15.2kPa (15%).

9.2 Carbon dioxide

Carbon dioxide is a by-product of metabolic activity, which is removed from the body by the process of respiration [Section 2.2.3]. The toxic effects of carbon dioxide start with headaches and breathlessness at concentrations between 1.5% and 3%. Between 3% and 7.5% the symptoms increase in severity and include dizziness, breathlessness, visual disturbance and fatigue, with the progressive deterioration of cognitive and physical performance. Concentrations of carbon dioxide of 7.5% cause narcotic effects and make physical work impossible, and at 10% carbon dioxide concentrations there is a very rapid loss of consciousness.

Two different exposure limits are defined for occupational exposure to carbon dioxide; a short-term (less than 15 minutes) exposure limit of 15000ppm, which is a 1.5% concentration and a long-term limit (up to 8 hours exposure) 5000ppm, which is a 0.5% concentration. Increased partial pressure of carbon dioxide in arterial blood results in increased pH and leads to a lower oxygen-haemoglobin saturation; the curve in Figure 2 shifts to the right. In view of the fact that reduced oxygen partial pressures increase the strain on the respiratory system and that the effects of mild carbon dioxide poisoning are similar to those resulting from exposure to a reduced oxygen partial pressure, the lower long-term limit should be applied in all situations.

10. Hazards and risk assessment

10.1 Overview

The intended audience for this document is insurance surveyors, risk managers and health and safety practitioners. By providing them with an understanding of the health and safety hazards related to exposure to a low oxygen environment it will help them give advice about occupational risks across a wide range of workplace situations.

They would, for instance, ensure that an employer is aware of any responsibility to carry out a general health and safety risk assessment for an employment task or workplace. Such an assessment would seek to identify, among other things, places where atmospheric conditions in terms of oxygen concentration expose workers to levels of oxygen that may cause a risk to health or result in impaired performance of their duties, potentially resulting in additional hazards.

10.2 The worker's state of health

The possibility of adverse health consequences due to an individual's pre-existing medical condition should be considered. Proper use of health screening should mitigate this risk. Although the evidence suggests that acquiring a tolerance to altitude is good for sufferers of many health conditions, it is based on small numbers of cases and may have failed to take into account the additional risk to the individual associated with the increase in blood clotting potential.

The risks are much higher if the oxygen concentration, in a low oxygen atmosphere environment, is reduced to 13% compared to 15%, for example. The incidence of symptoms of acute mountain sickness is much greater at 13% than at 15%.

10.3 Assessment of the physical and mental demands of the occupational role

The risk assessment should investigate the physical demands of the role in relation to the physical fitness of the individual. Individuals with existing medical conditions that might impair their physical performance should be assessed to determine whether they are suitable for the task, given the additional strain of working in a low oxygen environment. In view of the possible impact of lowered oxygen concentrations on cognitive performance, the types of tasks should be assessed in terms of their requirement for cognitive performance.

The ISO standard ISO 8996 (revised in September 2004) covers metabolic rates in relation to different types of work undertaken under a wide range of conditions. This standard should be used as part of an assessment of the physical demands of the work in question for the purposes of making a detailed risk assessment.

10.4 Heterogeneity of oxygen and depletion of oxygen in confined spaces

Consideration should be given to the heterogeneity of the oxygen concentrations in the low oxygen environment.

Short-term exposure to low oxygen atmospheres

Short-term exposure to reduced oxygen atmospheres may be experienced during evacuation (typically 12% oxygen, which is equivalent to 4450m altitude) following the release of an inert gas. In the development of an evacuation plan the impact of the low oxygen concentration on physical performance should be taken into account. Oxygen concentrations of 12% greatly reduce the ability of healthy individuals to undertake strenuous physical activity. Thus, strenuous physical activity should as far as is possible be avoided.

The impairment of motor activity and reaction times that is likely at the oxygen concentration levels expected in such a scenario should be factored into an evacuation plan. The evidence concerning the impact of low oxygen concentrations on cognitive abilities suggests that complex cognitive tasks, which would include those relating to carrying out a planned evacuation, are relatively resilient to lowered oxygen concentrations.

The degree of heterogeneity in the atmosphere should be considered, since there could be parts of a building where the oxygen concentration is much lower than 12%. The risk assessment should identify such areas and the evacuation plan should ensure that individuals are moved away from these areas as part of the evacuation procedure.

10.5 Long-term exposure to low oxygen atmospheres

It is necessary to consider exposure to reduced oxygen atmospheres, especially where normal daily physical and cognitive tasks need to continue.

A 17% low oxygen atmosphere environment (equivalent to an altitude of 1750m) does not appear to present any significant issues in the context of employee health and safety or performance.

In the presence of an appropriate risk management procedure a 15% (equivalent to an altitude of 2700m) low oxygen atmosphere environment does not appear to present any significant issues in the context of employee health and safety or performance for non-strenuous work. Elements of an appropriate risk management procedure are described in Sections 10.6 to 11. However, there is evidence to suggest that strenuous physical activity becomes difficult at that level and that it should be restricted in intensity and duration.

The risks associated with a 13% (equivalent to an altitude of 3850m) low oxygen environment are much greater than those associated with a 15% low oxygen environment. Most of the studies of the impact of low oxygen atmospheres on existing health conditions have been undertaken in the context of the safety of those travelling on long-haul flights (both customers and airline staff) where the equivalent altitudes being considered are 1800-2700m. There is considerable uncertainty concerning the health consequences for individuals with cardiovascular or pulmonary health conditions, who should therefore be excluded from such an environment.

Depletion of oxygen in confined spaces

There is the possibility that the oxygen in a confined space may become depleted while people are working there. While this is possible, and may become harmful, in a location which had a normal oxygen concentration, the depletion to a dangerously low level of oxygen would be more rapid in a low oxygen atmosphere environment. The health and safety risk assessment should identify any areas or working practices that may expose employees to this risk.

10.6 Toxic gases

Assessment of the risks of toxic gases

A risk assessment should identify any toxic gases that could be reasonably expected to occur in the low oxygen environment, since the low oxygen environment is likely to exacerbate the problems of toxicity that may arise. In some instances 'permissible' exposure levels for these substances may be inappropriately high for a low oxygen environment. Where it has been identified that the low oxygen concentration may increase the toxicity of a gas then it may be necessary to seek expert advice in order to arrive at a realistic exposure limit.

Carbon monoxide

The monitoring of carbon monoxide in the atmosphere is strongly recommended, as there is evidence that the toxicity of carbon monoxide is increased at altitude or in other environments with low oxygen atmospheres. Because of the difficulty of diagnosing carbon monoxide poisoning it should be considered as a possibility in any patient with non-specific flu-like symptoms.

Carbon dioxide

Carbon dioxide monitoring should also be considered where the risk assessment indicates that carbon dioxide is a potential threat.

10.7 Monitoring oxygen levels

Procedures for monitoring oxygen concentrations in a low oxygen atmosphere environment should be implemented to ensure that the oxygen concentration does not fall below the minimum limit, which would constitute a health risk, such a limit having been established as part of the risk assessment. Particular consideration should be given to confined spaces and the possibility of variability in the oxygen concentration across the area being monitored.

10.8 Liability risks arising from detrimental effects on employee health

The risk of liability arising for detrimental effects on employee health depends to a large extent on the context of the low oxygen environment. Depending on the type of employee activity, and where the occupational exposure is kept very short, then there is little chance of significant harm being done and therefore little chance of any liability arising. Where employees are working in such an environment for 35 to 40 hours a week then the risk of a detrimental impact to employee health arising will be greatly increased. In a low oxygen environment where the concentration of oxygen is 15% or lower a formal risk management process must be adhered to as part of the duty of care of the employer.

The health and safety issues should be considered in the assessment of overall costs and benefits as part of the decision-making process for the implementation of such an installation.

10.9 Pre-existing health conditions

Heart disease

For individuals with well-controlled heart and lung disease a low oxygen atmosphere of 15% does not present an immediate threat to health. For employees with these conditions, medical advice should be sought to determine an appropriate course of action. The risks increase significantly in a low oxygen atmosphere environment with a concentration of 13% and persons with these types of conditions should not be allowed to work in such an environment.

Anaemia and other blood disorders

Haematological diseases, such as anaemia, which is a decrease in the number of red blood cells, reduce the ability of the blood to transport oxygen. In general, individuals with these types of conditions should seek medical advice as to whether their condition is such that they should be excluded from low oxygen environments.

Asthma

At altitudes below 3000m, equivalent to a low oxygen atmosphere of just under 15%, there are no reported issues with asthma. Asthmatics should be assessed in a respiratory clinic prior to exposure to a low oxygen atmosphere environment to ensure that they have an adequate ventilation response. An asthmatic suffering an attack in a low oxygen atmosphere environment should be removed from that environment and given their normal treatment. Asthmatic attacks are generally infrequent, often in the order of an attack every 6 months. In the case of pilots flying aircraft, asthma is usually viewed as being incompatible with flying, due to the risk of an asthma attack during flight. Where an asthma attack would not cause a similar hazard in an occupational environment, that is, because the tasks undertaken are non-critical, and provided the attack victim is quickly removed to an area with normal oxygen levels, then there is no need to permanently exclude asthmatics from such an environment, particularly as asthmatic attacks are usually infrequent.

Smokers

The ranges of exhaled carbon monoxide levels in non-smokers have been found to be 0-10ppm compared with 1-39ppm in smokers. The Health and Safety Executive (HSE) standard for the maximum level of carbon monoxide is 50ppm, although this may be too high in a low oxygen atmosphere environment where the oxygen partial pressure is below 15.2kPa (15%). Given that the heaviest smokers have a level of carbon monoxide in exhaled breath that is close to the HSE limit it is possible that smokers could exhibit the mildest forms of carbon monoxide poisoning when entering a low oxygen atmosphere environment.

Where a smoker's lung function is similar to that of a non-smoker the risks posed by a low oxygen atmosphere where the oxygen partial pressure is 15.2kPa (15%) or above are very small.

Age

The incidence of the cardiovascular and pulmonary health conditions considered in this section tend to increase with age. However, since the risk assessment process should detect these conditions at the individual level, regardless of age, it is more useful to define the types of conditions for which a risk assessment should be assessing the impact, rather than having different risk assessment objectives for different age groups.

11. Health assessment

A risk assessment of the health of an individual working in low oxygen environment should concentrate on those factors which would have an impact on the efficiency of the process by which the body takes up oxygen and transports it to the tissues.

Asthma and other respiratory tract disorders reduce the ability of the respiratory system to transfer oxygen to the blood. Disorders of the blood, such as anaemia, reduce its capacity to transport oxygen to the tissues and increase the risks of working in a low oxygen atmosphere.

Health assessments for individuals who will be working in a low oxygen atmosphere environment should be made for:

- full time strenuous work in a 15% low oxygen atmosphere environment,
- full time work in a 13% low oxygen atmosphere environment.

The health assessment is not necessary if:

- the oxygen concentration will be 17%,
- where the exposure will be less than 2 hours per day.

For exposure to a 15% oxygen atmosphere environment a health assessment may be advisable depending on the precise nature of the tasks to be undertaken.

The following questions provide the basis for a questionnaire for an initial examination for screening purposes, with a follow-up examination periodically.

Medical history

If one of the questions below is answered with a 'yes' then a physician should perform a further investigation, together with a more comprehensive medical examination.

Questions

Do you smoke?

Have you ever suffered a stroke?

Are you suffering from any heart condition?

Have you any lung disease?

Do you suffer from asthma?

Are you anaemic?

Have you sickle-cell disease?

Do you have diabetes?

Would you pause to catch your breath while climbing a flight of stairs?

Have you experienced chest pains within the last year while at rest?

Have you experienced chest pains within the past year while under physical or mental stress?

Have you ever experienced dizziness in the last few months which has prevented you from pursuing your normal daily activities?

Have you been unconscious during the last year?

12. Summary

The approach to implementing risk management of the health hazards associated with low oxygen atmospheres must be founded on a suitable and sufficient health and safety risk assessment. That risk assessment needs to consider, broadly:

- what are the hazards associated with the occupation and the location(s) in which the particular task is performed?
- who are the people who could be at risk?
- can any of the hazards be eliminated, controlled or avoided?

This guidance document delivers a survey of those health hazard considerations, to provide the target audience with background information on the relationship between low levels of oxygen in an atmosphere and its potential impact on the health of a person therein. It is intended to help those concerned to provide advice to the persons who are responsible for performing the necessary risk assessment.

13. Reference

International Standards Organisation, *Ergonomics of the thermal environment -- Determination of metabolic rate,* 2004.

Low oxygen atmospheres and the risk control of associated health hazards

Guidance note

Protecting people, property, business and the environment

FPA Fire Protection Association

InFiReS