British Tunnelling Society

Compressed Air Working Group

Guidance on good practice for Work in Compressed Air

Based on the

Work in Compressed Air Regulations (SI 1996/1656)

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Guidance on good practice for work in compressed air.

The Compressed Air Working Group of the British Tunnelling Society produced its "Guide to the Work in compressed Air Regulations 1996" in June 2012 under the terms of an Open Government Licence for public sector information (http://www.nationalarchives.gov.uk/doc/open-government-licence/). At that time the Guide represented an update and comprehensive revision of HSE Guidance L96 "A guide to the Work in Compressed Air Regulations 1996 Guidance on Regulations" and the "Addendum to 'A guide to the Work in Compressed Air Regulations 1996 Guidance on Regulations' Guidance on OXYGEN DECOMPRESSION and the use of Breathing Mixtures other than Compressed Natural Air in the Working Chamber", both of which had been withdrawn by HSE prior to June 2012. The use of material previously published by HSE in L96 and its Addendum, is acknowledged.

In July 2017, HSE re-published "Guidance for appointed doctors on the Work in Compressed Air Regulations 1996", see https://www.hse.gov.uk/pubns/ms35.pdf. Reference is made to it in this document for example in connection with detailed requirements for medical examinations.

This document is a revision of the 2012 edition of the BTS Guide, expanded to incorporate guidance on work at pressures of 3.5 bar(g) and above along with changes arising from the revision of various British and European standards.

Detailed technical guidance for high pressure compressed air work is set out in the ITA/BTS CAWG Report 10 "Guidelines for good working practice in high pressure compressed air" ("Report 10") which is extensively referenced in this document.

This guidance is primarily drafted for use in Gt Britain and Northern Ireland where the relevant legislation is the Work in Compressed Air (Northern Ireland) Regulations 2004. However, it can be applied to work in compressed air in most countries.

This guide is no longer intended to be "Guidance on Regulations," however its structure still follows the layout of the Work in Compressed Air Regulations 1996. It was drafted under the auspices of the BTS Compressed Air Working Group, which is comprised of engineers, occupational health doctors, hyperbaric services specialists, physiologists and regulators with backgrounds in compressed air tunnelling and/or diving. The text reflects the collective experience of the members of CAWG.

This document can be considered to set out guidance on good practice and can facilitate compliance with the regulations however following this guidance is not compulsory. Compliance with this guidance does not confer immunity from legal obligations.

This guide is a living document in an evolving field of expertise and practice. It does not pretend to cover every aspect of work in compressed air and will be subject to further updates.

The British Tunnelling Society and CAWG take no liability for any adverse events that may result from attempting to follow of this guidance.

Contents

Regulation 1 Citation and commencement

These Regulations may be cited as the Work in Compressed Air Regulations 1996 and shall come into force on 16th September 1996.

1. Guidance relevant to Regulation 1

1.1. Introduction

1.1.1. The Work in Compressed Air Regulations 1996 (WCA Regulations) (SI 1996/1656) provide a framework for the management of health and safety risks by those undertaking tunnelling and other construction work in compressed air at any pressure. They replaced the Work in Compressed Air Special Regulations 1958. They also amplify general duties under the Health and Safety at Work etc Act 1974 (HSWA), the Management of Health and Safety at Work Regulations 1992 and the Construction (Design and Management) Regulations 2015.

1.1.2. The text of the regulations has been updated only to include amendments necessitated by the revision of the Construction (Design and Management) Regulations 2015.

1.1.3. The WCA Regulations 1996 address such issues as: appointment of a compressed air contractor; notifications; safe systems of work; plant and equipment; medical surveillance; compression and decompression procedures; control of oxygen; medical treatment; emergency procedures; fire precautions; provision of information, instruction and training; maintenance of health and exposure records and procedures for gaining exemptions to work at high pressure. Many of the duties are placed upon compressed air contractors to reflect the practical operation of the industry and in recognition of the fact that the contractor in charge of the compressed air operations is best placed to manage and control the health and safety risks of such work.

1.1.4. The classification of compressed air work by pressure, has changed. “Low pressure” is still work at pressures not requiring stage decompression i.e. <0.7 bar(g) in the UK; work requiring stage decompression but below the statutory limit is classified as “intermediate pressure” with “high pressure” being work in compressed air above the statutory limit i.e. 3.5 bar(g) in the UK.

1.1.5. This document provides general guidance on work in compressed air at any pressure as well as giving specific guidance on work at low and intermediate pressures. Guidance on high pressure compressed air work is set out in the current version of ITA/BTS CAWG Report 10 “Guidelines for good working practice in high pressure compressed air”. For guidance on the use of high pressure techniques such as mixed gas breathing mixtures or saturation techniques at pressures below 3.5 bar(g), the recommendations in both documents should be followed.

1.1.6. Leaving the EU has not affected the Work in Compressed Air Regulations 1996 however it has slightly changed the legal requirements for machinery safety. Whilst in the EU, it was a requirement that all plant and equipment used in UK construction had to be CE marked

as a declaration of conformity with the essential safety requirements of the Machinery Directive. In future all new plant and equipment for use in Gt Britain will have to be UKCA (UK Conformity Assessed) marked as part of a declaration of conformity with the Designated British Standard, i.e. the version of a European standard published by British Standards Institute (BSI). As long as the "Northern Ireland Protocol" remains in force, new plant and equipment for Northern Ireland requires a UKNI mark or a CE mark.

1.1.7. In this document a reference to BS EN XXXX implies the "Designated British Standard" as published by BSI, i.e. the British version of European standard EN XXXX.

1.2. Pressure

1.2.1. Although not specifically stated, pressures in this document are given as gauge pressures (bar(g)) unless indicated otherwise. Partial pressures are expressed in bar.

1.2.2. All pressures should be read/recorded in 0.05 bar increments rounded, if necessary, upwards, e.g. 0.96 bar(g) becomes 1.0 bar(g).

1.3. Scope of the Work in Compressed Air Regulations 1996

1.3.1. The Work in Compressed Air Regulations apply to all work in compressed air irrespective of pressure. The application of the Regulations is limited to "construction work" which meets the requirements of notification under regulation 6(1) of the Construction (Design and Management) Regulations 2015 (CDM2015) which last longer than 30 working days and have more than 20 workers working simultaneously at any point in the project or exceed 500 person days. The Regulations do not apply to such areas of work as diving, hyperbaric medicine (except for applications relating to construction work in compressed air), aircraft testing and clean rooms. The lower limiting pressure of 0.15 bar(g) excludes work at very low pressures where the risk of decompression illness is negligible. The upper statutory limit on exposure is 3.5 bar(g) however guidance is provided on procedures for obtaining an exemption from this limit.

1.3.2. For most, but not necessarily all, compressed air projects the compressed air contractor will be the principal contractor under CDM2015.

1.3.3. Compressed air work is now mainly undertaken on TBMs for inspection and maintenance purposes however the construction of in-tunnel airlocks and a working chamber formed by bulkheads in the tunnel lining remains permissible and is covered by this guidance.

1.3.4. This guidance also covers the application of compressed air to shaft construction and caisson sinking.

1.3.5. Because of the particular risks and conditions involved in work in compressed air, the WCA Regulations 1996 provide standards and requirements in addition to those in Part 4 of CDM2015 for emergencies, fire precautions and the welfare of any person engaged in work in compressed air.

1.3.6. This guidance is not a standalone text. In order to cover all aspects of work in compressed air, it should be read in conjunction with the relevant sections of the current versions of BS 6164 "H*ealth and safety in tunnelling in the construction industry - Code of practice" (in particular Clause 11 which states "This British Standard and the Guidance are complementary");* BS EN 16191 *"Tunnelling machinery – safety requirements";* BS EN 12110 *"Tunnelling machinery – airlocks safety requirements"* and the International Tunnelling Association/BTS Compressed Air Working Group *"Guidelines for good working practice in high pressure compressed air"* (Report 10) and HSE publication "Guidance for appointed doctors on the Work in Compressed Air Regulations 1996". The ITA/BTS CAWG Report 20 "C*lient guide to high pressure compressed air work"* is a normative reference in BS 6164:2019 clause 11.9.

1.3.7. ENs 12110:2014 and 16191:2014 are being revised at the time of publication of this document. It is expected that EN 12110 will be revised into two parts. With EN 12110-1 setting out requirements for airlocks utilising compressed air as the pressurising and breathing medium along with requirements for oxygen breathing systems for decompression purposes and EN 12110-2 setting out requirements for the use of non-air breathing mixtures and saturation techniques in personnel locks and for pressurized transfer shuttles.

1.3.8. Until the revisions are published as prENs or BS ENs the guidance in BS EN 12110:2014 (and if relevant BS EN 16191:2014) along with the relevant interim technical guidance in this document from page 139 onwards should be followed. On publication of the revision the interim technical guidance becomes time-expired.

1.4. Alternatives to compressed air

1.4.1. The application of compressed air is only one of a number of ground improvement techniques available for tunnelling, pipe-jacking or shaft sinking. Others include dewatering, grouting or ground freezing. None of the techniques is without health and/or safety risks. Dewatering and grouting can be susceptible to changes in ground permeability while the success of ground freezing can be dependent on the groundwater regime. Experience has shown that whilst the application of compressed air can be particularly useful in stabilising finer grained soils, it has been used successfully to control water ingress in a wide range of ground types. Work in compressed air can offer more flexibility than other ground improvement techniques when the work to be undertaken turns out to be more extensive than first envisaged or its precise location cannot be ascertained in advance.

1.4.2. A range of engineering techniques for the inspection and replacement of cutterhead tools (including remote wear sensing, CCTV inspection, robotic tool changing and tool changing in free air from within the spokes of an accessible cutterhead) is available but is not necessarily available for all diameters of tunnelling machinery. Additionally, the capability to undertake maintenance or repair of the cutterhead and any equipment associated with it such as screw closure doors or boulder crusher, and maintenance of robotic equipment has to be considered.

1.4.3. The risks arising from the use of some ground improvement techniques, for example dewatering, are predominantly safety-related while both safety and health risks arise from the use of other ground improvement techniques such as grouting or work in compressed air. No technique is without risk. Comparing the overall risk arising from different techniques can therefore be difficult. However, the likely worst-case consequences which could arise from each technique are usually foreseeable.

1.4.4. There are also commercial risks associated with not making adequate provision for inspection and maintenance of the cutterhead.

1.5. **Changing nature of compressed air work**

1.5.1. The nature of compressed air working has changed to reflect developments in tunnelling techniques and mechanisation. Periodic short excursions into the head of a tunnel boring machine for inspection and maintenance have become common and long periods of tunnelling in compressed air using hand excavation techniques or open face machines have ceased to be the norm.

1.5.2. To reflect the intermittent use of compressed air on some low and intermediate pressure contracts due to the mechanised nature of modern tunnelling along with the reliability of power supplies and air supply systems now available, some flexibility was introduced in the original version of this guide in respect of the requirements for personnel overseeing the work in compressed air and this has been continued in the current edition.

1.5.3. The use of non-air breathing mixtures and saturation techniques significantly increases the equipment, personnel and competences required to undertake compressed air work safely and without risks to health.

1.6. Health risks associated with work in compressed air

1.6.1. When compressed air is used, all reasonably practicable steps should be taken to minimise the number and severity of exposures but also to adopt exposure techniques which minimise the overall health risk to those undertaking the work.

1.6.2. Although mainly associated with high pressure compressed air work the adverse effects of increased work of breathing and narcosis attributable to breathing high partial pressures of nitrogen should be considered when determining exposure techniques for use at pressures in the upper intermediate pressure range.

1.6.3. There are three types of occupational ill-health which can be brought about by working in compressed air:

1.6.3.1. barotrauma, where a change in surrounding pressure causes direct damage to air-containing cavities in the body directly connected with the surrounding atmosphere, principally ears, sinuses and lungs;

1.6.3.2. decompression sickness, an acute condition which predominantly occurs as pain around the joints, or, more rarely, as a serious, potentially life-threatening condition which may affect the central nervous system, the heart or the lungs; and

1.6.3.3. dysbaric osteonecrosis, which is a long-term, chronic condition damaging the long bones, hip or shoulder joints.

1.6.4. Collectively they are referred to as decompression illness (DCI).

1.7. **Oxygen decompressio**n

1.7.1. Routine oxygen decompression was introduced in the UK in 2001 and is generally accepted to give significant medical benefits compared to air-only decompression, particularly at intermediate pressures and with longer duration exposures. Guidance on decompression from high pressure exposures is given in Report 10.

1.7.2. Whilst oxygen has beneficial effects, in excess, oxygen exposure can result in acute or chronic toxicity. Oxygen decompression tables should be designed to limit both instantaneous exposure and long term cumulative exposure to within recognised limits (see cl 7.5.1). Cumulative oxygen dose is measured in oxygen tolerance units (OTU).

1.7.3. The guidance on handling oxygen should be applied to any gas mixture containing 23.5% or more oxygen by volume.

1.8. Advanced hyperbaric techniques

1.8.1. Two techniques which have been extensively developed in the offshore commercial diving industry and which are now being adopted in high pressure compressed air tunnelling are the use of non-air breathing mixtures and saturation exposure techniques. Both are essential to allow interventions at high pressure to be undertaken safely. Work in compressed air at pressures over 10 bar(g) has been successfully undertaken internationally.

1.8.2. Guidance on the use of gas mixtures comprising oxygen, nitrogen and/or helium, other than natural air is set out in Report 10. Formal approval from HSE is not required for the use of gas mixtures containing oxygen, nitrogen and/or helium at pressures below 3.5 bar(g). However, a formal exemption is required from HSE for any mixed gas work at pressures over 3.5 bar(g).

1.8.3. Guidance on the use of saturation techniques is set out in Report 10. Formal approval from HSE is not required for the use of saturation techniques at pressures below 3.5 bar(g). However, a formal exemption is required from HSE for any saturation work at pressures over 3.5 bar(g).

1.8.4. This document sets out guidance on good working practice for work in compressed air. It is drafted to follow the structure of the WCA Regulations (reproduced in italics). Additional advice on technical and medical aspects of work in compressed air is contained in the appendices. This guidance has been prepared under the auspices of the British Tunnelling

Society Compressed Air Working Group. This Guide is a revision and update of the Guide which was published in 2012 by the BTS. Compliance with this guidance does not confer immunity from legal obligations.

1.8.5. Although technical guidance on high pressure compressed air work is set out in the ITA/BTS CAWG Report 10, there is guidance in this document on how the requirements of the regulations extend to high pressure work.

Regulation 2 Interpretation

(1) In these Regulations, unless the context otherwise requires -

"the *2015* Regulations" means the Construction (Design and Management) Regulations 2015(a);

"airlock" means an enclosed space capable of being pressurised and which is used for the compression or decompression of any person or any material when such person or material is passing into or, as the case may be, out of a working chamber;

"appointed doctor" means a registered medical practitioner appointed for the time being in writing by the Executive for the purposes of these Regulations;

"approved" means approved for the time being in writing for the purposes of these Regulations;

"compressed air contractor" means a contractor appointed under regulation 5;

"contract medical adviser" means a registered medical practitioner appointed under paragraph (1) of regulation 9 and who is competent to give the advice referred to in that paragraph;

"decanting" means the rapid decompression in an airlock to atmospheric pressure followed promptly by rapid compression in an alternative airlock and subsequent decompression to atmospheric pressure;

"employment medical adviser" means an employment medical adviser appointed under section 56 of the Health and Safety at Work etc. Act 1974;

"the Executive" means the Health and Safety Executive;

"project" means a project which includes work in compressed air;

"work in compressed air" means work within any working chamber, airlock or decompression chamber which (in each case) is used for the compression or decompression of persons, including a medical lock used solely for treatment purposes, the pressure of which exceeds 0.15 bar;

"working chamber" means an enclosed space in which work is carried out and which is accessible only through an airlock.

(2) Any reference in these Regulations to pressure in bar means that pressure above the surrounding atmospheric pressure.

(3) In these Regulations, unless the context otherwise requires, any reference to -

(a) a numbered regulation is a reference to the regulation in these Regulations so numbered;

(b) a numbered paragraph is a reference to the paragraph so numbered in the regulation in which that reference appears.

(a) SI 2015/51.

2. **Guidance relevant to Regulation 2**

2.1. Terms and definitions (In addition to the interpretation given in Regulation 2**)**

2.1.1. **breathing mixture** means any non-air respirable mixture such as oxygen and nitrogen (nitrox); oxygen and helium (heliox) or oxygen, helium and nitrogen (trimix). The terms **breathing mixture** and **mixed gas** are used interchangeably in the text.

2.1.2. decompression procedures – decompression tables along with actions such as formal checking of oxygen supplies and setting of recording pressure gauges before reduction in pressure begins along with the routine administration of oxygen, all of which are an essential part of the process of returning from working pressure to atmospheric pressure (0 bar(g)).

2.1.3. decompression table(s) – a schedule of pressures and times to be followed in effecting a return from working pressure to atmospheric pressure (0 bar(g)). It can include pressure change rates, oxygen administration pressures and oxygen/air cycle times.

2.1.4. **HPCA** means high pressure compressed air.

2.1.5. **oxygen** means 100% oxygen by volume;

2.1.6. **OTU** – oxygen tolerance unit

2.1.7. **pressurised transfer shuttle** 'shuttle' as defined in BS EN 12110-2

2.1.8. **Registered medical practitioner** means a medical practitioner who is registered with the General Medical Council of the UK (GMC), and is licensed to practise within the UK. The requirements of the GMC may alter in the future so it is important that the medical practitioner is legally entitled to practise medicine within the UK;

2.1.9. **Report 10** refers to the current version of ITA/BTS CAWG Report 10 "Guidelines for good working practice in high pressure compressed air". A comprehensive glossary of terms is given in Report 10.

2.1.10. **tunnel airlock** means an airlock formed by two or more bulkheads in a tunnel lining.

2.1.11. **tunnelling** includes pipe-jacking and shaft or caisson sinking;

2.1.12. **transfer under pressure** (TUP) is the operation of transferring persons between two pressurised environments whilst keeping them under pressure. Normally it is done between the surface habitat and the personnel lock in a pressurised transfer shuttle.

2.1.13. **shuttle path** is as used in BS EN 16191 and means the route through the backup equipment on a TBM between the point of transfer of a pressurised transfer shuttle from its tunnel transport vehicle and the docking position with the personnel lock.

2.1.14. **low pressure** is pressure below the threshold for stage decompression i.e. <0.7 bar(g).

2.1.15. **intermediate pressure** is pressure above the threshold for stage decompression and below the statutory limit i.e. 0.7 to 3.5 bar(g).

2.1.16. **high pressure** is pressure above the statutory limit i.e. >3.5 bar(g) in the UK.

2.2. Apart from in clause 7.6 which deals with requirements for competent persons, the word "competent" is implied but not stated when referring to people with roles or duties under these Regulations.

Regulation 3 Application

(1) These Regulations shall apply to and in relation to work in compressed air which is construction work within the meaning of regulation 2(1) of the Construction (Design and Management) Regulations 2015[(a)] and which is carried out in the course of a project which is notifiable within the meaning of regulation 6(1) of those Regulations.

(2) These Regulations shall not apply to any diving project within the meaning of regulation 2(1) of the Diving at Work Regulations 1997.[(b)]

(a) SI 2007/320

(b) SI 1997/2776.

3. Guidance relevant to Regulation 3

3.1. Scope of the WCA Regulations – comparison with diving

3.1.1. These Regulations apply to all people employed in tunnelling, pipe-jacking and shaft and caisson sinking operations carried out in compressed air, including the use of tunnel boring or shaft excavating machinery and similar operations, all as part of construction work.

3.1.2. The Regulations apply to all employers whose employees work in compressed air. This applies regardless of employment status and will include professional staff who may be working for, or on behalf of, the client.

3.1.3. If there is any doubt whether it is the WCA Regulations or the Diving at Work Regulations (DWR) 1997 which apply to work in a pressurised chamber or environment, the test to be applied is that construction work is subject to the WCA Regulations if the primary purpose of the compressed air is to control the ingress of groundwater and/or to stabilise the ground, while the DWR apply if the primary purpose of the compressed air is to provide a breathing or pressurising medium in an underwater environment. Therefore, WCA Regulations will apply to work in compressed air within the head of a tunnelling machine; however, DWR will apply to work in an air-pressurised underwater habitat accessed using underwater breathing apparatus. The terms "dive", "diver" and "diving" should not normally be applied to compressed air work.

3.1.4. If terms for personnel are required, compressed air worker (CAW), mixed gas worker (MGW) and mixed gas saturation worker (MGSW) should be considered.

3.1.5. The Work in Compressed Air (Special) Regulations 1958 covered work in non-construction related pressurised applications such as gas holders and aircraft testing but were revoked in 1996.

3.1.6. Therapeutic hyperbaric oxygen treatment carried out other than in the "adequate facilities" required by regulation 12 is not covered by these Regulations.

Regulation 4 Duties

(1) Any duty imposed upon a compressed air contractor under these Regulations is a duty in relation to the work in compressed air in respect of which that compressed air contractor has been so appointed.

(2) Regulation 10 (other than sub-paragraphs (3)(c) and (6)(a)) and paragraphs (7)(a) and (8) of regulation 11 shall apply to a self-employed person as they apply to an employer and an employee as if that self-employed person was both an employer and his own employee.

4. Guidance relevant to Regulation 4

4.1. The compressed air contractor will be responsible for the management and supervision of the work in compressed air at any pressure.

Regulation 5 Appointment of compressed air contractor

(1) The principal contractor for any project shall appoint as the compressed air contractor in respect of the work in compressed air included in that project a contractor competent to execute or to supervise the execution of such work.

(2) Nothing in paragraph (1) shall prevent the appointment of the principal contractor himself as the compressed air contractor provided he is competent to perform the relevant functions imposed by these Regulations.

(3) In this regulation, "principal contractor" and "contractor" have the meaning assigned to them by regulation 2(1) of the Construction (Design and Management) Regulations 2015.

5. Guidance relevant to Regulation 5

5.1. Compressed air contractor - responsibilities

5.1.1. The compressed air contractor will be responsible for the management and supervision of the work in compressed air at any pressure and is appointed by the principal contractor. The compressed air contractor can be the principal contractor or a separate, specialist contractor but any contractor so appointed should be competent to discharge the duties under these Regulations.

5.1.2. Because of the key role of the compressed air contractor, all employers on a site whose employees work in compressed air should ascertain who has been appointed as the compressed air contractor.

Regulation 6 Notifications

(1) Subject to paragraph (2), the compressed air contractor shall ensure that no person works in compressed air unless the compressed air contractor has given notice of the work in compressed air to the Executive in accordance with paragraph (4) at least 14 days before the work is to commence.

(2) Where owing to an emergency or to circumstances which could not reasonably have been foreseen it is not practicable to comply with the requirement of paragraph (1) that notice of work in compressed air be given at least 14 days before that work is due to commence, such notice shall be given as soon as is practicable after the necessity for such work becomes known to the compressed air contractor and, in any event, before such work commences.

(3) The compressed air contractor shall ensure that no person works in compressed air unless notice of the work in compressed air has been given in accordance with paragraph (4) to -

(a) any relevant hospital;

(b) local ambulance and fire services; and

(c) any other establishment in the vicinity which has an operable medical lock.

(4) The notice referred to in paragraphs (1) to (3) shall be in writing and shall contain the information set out in Schedule 1 to these Regulations.

(5) Where notice of work in compressed air has been given by virtue of paragraph (3), the compressed air contractor shall ensure that every

body to whom such notice has been given is informed without delay of the completion or suspension of that work.

(6) In this regulation, "relevant hospital" means a hospital with an accident and emergency unit to which any person suffering from any acute condition arising from the work in compressed air is likely to be taken.

6. Guidance relevant to Regulation 6

6.1. Organisations to be notified

6.1.1. Where any work in compressed air is about to be carried out, the compressed air contractor must inform the following:

6.1.1.1. HSE at WICAR@hse.gov.uk

6.1.1.2. relevant hospital - this is one with an accident and emergency (A & E) unit (but not necessarily a hyperbaric facility). It is advisable to copy the notification to the consultant in charge of the A & E unit. The notification should also be copied to the consultant in charge of the hyperbaric unit if there is one at a local hospital;

6.1.1.3. local ambulance service;

6.1.1.4. local fire service - the notification to the local fire service should include information on any intended storage of oxygen or breathing mixtures on the site, on the use of gas cylinders underground and on the undertaking of saturation techniques including use of a surface habitat and transfer under pressure if relevant;

6.1.1.5. local establishments operating hyperbaric facilities. Details of emergency hyperbaric facilities and an emergency helpline are maintained by the British Hyperbaric Association (https://www.ukhyperbaric.com/) .

6.1.2. Where saturation techniques are being undertaken, the notification to hospitals and local hyperbaric facilities should specifically highlight this.

6.1.3. The compressed air contractor may also wish to inform the local police and, if mains power is being used, the regional electricity supply company.

6.1.4. Where the escape of air from the workings can be seen as bubbles on the ground surface and be mistaken by the public for a domestic gas leak, the compressed air contractor may wish to advise the local gas distribution network operator that work in compressed air is taking place.

6.2. Hospitals

6.2.1. Interpretation of the term 'relevant hospital' will need to take account in rural areas of the nearest large town and in urban areas of the possibility that there could be several hospitals to which casualties can be taken.

6.2.2. Hospitals near to the site with A & E departments need to be notified because workers who develop symptoms of decompression illness away from the site may be referred or taken to an A & E department. It is important that hospital staff are aware that work in compressed air is being undertaken locally so that decompression illness can be considered if a worker from the site reports they are unwell. Notified hospitals should be made aware that compressed air workers must carry a card or badge advising ambulance and A & E staff to consider serious decompression illness if the worker is found unconscious or is otherwise unable to give a history of their illness. If decompression illness is diagnosed, arrangements should be made for transfer of the worker to a designated medical lock (usually located at the site) for recompression therapy, which is the initial treatment for all decompression illness.

6.2.3. The contract medical adviser may need to consider whether it is necessary also to advise hospitals with A & E departments in the areas where compressed air workers live or to which they regularly travel at weekends.

6.3. Intermittent working

6.3.1. Where work in compressed air is being undertaken intermittently, the compressed air contractor should ensure that those notified under regulation 6 are aware of this and that they are kept informed as necessary of when work in compressed air is taking place.

6.4. **Suspension and completion of work**

6.4.1. Although "suspension of the work" is not defined in the regulations, HSE has indicated in the past that it would be considered to be a suspension lasting 28 days or more. Notification of completion of the work in compressed air is also required to be given to those initially notified of the work.

Regulation 7 Safe system of work

(1) The compressed air contractor shall ensure that no person works in compressed air or enters or leaves compressed air except in accordance with a system of work which, so far as is reasonably practicable, is safe and without risks to health.

(2) The compressed air contractor shall ensure that a sufficient number of competent persons are present on site to supervise the execution of work in compressed air at all times when such work is being carried out and, in the case of such work undertaken at a pressure of 0.7 bar or above, for 24 hours thereafter.

7. **Guidance relevant to Regulation 7**

7.1. **Safe system of work**

7.1.1. To develop a safe system for work in compressed air, the compressed air contractor will need to carry out an assessment of all risks associated with the work in compressed air

and draw up a management plan setting out how the risks which cannot be eliminated are to be managed including procedures for responding to emergencies. The plan should include compression and decompression procedures along with roles and responsibilities for statutory appointees and others set out in clause 7.6 below as well as those in managerial and supervisory positions. This should be done in conjunction with and taking the advice of the contract medical adviser and hyperbaric supervisor, having taken advice from other professional advisers as appropriate. The plan should be reviewed periodically and added to as necessary. It should form part of the construction phase plan developed by the principal contractor under regulation 12 of the 2015 Regulations. All employers on site need to liaise closely with the principal contractor/compressed air contractor to ensure risks on site are assessed and, where appropriate, controlled and relevant information incorporated in the construction phase plan. Sub-contractors bringing potential risk to the work need to inform the principal contractor/compressed air contractor.

7.1.2. When working in compressed air, the working chamber can either be the space around and behind the cutter head of a tunnel boring machine, access to which is through airlocks on the tunnel boring machine; a length of tunnel pressurised through the installation of bulkheads in the tunnel with airlocks in the bulkheads or a shaft or caisson pressurised through the provision of an air deck in the structure with airlocks connected to the airdeck. The compressed air contractor will need to assess the particular risks inherent in such work and ensure that all necessary steps are taken to prevent collapse of the tunnel face, loss of stability of the shaft/caisson invert or sudden loss of pressure in the working chamber and airlocks for any other reason. The guidance in the current version of BS 6164 clause 11 and BS EN 16191 should be followed.

7.1.3. The safe system of work should take account of the condition of the ground around the pressurised structure and the interaction between the ground and the structure bearing in mind the cyclic nature of the loadings on both, due to the work in compressed air. In particular, the compressed air contractor should ensure that the ground around the air locks and working chamber is fully capable of resisting the loads imposed on it from the application or removal of compressed air.

7.1.4. Flooding the face periodically with bentonite to form a protective cake can be undertaken to reduce air loss in permeable ground. As rotation of the cutterhead to facilitate maintenance work can remove the protective cake, careful planning of maintenance work should be undertaken to minimise the need for cutterhead rotation.

7.1.5. As personnel have to be withdrawn from the working chamber to the intermediate chamber or personnel lock during re-caking operations, the effects of changing the gas breathed and/or the composition of the atmosphere in which personnel are immersed should be considered when planning saturation exposures.

7.1.6. The compressed air contractor should set out in advance, criteria for determining when re-caking is required. Safety-critical criteria for this decision include the actual air loss and the capacity of the air supply system to compensate for it.

7.1.7. No person should work alone in the working chamber because of the danger of illness or accident in the isolated compressed air environment.

7.1.8. The safe system of work should take account of the need to avoid excessive physical exercise in the initial hours after decompression. The compressed air contractor should, where appropriate, provide transport such as manriding facilities or mechanical hoists to enable people to return to the surface after decompression with the minimum of effort.

7.1.9. The safe system of work should take account of the storage and use of oxygen or breathing mixtures as appropriate. Industry guidance is given in Report 10, BS EN 12110 and BS EN 16191.

7.2. Failure of power or air supply

7.2.1. As part of the safe system of work, in the event of failure of the main power supply or a duty compressor, work in the working chamber should be suspended, any exposed ground made safe and a controlled evacuation to the personnel lock undertaken. Decompression or transfer under pressure to the habitat should then be carried out.

7.3. **Compression and Decompression procedures**

7.3.1. The procedures for compression or decompression include generic procedures to be followed during all compressions or decompressions; along with specific procedures in the form of decompression tables. These set out the decompression profile following a given duration of exposure to a particular pressure. Additionally, decompression can include site-specific arrangements instituted by the compressed air contractor.

7.3.2. HSE no longer has approved procedures under regulation 11(1), which contractors are required to use. Compressed air contractors should select appropriate procedures for decompression to ensure they provide a safe system of work for those who are entering and working in compressed air under their control.

7.3.3. Annex 2 sets out decompression procedures which were published in earlier versions of this guidance. Compressed air contractors can still use these procedures should they consider the procedures provide a safe system of work for the exposures being undertaken. The procedures in Annex 2 are not the only ones which can be used and are applicable only for low or intermediate pressure exposures.

7.4. Procedures for compression

7.4.1. When selecting suitable compression procedures, the rates of compression should be selected to avoid discomfort. The procedures should also set out how to deal with any cases of discomfort experienced. The following guidance has been shown by experience to be appropriate :-

7.4.1.1. increase the pressure in the personnel lock gradually to not more than 0.3 bar(g) in the first minute after starting compression;

7.4.1.2. maintain the pressure of 0.3 bar(g) until the lock attendant has checked that no person in the lock complains of discomfort;

7.4.1.3. thereafter, increase the pressure at a uniform rate not faster than 0.6 bar per minute and such that no one suffers discomfort.

7.4.1.4. If a person complains of discomfort at any time during compression, the compression should be stopped immediately. If the discomfort does not quickly cease, the pressure should be gradually decreased. If the discomfort does not cease during decompression, the person concerned should be released from the lock when atmospheric pressure is reached and referred to the contract medical adviser.

7.4.1.5. If a person appears to be suffering from deafness or vertigo during compression, the person concerned should be carefully decompressed as soon as possible, released from the personnel lock and referred to the contract medical adviser.

7.4.2. The contract medical adviser should ensure there is an abort procedure which can be initiated in the event that someone is taken ill during a compression for saturation

7.5. **Procedures for decompression**

7.5.1. The following recommendations should be taken into account when selecting decompression procedures.

7.5.1.1. Decompression following work in compressed air at low pressure should be a return to atmospheric pressure at a rate not exceeding 0.3 bar/min.

7.5.1.2. Decompression following work in compressed air at intermediate pressures should be a stage decompression, including the breathing of pure oxygen for part of the decompression.

7.5.1.3. Air breaks of 5 minutes duration at regular intervals of 20 – 30 minutes should be part of the decompression profile during oxygen beathing.

7.5.1.4. For intermediate pressure exposures the maximum oxygen dose resulting from decompression should not exceed 400 OTU per day for 5 consecutive days to be followed by a break of 2 days at atmospheric pressure. Otherwise, the daily limit should be reduced to 300 OTU.

7.5.1.5. Overall a limit of 1800 OTU in any period of 7 days should apply.

7.5.1.6. No more than 7 consecutive days should be worked at intermediate pressure to be followed by a break of at least 2 days at atmospheric pressure.

7.5.1.7. Recommendations for decompression following high pressure exposures are set out in Report 10.

7.5.2. Criteria for determining the effectiveness of decompression procedures are set out in clause 11.8.

7.5.3. Information on the effectiveness of Blackpool tables + oxygen is contained in HSE Report "Trials of a Blackpool table decompression with oxygen as the breathing gas" Contract Research Report 369/2001. Information on the theoretical effectiveness of a selection of decompression tables is contained in HSE Research Report 126 "A comparison of oxygen decompression tables for use in compressed air work". If it is intended to use decompression tables or other compression or decompression procedures which are different from those in appendix 8 then the compressed air contractor should be able to demonstrate they meet the effectiveness criteria in clause 11.8. If the compressed air contractor wishes to use the procedures detailed in Annex 2 below, it is for them to satisfy themselves that this is a safe system of work for the circumstances of their planned works. Information on compression and decompression relating to high pressure exposures is set out in Report 10.

7.6. Competent persons

7.6.1. All people underground should be competent for the environment in which they are working and for the work tasks and activities they are required to carry out. Supervisory staff should be competent with both the work being undertaken and in the techniques of management, communications and supervision. The compressed air contractor's delegation of duties to competent persons does not detract from the compressed air contractor's responsibilities under these Regulations.

7.6.2. There are specific roles which must be fulfilled by people with specific competencies to ensure that work in compressed air can be undertaken safely. These roles have developed over time and reflect the application of good hyperbaric practice to the modern tunnelling environment. Whenever people are working in compressed air there should be a sufficient number of competent persons available to fulfil the roles below appropriate to the pressures and/or exposure techniques being used.

7.6.3. **Competent persons for all pressures**

7.6.3.1. person in charge (with deputies to cover for shift working) – responsible for the management of all aspects of the work in compressed air;

7.6.3.2. hyperbaric plant supervisor – responsible to the person in charge for the installation and operation of the plant and equipment necessary for work in compressed air;

7.6.3.3. compressor attendant – responsible to the hyperbaric plant supervisor for the day-to-day operation and maintenance of compressed air equipment on the surface as well as for oxygen supply equipment for non-mixed gas exposures;

7.6.3.4. underground plant attendant – responsible to the hyperbaric plant supervisor for the day-to-day operation and maintenance of compressed air supply equipment

underground as well as for oxygen supply equipment for decompression. The underground plant attendant should also be competent to assist with mixed gas supply equipment for non-saturation exposures;

7.6.3.5. lock attendant - responsible to the hyperbaric supervisor or person in the MGSW deployment role (Report 10 cl 4.7.1.2) for the safe operation of an airlock. Two attendants are required to be on duty when breathing mixtures are in use.

7.6.3.6. hyperbaric supervisor – responsible to the person in charge for the day-to-day organisation of the compressed air activity for all non-saturation exposures;

7.6.4.**Competent persons for all work in compressed air at pressures of 1.0 bar(g) or over:**

7.6.4.1. medical lock attendant – responsible to the contract medical adviser for the safe operation of the medical lock;

7.6.4.2. medical lock tender – responsible to the contract medical adviser and medical lock attendant for assisting with patient care.

7.6.5.**Competent persons for saturation exposures**

7.6.5.1. Guidance on the personnel considered necessary to undertake such work are set out in Report 10 clause 4.7.

7.6.6.**Other recommendations relating to competent persons**

7.6.6.1. People may undertake more than one role provided they have the necessary competence and time to do so without jeopardising the health and safety of those working in compressed air. The person in charge may allow an individual to perform other tasks on site, provided that the person in charge has taken advice from the contract medical adviser and is satisfied the individual is sufficiently competent and readily available to discharge all of their roles under these Regulations.

7.6.6.2. Where work in compressed air is being undertaken on a continuous basis over a period of weeks, a number of teams of competent persons, routinely working shifts, will be required to meet the recommendations of clause 7.6.

7.6.6.3. Where the tunnelling techniques used require only intermittent work in compressed air, the competent persons required by this regulation may be brought to site for the duration of that work only.

7.6.6.4. One or more lock attendants are required to be present whenever any person is in a lock or in the working chamber to which the lock affords direct or indirect access.

7.6.6.5. A lock attendant may be in charge of more than one airlock if only one is for the passage of personnel, breathing mixtures are not in use and the lock attendant can observe all the locks simultaneously.

7.6.6.6. A compressor attendant is required to be available on site for a period of 24 hours after the last person has been decompressed, and for decompression from 1.0 bar(g) or over, a medical lock attendant is also required.

7.6.6.7. Current industry practice is not to differentiate between medical lock attendant and lock attendant by having a pool of attendants able to undertake either role. In these circumstances the hyperbaric supervisor should allocate their duties according to their competence and the needs of the undertaking.

7.6.6.8. For night shift and weekend cover when no work is taking place but the working chamber remains pressurised, a compressor attendant needs to be available on site, unless a control system with an appropriate safety performance level assessed in accordance with BS EN ISO 13849:2006 is in place and suitable arrangements exist for bringing a compressor attendant to site within a time determined by the person in charge in conjunction with the hyperbaric plant supervisor, taking account of ground conditions and risk associated with change of working chamber pressure.

7.6.7. **Other recommendations relating to competent persons for saturation**

7.6.7.1. The person in charge through the persons fulfilling the roles in Report 10 clauses 4.7.1.1 and 4.7.1.2 along with the hyperbaric plant supervisor should ensure sufficient competent persons are available on site so that when work in compressed air is being undertaken, it can be undertaken safely.

7.6.7.2. At all times when a habitat is occupied, there should be at least two life support personnel on duty at the habitat. Other personnel are likely to be required to be available to manage gas supplies etc.

7.7. Person in charge

7.7.1. The compressed air contractor should nominate the person in charge, (and deputies to allow for shift work), to be his representative routinely on site and in overall charge of the work in compressed air. The person in charge (and deputies) will need an engineering background, be senior members of the compressed air contractor's site management and have sufficient authority and competence to act on behalf of the compressed air contractor to be able to discharge their duties. Also, they should have had previous experience of work in compressed air, or otherwise be advised by people who have had relevant experience. HPCA work and in particular the use of saturation techniques requires additional management roles to be filled and a more extensive and sophisticated management structure to be established.

7.7.2. The person in charge should be responsible for overall management of the work in compressed air including:

7.7.2.1. organisation of the work in compressed air;

7.7.2.2. development and implementation of the management plan;

7.7.2.3. development and implementation of the relevant parts of the health and safety plan;

7.7.2.4. emergency procedures including planning and implementation;

7.7.2.5. liaison with emergency services during an emergency;

7.7.2.6. procedures to implement the prohibition of smoking materials, alcoholic drinks and drugs;

7.7.2.7. arranging for the maintenance of health and exposure records;

7.7.2.8. delegation of duties to the hyperbaric supervisor, hyperbaric plant supervisor and the persons responsible for the roles in Report 10 clauses 4.7.1.1 and 4.7.1.2. including delegation onwards to those reporting to them.

7.7.2.9. ensuring the provision of information, instruction and training;

7.7.2.10. designation of people to be responsible for determining the pressure of air in the working chambers; and

7.7.2.11. liaison with contract medical adviser and those reporting to the CMA.

7.7.3. Where responsibilities have been delegated to the hyperbaric supervisor, hyperbaric plant supervisor or the persons undertaking the roles in Report 10 clause 4.7 and to those reporting to them such as the compressor attendant, lock or medical lock attendants, the person in charge will need to make those working in compressed air aware of the authority delegated to those people. In particular, the person in charge should make clear the names of those who have authority to determine or vary the working pressure and the extent to which they can vary the pressure.

7.7.4. Additionally, the person in charge should ensure the capability of the overburden to restrain the applied air pressure has been confirmed before authorising any increase in working pressure.

7.8. Hyperbaric supervisor

7.8.1. The role of the hyperbaric supervisor is to be routinely on site when work in compressed air involving non-saturation exposures is being undertaken and be responsible to the compressed air contractor for ensuring the effective implementation of the safe system of work. The hyperbaric supervisor should have had previous experience of hyperbaric operations in a tunnelling environment and be competent to manage the day to day running of the hyperbaric operations being undertaken. For low and intermediate pressure exposures not involving the use of breathing mixtures the hyperbaric supervisor may also undertake the role of medical lock attendant. At pressures of less than 1.0 bar(g),

where a medical lock attendant is not required, the hyperbaric supervisor may undertake the role of lock attendant.

7.8.2. Deputies for the hyperbaric supervisor to cover shift working are not required provided the hyperbaric supervisor has made appropriate arrangements for the work to be undertaken safely.

7.8.3. The hyperbaric supervisor should:

7.8.3.1. liaise with the person in charge, the contract medical adviser and hyperbaric plant supervisor to ensure the correct implementation of the safe system of work;

7.8.3.2. ensure that there are sufficient resources and a sufficient pool of competent persons on site to undertake the hyperbaric procedures in accordance with the safe system of work;

7.8.3.3. supervise the day-to-day operation of all hyperbaric procedures on site including the storage and supply of gas;

7.8.3.4. ensure that all the emergency procedures are reviewed as necessary and are tested periodically as agreed with the person in charge;

7.8.3.5. ensure that adequate records of exposure are kept as required by these Regulations.

7.8.3.6. For high pressure non-saturation exposures, the responsibilities of the hyperbaric supervisor remain as above.

7.8.4. For saturation exposures it is suggested the hyperbaric supervisor undertakes the MGSW Deployment role as set out in clause 4.7.1.2. of Report 10. It is also suggested the hyperbaric supervisor is considered senior to the person discharging the Surface operations role in clause 4.7.1.1.

7.9. Hyperbaric plant supervisor

7.9.1. The role of the hyperbaric plant supervisor is to be responsible to the compressed air contractor for ensuring the effective implementation of the safe system of work so far as it depends on plant and equipment, along with ensuring the availability of sufficient competent persons to attend to that plant and equipment.

7.9.2. Deputies for the hyperbaric plant supervisor to cover shift working are not required.

7.9.3. The hyperbaric plant supervisor should:

7.9.3.1. normally be a senior mechanical engineer or plant supervisor on the staff of the compressed air contractor or of a specialist subcontractor available to come to site as necessary particularly during plant/equipment set up, testing or major alteration;

7.9.3.2. have extensive knowledge and experience of the plant or equipment required for hyperbaric operations;

7.9.3.3. have knowledge of the operation of tunnelling equipment which could adversely affect the safety of work in compressed air;

7.9.3.4. be familiar with the hyperbaric system on site;

7.9.3.5. work closely with specialist suppliers of hyperbaric plant and equipment to ascertain the requirements for safe operation and maintenance of that equipment;

7.9.3.6. ensure there are enough competent persons available to undertake the role of compressor attendant for compressed air plant on the surface and underground plant attendant where the compressed air plant is underground;

7.9.3.7. determine the operational and maintenance requirements and the related records to be kept;

7.9.3.8. liaise with the hyperbaric supervisor.

7.9.4. When saturation exposures are being undertaken, the hyperbaric plant supervisor should have knowledge and experience of the plant or equipment required for such operations.

7.10. Compressor attendant and underground plant attendant

7.10.1. Compressor attendants need to be competent to operate and routinely maintain the electrical equipment and mechanical plant in their charge. They are required to be immediately available on site, except where the compressed air plant is covered by a control system meeting the requirements of clause 8.5.11. In this case, the person in charge in liaison with the hyperbaric plant supervisor should determine the extent to which a dedicated compressor attendant is required or whether a competent member of the compressed air contractor's maintenance staff is sufficiently readily available to undertake the relevant duties. The compressor attendant or substitute should have access to professional electrical and mechanical engineering advice and supervision.

7.10.2. The compressor attendant's duties include:

7.10.2.1. daily inspection of the compressed air plant on the surface;

7.10.2.2. operation and routine maintenance of the compressed air plant within their charge and maintenance of appropriate records;

7.10.2.3. varying the working pressure in response to instructions from the person in charge or other people designated by him;

7.10.2.4. notifying the hyperbaric supervisor of any change in pressure;

7.10.2.5. maintaining records of air pressure and quality of air being supplied to the compressed air workings;

7.10.2.6. responding to high/low pressure alarms; and “loss of main power” and “duty compressor failed” alarms;

7.10.2.7. being able to pressurise and depressurise the medical lock under instruction from the medical lock attendant in an emergency.

7.10.3. Where oxygen is supplied from the surface, the compressor attendant should be available to assist the lock attendant by operating or monitoring, under his supervision, the above ground parts of the gas supply. Where mixed gas is being used, a separate person should be specifically employed to manage gas supplies.

7.10.4. Where any part of the compressed air, oxygen or mixed gas supply when undertaking non-saturation exposures, requires operation or maintenance underground (see clauses 8.5.27.3 and 8.5.35) it is current practice to have an underground plant attendant in these circumstances.

7.10.5. The role of an underground plant attendant should be considered identical to that of a compressor attendant but in respect of mechanical and electrical plant located underground.

7.11. Lock attendant

7.11.1. Lock attendants need to be competent to operate the locks in their charge. They should be competent to undertake oxygen decompression procedures and to operate breathing mixture procedures as appropriate. In addition, they should be competent to operate (pressurise and depressurise) the medical lock and its oxygen breathing system under instruction in an emergency.

7.11.2. For low and intermediate pressure work, the lock attendants should be qualified to at least the level of International Marine Contractors Association (IMCA) life support technician, Australian Diver Accreditation Scheme lock operator, air diver supervisor or have experience of operating a hyperbaric chamber in a medical facility. They should be medically fit and willing to go into compressed air and should operate under the supervision of the hyperbaric supervisor. Lock attendants should have had experience of the use of hyperbaric oxygen procedures and the use of breathing mixtures as appropriate.

7.11.3. For mixed gas exposures, lock attendants should hold an IMCA certificate as a life support technician or offshore diving supervisor.

7.11.4. All lock attendants should have had experience of working in a tunnelling environment or undergo appropriate familiarisation training.

7.11.5. Lock attendants should carry out or directly supervise all operations in the tunnel involving the use of oxygen or breathing mixtures including the connecting up of cylinders, the opening and shutting of cylinder valves on line to the personnel lock, the control of

oxygen to the personnel lock, the control of the use of oxygen in the personnel lock, the supply of breathing mixtures to the working chamber and the discharge of exhaled gas.

7.11.6. Lock attendants should be competent to vary the air or gas supply pressure as required by the procedures for compression and decompression and to maintain records of air or gas pressure along with the quality of and quantity of air or the composition and quantity of gas being supplied to the tunnel.

7.11.7. Lock attendants should ensure that:

7.11.7.1. no compression or decompression of any person is carried out except in accordance with the procedures selected by the compressed air contractor;

7.11.7.2. only people certified fit for work in compressed air are compressed. Fitness may be indicated by presence on a list of authorised people or by presentation of a duly completed compressed air worker's health and exposure record;

7.11.7.3. no person is compressed who is suspected of being under the influence of alcohol or drugs. Such a person should be referred to the compressed air contractor person in charge and the contract medical adviser;

7.11.7.4. no person is compressed who is suspected of suffering decompression illness or is obviously unfit due to colds or influenza. Such a person will need to be referred to an appointed doctor;

7.11.7.5. decompressions are carried out accurately in accordance with the relevant table and line of the decompression tables being used, and accurate records are maintained of all compressions and decompressions of people;

7.11.7.6. personnel lock decompression records are kept safe until passed to the person in charge. For all decompression cycles recorded, the record should be clearly annotated with the date, shift/time, and names of people being decompressed;

7.11.7.7. all clocks, gauges, valves, doors and door seals are in good working order, and any defects reported to the person in charge;

7.11.7.8. so far as is reasonably practicable, no alcohol, drugs or materials for smoking are taken into the compressed air workings; and

7.11.7.9. any personnel lock under their control is kept adequately cleaned for oxygen decompression purposes.

7.11.8. Lock attendants should be able to participate in providing the information, instruction and training given to people working in compressed air, and in addition be trained in the problems associated with compression and decompression, decompression illness and with the keeping of records.

7.11.9. It is good practice to ensure that at least one of the compressed air contractor's fitters or front line supervisors on site is competent to provide short term or emergency cover for the lock attendants, for example, should one of them be required to assist with the medical lock.

7.11.10. References to "life support technician" and "life support supervisor" in guidance relevant to Regulations 11 and 12 apply to high pressure compressed air work.

7.12. Medical lock attendant

7.12.1. Medical lock attendants should be qualified to the level of IMCA life support technician, Australian Diver Accreditation Scheme lock operator, or diver supervisor and hold the IMCA diver medic technician qualification or hold equivalent qualifications acceptable to the contract medical adviser. Additionally, they should have had experience of working in a tunnelling environment or undergo appropriate familiarisation training. They should work under the medical oversight of the contract medical adviser and be medically fit and willing to go into compressed air. They should be competent to operate the medical locks available on site and to undertake therapeutic decompression treatments using oxygen. They should be competent to implement the hyperbaric emergency procedures.

7.12.2. Medical lock attendants' duties can require them to:

7.12.2.1. make an adequate assessment of a person complaining of symptoms suggesting acute decompression illness;

7.12.2.2. question workers about symptoms in the neurological system;

7.12.2.3. examine a patient to monitor vital functions;

7.12.2.4. give first aid;

7.12.2.5. understand the need to assess regularly the progress of individuals under treatment;

7.12.2.6. have immediate access to all records of pressures and other relevant information regarding conditions in the working chambers and personnel locks;

7.12.2.7. be available to assist the appointed doctor with routine medical assessments and accompany new starters in the airlock during lock tests; and

7.12.2.8. operate the medical locks.

7.13. Medical lock tender

7.13.1. A person undergoing treatment should be accompanied in the recompression chamber by a tender. Medical lock tenders should hold an IMCA diver medic technician qualification or equivalent acceptable to the contract medical adviser and be medically fit and willing to go into compressed air. They should be able to ensure that information on the clinical

condition of a worker under treatment can be relayed accurately to the contract medical adviser, and that action is taken on the basis of the advice received back.

7.13.2. Medical lock tender is not intended to be a role for which a person is employed exclusively whenever work in compressed air is being undertaken but one which is undertaken when necessary, by a person otherwise employed on site. For example, a suitably competent lock attendant could be called upon as necessary to undertake this role.

7.13.3. A medical lock attendant would normally be able to undertake this role.

7.13.4. It is also expected that a medical lock tender could enter the working chamber to assist with first aid treatment or with the extrication of a casualty as necessary.

Regulation 8 Plant and equipment.

(1) The compressed air contractor shall ensure that there is available for immediate use all plant and ancillary equipment which is necessary for the conduct of work in compressed air in a manner which is, so far as is reasonably practicable, safe and without risks to health and that, where necessary, all such plant and equipment is used.

(2) The compressed air contractor shall ensure, so far as is reasonably practicable -

(a) that all plant and ancillary equipment used for the purpose of carrying out work in compressed air is of appropriate design and construction and of sufficient capacity for that purpose;

(b) that all plant and ancillary equipment used for the purpose of carrying out work in compressed air is safe and without risks to health and is maintained in such a condition as to ensure that it remains safe and without risks to health at all times when it is being used; and

(c) that all plant and ancillary equipment used for the purpose of carrying out work in compressed air and which is to contain air at a pressure in excess of 0.15 bar is -

(i) examined and tested by a competent person and rectified of any faults before work in compressed air commences; and

(ii) re-examined and re-tested after any modification or alteration which has the potential to affect the safety of that plant or equipment.

8. **Guidance relevant to Regulation 8**

8.1. **Plant and equipment - general**

8.1.1. Since the coming into force of the Work in Compressed Air Regulations in 1996, the nature of compressed air work has changed. Into the 1990s it was common for whole lengths of

tunnel to be pressurised behind air locks attached to or formed by bulkheads built into the tunnel (or shaft) lining. Compressed air plant was normally situated on the surface and excavation was carried out by hand or using TBMs operating wholly within the pressurised workings. Where such techniques are still being used, reference can still be made to the 2012 version of this Guide.

8.1.2. Although the guidance in this document is mainly aimed at TBM locks it is applicable to boiler locks on bulkheads in tunnels which can be used at any pressure. Traditional locks formed by the tunnel lining between sets of bulkheads remain acceptable for low and intermediate pressure work but should not be considered acceptable for high pressure compressed air work.

8.2. **Revision of EN 12110:2014**

8.2.1. Technical safety requirements for airlocks on TBMs are set out in EN 12110. EN 12110:2014 is currently being revised into two parts – EN 12110-1 sets out requirements for airlocks utilising compressed air as the pressurising and breathing medium along with requirements for oxygen breathing systems for decompression purposes whilst EN 12110-2 sets out the additional requirements for the use of non-air breathing mixtures and saturation techniques in personnel locks. EN 12110-2 also sets out requirements for pressurized transfer shuttles.

8.2.2. Reference in this guidance to BS EN 12110 implies reference to BS EN 12110:2014 along with the relevant interim technical guidance until the revised standard has been published as prEN documents which then should be considered the reference standard. On harmonisation, the British designated version of the harmonised revised EN, i.e. BS EN 12110 will become the reference standard.

8.3. **General plant and equipment matters applicable to all compressed air work.**

8.3.1. Compressed air contractors have duties under this regulation relating to the provision of the plant and ancillary equipment ("plant" in the guidance below) required to carry out the work in compressed air in a safe manner irrespective of pressure. The hyperbaric plant supervisor should assist the compressed air contractor to discharge these duties.

8.3.2. The plant supplied needs to be of a type intended for use in the harsh environment of a construction site and underground workings as well as being capable of operating reliably at its rated output for long periods of time. Plant should be operated in accordance with the manufacturer's instructions.

8.3.3. The plant required to be supplied by the compressed air contractor includes means of supply of electrical energy, air compressors and ancillary equipment (including filters and coolers as appropriate), air receivers, airlocks, bulkheads, control equipment and pipework.

8.3.4. With the exception of the supply of electrical energy, these items make up the 'pressure equipment' for work in compressed air.

8.3.5. For high pressure compressed air work, mixed gas capability along with possibly transfer under pressure facilities and surface habitat will also be required. The mixed gas capability includes the provision of gas in cylinders both on the surface and in the tunnel, cylinder storage facilities on the surface, gas distribution and control equipment, helium reclaim and gas mixing equipment. Guidance on the technical aspects of the gas supply is set out in Report 10 and the reference documents referred to in Report 10.

8.3.6. Where saturation techniques are being undertaken, the statutory requirements covering plant and equipment extend to include the provision of a surface habitat including emergency standby chamber, ancillary equipment essential to support the habitat through heating, cooling and gas supply as well as the structures to accommodate this equipment. Guidance on the plant and equipment for saturation techniques is set out in this guide, in Report 10 and in the reference documents referred to in Report 10.

8.3.7. BS EN 16191 is also being revised. That revision will include requirements for the supply of oxygen and mixed gas from the TBM to the personnel locks, the transfer of the pressurised transfer shuttle through the TBM along with the lifting of the shuttle into a docking position with a personnel lock and the provision of an intermediate chamber between the personnel lock and the working chamber.

8.3.8. Reference in this guidance to BS EN 16191 implies reference to BS EN 16191:2014 along with the relevant interim technical guidance until the revised standard has been published as a prEN document which then should be considered the reference standard. On harmonisation, the British designated version of the harmonised revised EN, i.e. BS EN 16191 will become the reference standard.

8.3.9. The compressed air contractor is required to ensure that the plant and ancillary equipment fully satisfies the requirements of the Provision and Use of Work Equipment Regulations 1998 as amended and the Lifting Operations and Lifting Equipment Regulations 1998 (LOLER Regulations).

8.3.10. In some situations, the requirements of the Pressure Systems Safety Regulations 2000 will apply to the compressed air plant and guidance on this is given in Annex 1.

8.3.11. The design, fabrication and pressure integrity testing of any pressure vessel for human occupancy (PVHO) intended for use in connection with work in compressed air should be undertaken in accordance with BS EN 13445 parts 1 - 5. Further testing including functional testing of airlocks, bulkheads, airdecks and other pressure equipment including shuttles should be undertaken in accordance with the requirements of BS EN 12110 and this Guide.

8.3.12. After installation and again after any significant repair or modification, but before work in compressed air is carried out or starts again, the whole pressure system is required to be examined and tested by a competent person and any faults rectified before work begins. As part of the examination the competent person needs to ensure that the installation has been built or modified in accordance with the design. The installation of

bulkheads forming tunnel airlocks must be checked in accordance with the design (see 8.12.5) and a Permit to Load issued in accordance with the contractor's Temporary Works procedures (see BS 6164:2019 cl 6.4). Persons responsible for the design, construction, installation, maintenance, examination or testing of such plant and equipment will need to consider the guidance contained in the Approved Code of Practice for the Pressure Systems Safety Regulations 2000 (Safety of pressure systems HSE Books 2000 ISBN 978 0 7176 1767 8).

8.3.13. Where work in compressed air is being undertaken intermittently, it is good practice to undertake a functional test of the pressure system before being put back into use after any significant period of inactivity.

8.3.14. As part of the commissioning process, the pressure equipment needs to be functionally tested. Where design permits this should be to a maximum of 105% but no less than 100% of the maximum working pressure. Functional testing should be for a period of not less than 30 minutes before work in compressed air commences. At no time should the working pressure exceed the maximum working pressure for which the pressure equipment has been tested. This may result in the pressure equipment having to be periodically re-tested to progressively higher pressures as work proceeds (where, for example, kentledge is added incrementally to an airdeck). On projects where compressed air is used intermittently but the compressed air plant is continuously available for use, testing of the whole pressure system is only required on installation and after significant repair or alteration, unless the maximum working pressure is to be increased.

8.3.15. The ability of airlock structures, bulkheads, airdecks, shaft linings, tunnel linings, jacking pipes and in particular the ground surrounding them, to resist all loads imposed by ground loading (see BS 6164:2019 clauses 11.2 and 11.3) along with air or gas pressure up to the maximum working pressure envisaged, should be confirmed by the compressed air contractor as part of the safe system of work (see 8.12.5). Load reversal may occur when air or gas pressure is reduced or removed. This is particularly important when periodic retesting as described in clause 8.3.14 is being undertaken.

8.3.16. All plant located above ground should be so located or protected as not to be at risk from vehicle impact and falling objects. Above ground plant should be protected by weatherproof structures against adverse weather conditions and risks such as flooding or inundation. Structures protecting life safety critical plant should have fire suppression systems.

8.3.17. Plant should be regularly maintained. In the case of non-saturation exposures, maintenance can be undertaken by or under the supervision of a compressor attendant. Plant for saturation and mixed gas exposures should be maintained by persons experienced in such work.

8.4. Power supply – all pressures

8.4.1. The main supply of electrical energy to the air supply plant should normally be from the public electricity supply but may be from independent generating plant. In both cases there needs to be a standby power supply available. The capacity of the standby power supply needs to be sufficient to power all the duty compressors and their ancillary equipment. Duty and standby power systems should be engineered to ensure adequacy of supply to maintain essential services at all times. Experience has shown that the standby power supply should be available for use within not more than five minutes of a failure of the main power supply. This includes the situation in which the compressors are located in the tunnel.

8.4.2. Where power for compressors is supplied from the TBM, the requirements in clause 8.4.1 for a standby power supply still apply.

8.4.3. For installations associated with saturation exposures, the life-safety critical nature of such installations should be made known to the local energy distribution network manager .

8.4.4. In the event of failure of the main power supply, a *loss of main power* alarm should be initiated both locally at the site of the compressors, in the TBM control cabin where TBM locks are being used, and in the site offices.

8.5. **Air supply** - **all pressures**

8.5.1. The compressed air contractor should ensure there is always a reliable supply of compressed air available which is sufficient in both quantity and quality for respiration and for compression purposes. Contractors with limited experience of this matter should consider seeking specialist advice.

Note: in the absence of accurate data, an indicative figure for initial estimation of air loss through a granular or mixed ground face can be taken as 1m^3/minute/m^2 of excavated diameter.

8.5.2. The long term practice of having a surface compressor station with twin supply lines to the airlocks (cl 8.7) has been shown over time to work satisfactorily without incident. Currently it should be considered the default option.

8.5.3. There are various risk factors which the compressed air contractor should consider in determining the air supply provisions.

8.5.3.1. These include factors which arise because of the temporary nature and installation requirements for the air supply pipework. These normally consist of numerous discrete lengths of shouldered pipe flexibly jointed using a bolted clamp consisting of two semi-circular sections within which a rubber sealing gasket is set. The reliability of this method should be carefully assessed.

8.5.3.2. Long lengths and higher internal pressures could necessitate lateral restraint as well as vertical support along with allowance for thermal effects.

8.5.3.3. The potential energy stored within compressed air pipelines as well as the storage they provide,

8.5.3.4. The effect of fire, heat or impact on the twin supply lines,

8.5.3.5. The effect of fire or heat on the tunnel ventilation ducting including any release of hazardous substances into the ducting and its air supply or even total severance of the duct,

8.5.3.6. The risk of an atmospheric contamination incident in the tunnel,

8.5.4. Ensuring the integrity and robustness of the air supply should be managed as part of the temporary works management procedures on site.

8.5.5. For low and intermediate pressure exposures the supply should be capable of providing sufficient air to pressurise the working chamber and compensate for estimated losses through the face along with a suitable margin for safety depending on the variability of ground conditions as well as for pressurisation of the locks (see cl 8.5.7.). Guidance on air quality is in clause 8.6.

8.5.6. For high pressure exposures there should be a supply of respirable air to the locks. Air to pressurise the working chamber should also be of respirable quality if it is exhausted into the tunnel on discharge from the chamber.

8.5.7. The air supply should be sufficient to compress the largest personnel lock compartment in the tunnel to working pressure, at a rate of 2 bar per minute up to a pressure of 2 bar and at a rate of 1 bar per minute thereafter.

8.5.8. The air supply system should incorporate sufficient storage to allow the safe abandonment of the intervention along with enough air for a full decompression including flushing the personnel locks for ventilation and being able to compress them once from atmospheric pressure.

8.5.9. Electrically driven compressors should be used. A standby compressor of capacity equivalent to the largest of the duty compressors needs to be provided. Where more than five duty compressors are in operation, two standby compressors need to be provided.

8.5.10. In the event of failure of a duty compressor, a *duty compressor failed* alarm should be initiated both locally at the site of the compressors, in the TBM control cabin where TBM locks are being used and in the site offices. It should be possible to restore full air supply within not more than five minutes of the failure of a duty compressor.

8.5.11. The air supply plant and its power supply may be operated through a control system. That control system should be to a required performance level determined in accordance with BS EN ISO 13849-1. In the event of failure of the main power supply, the control

system should be capable of switching automatically to the standby power supply within ten seconds of the failure occurring. The control system should automatically restart the compressors as soon as power is restored.

8.5.12. The control system should also be capable of switching from duty to standby compressors in the event of failure of the duty compressors within one minute of the failure occurring.

8.5.13. The control system should initiate the *loss of main power* and/or *duty compressor* failed alarms as relevant.

8.5.14. Where generators or compressors are controlled through a control system, all alarms should be integrated into it.

8.5.15. All electrically powered components of the compressed air control system including control valves anywhere on the system upstream of the airlock control panel, which are not powered by the supply and standby power supply for the compressors shall have an independent standby power supply.

8.5.16. Where diesel powered generators or compressors are installed for standby use and located on the surface, an adequate supply of fuel should be available on site. There should be a separate emergency reserve of fuel stored on site which can power the plant for a minimum of 24 hours. Where saturation exposures are being undertaken that fuel reserve should be for a minimum of 96 hours.

8.5.17. Each diesel powered generator or compressor should be fitted with an alarm to indicate when the fuel in its tank falls to 10% of stored capacity or one hour running time on full load, whichever represents the longer time. A *low fuel* alarm should be given both locally at the site of the compressors and in the site offices.

8.5.18. If diesel compressors are used for the surface air supply, the compressed air contractor should consider the need for additional standby compressors to give an equivalent degree of reliability in the air supply to that provided by the standby power/standby compressor scenario in clauses 8.4.1 and 8.5.9.

8.5.19. Care needs to be taken to ensure that the air entering the compressor intakes cannot be contaminated by exhaust emissions.

8.5.20. A pressure relief valve meeting the requirements of BS EN 12110 and of sufficient capacity to vent to atmosphere the maximum output of the compressor(s), is necessary immediately downstream of each compressor. Pressure relief valves on in-tunnel locks formed by bulkheads in the tunnel should be set to open at 105% of the maximum working pressure. Following operation, all pressure relief valves should re-seat before 100% of the maximum working pressure has been reached. The hysteresis in the valve should be taken into account when selecting and testing the correct operation of the valve.

8.5.21. The supply of compressed air for pressurising the locks and working chamber should be controlled via the lock attendant's station. For low or intermediate pressure projects the maximum supply pressure to the lock attendant's station should be 10 bar(g). For high pressure projects the maximum supply pressure should be no more than 5 bar above maximum working pressure.

8.5.22. The compressed air system should be fitted with a *low air supply pressure* alarm clearly audible at the compressor attendant's station to indicate when the pressure of compressed air being supplied to the lock attendant's station falls below a predetermined limit set by the hyperbaric supervisor. This alarm should be integrated into the control system, if fitted.

8.5.23. A data recorder accurate to +/-0.05 bar, should be fitted to provide a record of pressure of the compressed air supply to the lock attendant's station. Pressure data should be recorded electronically at 10 second intervals in real time.

8.5.24. The compressed air contractor should provide suitable accommodation as relevant for housing all air supply plant and the attendants to oversee and operate it. The compressor attendant needs to be able to monitor and control the compressed air plant and supply of compressed air from that accommodation.

8.5.25. However increasingly long tunnels are being driven using large closed-face TBMs which require hyperbaric interventions for face and cutterhead inspection and maintenance. In addition, there is the foreseeability of high pressure interventions being undertaken which would require a higher pressure supply.

8.5.26. This can result in long air supply lines and/or higher supply pressures being required to the extent that supplying air from a surface compressor station at the initial drive shaft/portal location ceases to be the preferred option for the compressed air contractor in terms of safety and reliability of supply. At that point the compressed air contractor may consider an alternative method of supplying air to the TBM and locks, provided the safety and reliability of the alternative supply can be demonstrated to be as robust or better than the existing "from the surface" practice in terms of air quality and/or quantity.

8.5.27. Potential alternative methods which can be considered on a case by case basis include:-

8.5.27.1. The use of intermediate shafts required as part of the permanent works. These sites should be utilised as intermediate surface compressor station sites with the plant and equipment moved up to provide a supply nearer to the working TBM. This is a relatively minor variant of currently preferred practice which has been used successfully in the past.

8.5.27.2. Where no intermediate shafts are planned, the compressed air contractor should consider installing a dedicated feed by means of a specially sunk cased borehole. This should be sunk on-line or slightly off-line to the side of the tunnel and connected after the tunnel drive has progressed sufficiently.

8.5.27.3. An in-tunnel compressor station which should be sited on the TBM backup or on a dedicated platform towed or semi-static in the tunnel but moved up periodically as the works progress. In-tunnel compressors and their standby compressors should be electrically powered. The intake air for the compressors should come directly from the tunnel ventilation system or via a dedicated feed from the surface down an intermediate shaft or specially sunk cased borehole. The tunnel ventilation system and its components parts should meet the requirements of BS 6164:2019 clause 15.7.

8.5.28. Safety and reliability of supply along with quality and quantity of air delivered as opposed to cost and convenience should be the determining factors.

8.5.29. For all air supply scenarios the guidance appertaining to the "supply from surface compressors" scenario applies e.g. power (cl 8.4), standby compressors (cl 8.5.98.5.9), twin lines (cl 8.7) etc.

8.5.30. Plant located underground should be so located or protected as not to be at risk from vehicle impact and falling objects.

8.5.31. An intermediate compressor station or dedicated surface air intake not located within a site compound should be in a secure enclosure and protected from adverse weather and its consequences as well as from vandalism. Security surveillance from the main site offices should be provided at least when no on-site personnel are present at the station. Suitable facilities and accommodation for a compressor attendant should be provided. Air duct intakes should terminate at least 2 m above ground level and should be covered by an appropriate grating.

8.5.32. Where the compressed air contractor opts for an in-tunnel air supply station electrically powered compressors should be used. They should be powered from the tunnel electrical supply. However, they may be powered from diesel generators. Intake air should come directly from the surface or via the tunnel ventilation system.

8.5.33. Diesel generators should conform with BS 6164:2019 clauses 24.8.1 and 25.15. Generators and compressors should also conform with clause 13.1.8 in respect of fire suppression. Generators and compressors should be brought into the tunnel only for the duration of individual interventions. Generators should be located downwind of respirable air compressors with exhaust emissions ducted away from the respirable compressor location. Diesel exhaust emissions should be discharged into a ventilation flow downstream of any compressor intakes. Each machine should have sufficient fuel to run for the duration of the intervention plus one hour. An audible and visible alarm on the machine should be triggered when the fuel remaining drops below the "1 hour" level.

8.5.34. Other power sources may become available during the life of this guidance. Appropriate backup to ensure reliability of power supply should be provided.

8.5.35. Any compressors forming part of the permanent equipment of the TBM but used to provide an emergency backup air supply for the evacuation of the working chamber in the

event of total failure of the compressed air supply and its backup should ideally draw air directly from the incoming fresh air duct.

8.5.36. An air supply and an independent backup, each capable of supplying compressed air at a rate sufficient to compress the medical lock at a rate of at least 0.3 bar per minute and to a pressure of at least 1.0 bar above the pressure in the working chamber, also need to be available at the medical lock. This air supply should be available for 24 hours after people have ceased to work in compressed air on the site.

8.5.37. Action to be taken in respect of abandoning the intervention in the event of any tunnel emergency is set out in clause 13.3.1 and 13.3.2.

8.6. Air supply quality

8.6.1. Air for pressurisation or respiration should be drawn into the compressors at a place free from smoke, dust, exhaust fumes, ground gases including methane and hydrogen sulphide or other contaminants.

8.6.2. Air intakes to compressors located underground should be monitored for CO/CO_2, NO/NO_2, CH_4 and other possible contaminants. Alarms should be triggered at the lock attendant's station, the TBM control cabin and in the site offices when the level of any contaminant exceeds 25% of limits in HSE publication EH75/2 "*Occupational exposure limits for hyperbaric conditions: Hazard assessment document"* for long term exposure.

8.6.3. All necessary coolers, scrubbers and filters should be provided to maintain the respirable quality of the compressed air supply when the intake supply is contaminated with any foreseeable contaminant.

8.6.4. Compressed air supplied for pressurisation or respiration should meet the purity requirements of BS EN 12021. It should be smoke free, dust free, odourless with an oil content not exceeding 0.5 mg/m^3 at normal atmospheric pressure. Guidance on hyperbaric exposure limits is given in HSE publication EH75/2 "*Occupational exposure limits for hyperbaric conditions: Hazard assessment document"* and see HSE Report OTO 98/173 "*Occupational Exposure Limits and Olfaction in Hyperbaric Environments*" for background information.

8.6.5. The supply of compressed air should be sufficient to maintain an atmosphere in any personnel lock or the working chamber such that the level of any contaminant (other than oil content) does not exceed the exposure limits for that contaminant in the current edition of EH75/2 *Occupational exposure limits*.

8.6.6. Ventilation is also required to maintain a comfortable working environment and, therefore, the minimum supply of compressed air needs to be at least 300 litres per minute measured at working chamber pressure for each worker in the chamber.

8.6.7. Ventilation of personnel locks at low and intermediate pressures should be sufficient to maintain a comfortable thermal environment and levels of carbon monoxide and carbon dioxide below the prescribed limits.

8.6.8. A comfortable thermal environment along with an atmosphere fit for respiration should be maintained in personnel locks at high pressure. This can be done either by flushing or by recycling techniques.

8.6.9. Air quality should be checked at least once a day and the results recorded.

8.7. Air pipelines

8.7.1. Any line supplying compressed air for pressurisation or respiration whether from a compressor station on the surface or from a compressor station underground needs to be duplicated between the compressor station and the lock attendant's station. Downstream of the connection to the lock attendant's station on a TBM, the requirements of EN 12110-1 apply.

8.7.2. The twin air supply lines should be independent and routed separately in the tunnel.

8.7.3. Air supply pipelines should have sufficient in-built flexibility to accommodate foreseeable movement and be capable of resisting foreseeable vibration. However they should be restrained against excessive movement. Pipelines should be protected against impact damage but in the event of damage to one supply line it should be possible to isolate it without interrupting the air supply. Failure of one pipe should not lead to escape of air from the other.

8.7.4. When adding pipes to a pipejack being driven under compressed air, one air pipeline should always be connected and operable while the other is disconnected/connected and threaded through the added pipe.

8.7.5. Any pipeline supplying compressed air into an airlock or to the working chamber needs to be fitted with a non-return valve at the point of discharge.

8.7.6. Silencers should be fitted to supply or exhaust pipework if the noise from the air pipeline discharge at maximum flow rate at any working pressure exceeds a sound power level of 80 decibels.

8.7.7. The inlet orifice of any pipeline exhausting air from an airlock or the working chamber should be fitted with a suitable mesh guard to prevent injury, due to hands etc being sucked in. Mesh guard will also prevent debris being sucked into the pipe.

8.7.8. In a tunnel airlock, the compressed air supply and exhaust pipelines should be laid out in a manner to ensure a circulation of air in the working chamber. When natural circulation due to air loss through the face is insufficient, induced circulation by means such as the use of a snorer will need to be considered.

8.7.9. Air supply and exhaust pipelines between the lock attendant's station and the personnel lock need to be suitably sized to prevent an excessive rate of compression and decompression of the airlocks. They should also be appropriately marked with their function.

8.7.10. In an emergency, it is necessary to be able to compress a tunnel airlock directly from the air being supplied from the compressors without drawing air from the working chamber.

8.7.11. Any pipeline supplying compressed air in the tunnel needs to be adequately protected from impact damage. Pipelines which are in shafts need to be secured to the shaft wall. Air supply pipelines ought to be marked at regular intervals with the direction of flow and an appropriate legend to describe their function.

8.7.12. Any electrical or pneumatic control lines for the regulation of the compressed air supply in a tunnel need to be protected from mechanical damage and from the effects of adverse weather. In particular, pneumatic control lines on the surface need to be positioned so that water will not collect in the lines and freeze in the event of sub-zero temperatures.

8.7.13. Air supply lines or if buried, the route of such lines, should be clearly marked at regular intervals.

8.7.14. Power-operated pressure control valves supplying or regulating air to the locks and working chamber for compression purposes, should have a manual over-ride or an emergency power supply.

8.8. Supply of oxygen or breathing mixtures

8.8.1. The oxygen supply system for decompression purposes should be in accordance with BS EN 12110-1. Oxygen should normally be supplied from high pressure cylinders brought temporarily into the tunnel. Only the minimum volume of oxygen required for decompression and if required by the CMA, a standby supply of similar volume to the main supply, should be taken underground. The supply should be sufficient for those normally on a shift along with an allowance for a rescue team of two emergency workers. In addition, there should be a reserve supply of oxygen which could be brought into the tunnel at short notice should it be necessary to undertake therapeutic recompression in the tunnel lock or TBM personnel lock.

8.8.2. Oxygen should be of medical, diving or aviation grade and meet the requirements of BS EN 12021:2014.

8.8.3. Oxygen pipework should be clearly marked with contents and direction of flow at intervals of not more than 5 m and be routed separately from electrical cables.

8.9. Supply of breathing mixtures

8.9.1. The breathing mixture supply including sourcing, mixing, testing, gas quantities, reliability of supply etc should all be in accordance with the guidance in Report 10. Whilst pipework,

valves etc on personnel locks should conform with BS EN 12110-2, other pipework etc carrying breathing mixture should be to a similar standard of good hyperbaric engineering practice.

8.9.2. Gas pressure in all pipework etc should be the minimum required for the safe functioning of the supply.

8.10. Transport of cylinders

8.10.1. Gas cylinders and associated pipework taken underground should be contained in a secure, purpose-built cage or frame capable of being lifted safely by mechanical means and providing mechanical protection against impact damage during handling in the shaft or tunnel. Valve guards should be fitted where necessary. Transport should be on a train or vehicle, used specifically for that purpose while mixed gas breathing is being undertaken.

8.10.2. The train or vehicle transporting the gas cylinders should be provided with a full onboard fixed fire suppression system. When parked in a tunnel, the parking brake should be securely applied. In addition, the train or vehicle should be chocked or otherwise prevented from moving in the event of failure of the parking brake when the gradient is sufficient to allow a run-away. A mechanical barrier should be provided to protect the train or vehicle from being struck by other trains or vehicles if they were to run away.

8.11. Working chamber

8.11.1. The thermal environment in the working chamber should, so far as is reasonably practicable, be maintained at a comfortable level for the work to be done. The CMA should advise on temperature and humidity having taken account of the work to be done and the wellbeing of those undertaking the work.

8.11.2. The compressed air environment increases the normal effects of cold and heat by allowing greater heat loss from the body in cold conditions but reducing heat dissipation by sweating when warm. Being cold (especially during decompression) or hot (during exposure) can increase the risk of decompression illness. In hot conditions there is a risk of heat stress developing. Thermal indices which can be referred to for guidance are normally for normobaric conditions on the surface (such as Wet Bulb Globe Temperature) – equivalent indices for use underground and in hyperbaric environments do not exist (see "Engineering and Health in Compressed Air Work – Proceedings of 2nd International Conference, Oxford, 2002. Slocombe, R.T., Buchanan, J., Lamont, D.R., editors, Thos Telford, London.)

8.11.3. It is important, therefore, to ascertain workers' subjective opinions of the thermal environment by direct questioning. In cold and wet conditions, opportunities to stop work and to warm up, possibly including the provision of hot food and drink, need to be considered. If heat stress is a possibility, extra rest breaks and the provision of cool refreshments may help and ideally the fluid intake of individual workers should be

monitored by lock attendants. In some cases, adjusting the humidity of or cooling of the air supplied to the chamber may need to be introduced.

8.11.4. Whilst in the absence of more appropriate recommendations it is recommended that the wet bulb temperature in a working chamber should not be allowed to exceed 27 °C and that the temperature of the air supplied should, wherever possible, not exceed 21 °C. (See Regulation 18 for further information.). It is also recognised that this recommendation may be impossible to meet in tunnels in countries with high ambient surface temperatures.

8.12. Airlocks – General requirements

8.12.1. Airlocks should meet the requirements of BS EN 12110 – 1. The standard sets out basic requirements for all TBM airlocks. It also sets out the requirements for materials locks on TBMs. Additional requirements for personnel locks are given. Combined locks should meet the requirements for personnel locks.

8.12.2. BS EN 12110-2 sets out further requirements for TBM personnel locks with mixed gas breathing capability. It also sets out requirements for personnel locks used with saturation exposures. Pressurised transfer shuttles – in practice mobile personnel locks with mixed gas and saturation capability – are also covered.

8.12.3. There are further requirements relating to airlocks on TBMs in BS EN 16191.

8.12.4. Airlocks can be attached to a single bulkhead built into the tunnel lining (a boiler lock) or formed by multiple bulkheads built into the tunnel lining. Bulkheads are covered by BS EN 12110-1. Boiler locks should conform with BS EN 12110-1. Although airlocks formed by bulkheads in a tunnel are not specifically covered by BS EN 12110-1, the engineering principles in the standard should be followed along with relevant parts of this document.

8.12.5. In both cases the bulkheads and tunnel should be designed to take account of the structural and geotechnical considerations set out in clause 11 of BS 6164:2019. They should be considered to be temporary works and should be managed in accordance with clause 6.4 of BS 6164:2019 and subject to a Category 3 check as described in clause 6.4.2 of BS 6164:2019. Guidance on such airlocks is also contained in the document.

8.12.6. The use of sacrificial flanges inserted at intervals in the lining or using a flanged collar secured to the lining intrados, can provide flexibility in locating bulkheads.

8.12.7. An airtight seal between an airlock door and the door frame should be achieved by the provision of a compressible gasket between the door and door frame. This gasket should be regularly inspected and maintained in a serviceable condition.

8.13. **Personnel locks - general requirements**

8.13.1. Personnel locks on TBMs should conform with BS EN 12110 both parts.

8.13.2. In-tunnel personnel locks do not come within the scope of BS EN 12110. However, its engineering standards and principles can be applied along with other relevant guidance from this document.

8.13.3. Personnel locks located above ground should be protected from the extremes of weather by a fire-resistant structure.

8.13.4. In-tunnel personnel locks should be situated as high above the tunnel invert as possible. If the tunnel gradient and diameter permit, partial bulkheads or curtains should, where appropriate, be constructed in the working chamber across the upper part of the tunnel cross-section to form air pockets in which compressed air workers may seek refuge in the event of flooding of the tunnel.

8.13.5. Personnel locks should not contain any hydraulic oil tank, pump or motor or other hydraulic equipment or pipework. Cables passing through the lock should be contained in steel ducts sealed from the lock interior.

8.13.6. Personnel locks should be sufficiently large to accommodate all the people likely to be in the working chamber at any time. Appropriate allowance should be made for any rescue team personnel and a casualty on a stretcher.

8.13.7. A copy of the decompression tables in use should be available inside the personnel lock.

8.14. Precautions when undertaking oxygen decompression

8.14.1. Oxygen decompression should be carried out in accordance with the decompression tables selected by the compressed air contractor on the advice of the CMA in conjunction with the hyperbaric tunnelling consultant (if involved) and/or hyperbaric supervisor as appropriate. There should also be an emergency air-only table selected for use in the event of failure of the oxygen system. The contractor should be able to justify the choice of tables and be able to demonstrate their effectiveness in terms of decompression safety.

8.14.2. Personnel locks should be kept thoroughly clean at all times and free of any mineral oil or grease. All materials, fixtures and fittings in the lock should be chosen to minimise the risk of static electrical discharge.

8.14.3. All personnel lock fixtures and fittings including any electrical equipment should be capable of being thoroughly washed down by a pressure washer without being adversely affected.

8.14.4. Personnel lock doors should be thoroughly cleaned of mineral oil and grease. Where required, an appropriate oxygen compatible lubricant should be applied to the lock door hinges.

8.15. Combined locks

8.15.1. Combined locks should meet all the requirements for personnel locks. Combined locks may be used for the compression and decompression of people where it is not reasonably

practicable to have separate personnel locks and materials locks. People and materials may occupy a combined lock simultaneously for compression only, provided free movement of people is not restricted. When a combined lock is to be used for oxygen decompression, all materials should be taken out from the lock prior to decompression starting and any spills or surface contamination by oil or grease removed.

8.16. Intermediate chamber – for mixed gas exposures only.

8.16.1. On TBMs where mixed gas exposures are being undertaken there should be an intermediate chamber between the main compartment of the personnel lock and the TBM bulkhead (see revision of BS EN 16191:2014).

8.16.2. The intermediate chamber provides a dirty working space between the personnel lock and the working chamber. It is intended the chamber atmosphere should be air. In accordance with EN 16191, it is not an airlock or pressure vessel but is subject to fluctuating loads from air pressure and ground loading. It provides a place of relative safety should it be necessary to evacuate the cutterhead in an emergency. The intermediate chamber is the location from which entry into the cutterhead should be made and controlled.

8.16.3. The intermediate chamber should be designed to the pressure requirements of EN 12110 and fitted with a pressure relief valve.

8.16.4. The intermediate chamber should have a headroom of at least 2m above invert or any floor plate.

8.16.5. The breathing mixture supply to the intermediate chamber should be piped from the personnel lock control panel to manifolds in the intermediate chamber. It should be fed from the main inlet supply manifold located upstream of the control panel.

8.16.6. There should be a separate emergency supply of breathing mixture piped from the emergency supply to the personnel lock control panel to a separate manifold in the intermediate chamber. This manifold should feed the “separate core” of the umbilical (Report 10 clause 6.11).

8.16.7. All umbilicals for use in the working chamber should originate from the intermediate chamber.

8.16.8. It should be possible to control the flow to both cores of the umbilical and monitor the composition and pressure of the flow in these cores from the personnel lock control panel.

8.16.9. Information on gas supply pressure should also be indicated in the intermediate chamber.

8.16.10. Power cables or supply lines required for maintenance activity in the cutterhead should be ducted through the intermediate chamber and have their own penetrations through the TBM bulkhead.

8.17. Pressurised Transfer Shuttles

8.17.1. These should conform with BS EN 12110-2 and have an entry compartment and a main compartment. There should be at least one shuttle per living compartment of the habitat. Each shuttle should be capable of holding the entire crew of the compartment.

8.17.2. If only one shuttle is available on site, the impact of this on emergency procedures needs to be carefully considered by the compressed air contractor.

8.18. Transport and multiple use considerations

8.18.1. There can be commercial advantages for security of fittings, ease of handling, prevention of damage and in reuse of equipment, in being able to fit a habitat chamber, wet pod or shuttle into a standard ISO shipping container or within an ISO tank frame fitted with detachable protective panels.

8.18.2. The headroom requirements for habitat chambers should not be compromised just to facilitate transport.

8.19. Vertical locks

8.19.1. Vertical (blister) locks are not in the scope of BS EN 12110. However, the requirements in BS EN 12110 for the design, fabrication, and use of locks as pressure vessels are applicable.

8.19.2. Vertical locks may be used for compression of people to all permissible intermediate pressures but should only be used for the decompression of people from pressures of less than 0.7 bar(g) otherwise decompression in the comparatively restricted space of a vertical lock would necessitate standing for too long.

8.19.3. Vertical (blister) locks should have a volume of not less than 0.75 m^3 and a floor area of 0.4 m^2 per person.

8.19.4. Where practical, all lock doors on a vertical lock need to be hinged to open in the direction of higher pressure. Where this is not practical, e.g. on a materials lock, both doors need to be fitted with pressure activated mechanical interlocks to prevent the outer door from being opened when the lock is pressurised, or the inner door is open.

8.19.5. Single compartment vertical locks do not meet the requirements of the WCA Regulations in respect of having separate means of access and escape and should not be used.

8.19.6. Vertical personnel locks should have the controls, instrumentation and communications capabilities of an in-tunnel personnel lock.

8.20. Airdecks

8.20.1. The structural design of an airdeck and its connection to the shaft lining needs to take account of live and dead loading on the airdeck with and without air pressure in the working chamber. The requirements of BS EN 12110-1 in respect of bulkheads apply.

8.20.2. When an airdeck is not built into a shaft but is set on top of it, the combined weight of the airdeck, airlock and kentledge needs to exceed the upthrust on the airdeck from compressed air at the maximum working pressure by 20%.

8.20.3. When an airdeck is built into a shaft, skin friction between the shaft and the ground should be ignored when calculating the ballast requirement.

8.20.4. The design of the shaft lining should take appropriate account of any tensile loads which could be transferred into the lining due to uplift on the airdeck.

8.21. Valves, controls and gauges – in-tunnel locks

8.21.1. Normally tunnel airlocks are significantly greater in volume than TBM airlocks. Some are two compartment, some are three compartment locks. In three compartment locks the middle compartment can normally accommodate the train with the end compartments being used for personnel to allow a train to be locked in or out and pass those undergoing decompression. The inner door of the inner compartment is normally left open to facilitate egress in the event of an emergency and the outer door of the outer compartment is normally left open to allow access to the working chamber in an emergency.

8.21.2. Because of large lock volumes, air is normally back-fed from the working chamber to the lock attendant's station.

8.21.3. The normal configuration of valves for controlling the flow of air into or out of a personnel lock is required to enable the lock attendant to control the flow with sufficient accuracy so that the compression/decompression rules can be adhered to. The provision of small diameter pipework specifically for better control during personnel compression/decompression should be considered.

8.21.4. Lock attendants should have the capability to simultaneously supply air to and exhaust air from lock compartment being used for the decompression of personnel so that the compartment can be ventilated without varying the pressure of air in it. The use of a single 3-way valve to control both supply and exhaust airflow does not permit this as only one function is available at a time.

8.21.5. Servo-operated valves should only be used if they can be manually operated in the event of a failure of the servo-mechanism. They need to be of a type, which in the event of failure, fail to the closed position.

8.21.6. The layout of pipework and valves in a manlock needs to be such that, in an emergency, pressure can be reduced from within by the occupants.

8.21.7. The valves, controls and gauges which allow lock attendants to operate and monitor the airlock under their control need to be situated at the lock attendant's station, which needs to be situated in free air as close as possible to the airlock under their control.

8.21.8. The normal requirements regarding ergonomic layout and marking of valves, controls and gauges along with capability to observe lock interiors apply.

8.21.9. Similarly, the normal requirements for accuracy and calibration of gauges including keeping of records apply.

8.21.10. Likewise, the requirements for TBM locks in respect of the analogue or digital recording of pressure during decompression apply.

8.22. Gas supply - Decompression oxygen supply

8.22.1. Oxygen for decompression purposes should be brought into the tunnel prior to use and removed immediately after use. There should be a designated storage/parking area within the tunnel or TBM and its back up from which the supply is piped to the lock control panel. First stage pressure reduction, excess flow prevention and the capability to change supplies without interrupting flow should be available adjacent to the high pressure supply source.

8.22.2. Any oxygen delivery systems should be designed, installed and commissioned under the supervision of a competent person. For personnel locks on TBMs, design, construction and testing of the oxygen system should be in accordance with BS EN 12110-1. For in-tunnel locks the requirements of BS EN 12110-1 should be met so far as they are relevant and technically possible.

8.22.3. There is interim technical guidance on oxygen decompression systems.

8.23. Gas supply – breathing mixture supply

8.23.1. There is extensive guidance on the supply of mixed gas and breathing mixtures. Report 10 provides guidance on the procurement, storage, supply and utilisation of mixed gas for high pressure compressed air working. BS EN 12110-2 sets out the requirements for the installation of mixed gas breathing systems in personnel locks on TBMs.

8.23.2. There is interim technical guidance on mixed gas installations.

8.23.3. It is conceivable that mixed gas could be used in in-tunnel personnel locks. In that case the principles of the guidance in Report 10 and in BS EN 12110-2 should be followed so far as is reasonably practical to do so.

8.23.4. Where mixed gas is supplied from a portable supply within the TBM backup, the use of long flexible hoses should be minimised. The requirements of BS EN 16191 should be followed.

8.23.5. On a TBM the supply should be by means of rigid pipework fixed to the gantries where possible. The emergency supply should be routed differently to the primary and secondary supplies. Flexible hose should be used to span all joints between gantries to accommodate movement and vibration.

8.23.6. Exceptions to this may be the emergency supply to the shuttle during transport through the TBM when long hoses may be used or an umbilical for supply in a shaft during shuttle hoisting/lowering.

8.24. Gas supply - oxygen cleanliness

8.24.1. All pipework, hoses, fittings etc conveying a gas with more than 23.5% oxygen should be oxygen compatible. All such pipework, hoses etc should be oxygen cleaned in conformity with BS EN ISO 15001:2010 or IEC/TR 60877:1999 before use or after modification. Open-ended pipes and hoses should be sealed or capped after cleaning.

8.24.2. Should there be any suspected ingress of dirt or foreign bodies to the oxygen system, it should again be oxygen cleaned as a precaution, or replaced. Foreign bodies include oil, grease or other organic material, metallic particles or grit. All connections should be blown out to remove dirt before being made.

8.24.3. When not in use, all open-ended pipes in the gas supply system should be capped and bagged or otherwise secured to prevent the ingress of dirt.

8.25. Lock attendant's station

8.25.1. Where appropriate, lock attendants' stations need to be protected from extremes of weather by fire-resistant shelters.

8.25.2. The control panel at the lock attendant's station for air mode exposures and oxygen decompression should conform with the requirements of BS EN 12110 -1.

8.25.3. For mixed gas operations the requirements for the control panel at the lock attendant's station should conform with the requirements of BS EN 12110 -2.

8.26. Emergency lighting

8.26.1. For tunnel airlocks, arrangements should be made for emergency lighting in case the normal tunnel lighting system fails. Depending on the circumstances, a backup power supply from a different source or surface standby generator, independent battery-powered lights of at least four hour's duration, personal cap lamps, hand lamps or air lamps could be provided. A failure of the main power supply, or fire affecting it, should not adversely affect the emergency power supply.

8.26.2. Equipment kept for emergency use needs to be well maintained to ensure it is always usable taking into account the adverse conditions to which it is likely to be exposed.

8.26.3. Emergency lighting for TBM locks should meet the requirements of BS ENs 12110 and 16191.

8.27. Communications systems

8.27.1. Although there are requirements for communications in connection with the airlocks in BS EN 12110, a wider interconnected network is required as part of the overall safe system of work. There should be at least one system of voice communications provided linking as appropriate: the office of the person in charge; the compressor attendant's station; the top of any shaft giving access to an airlock; each lock attendant's station; each compartment of a personnel lock; the working chamber adjacent to each personnel lock; the gas storage area on the surface; the location at which gas cylinders are attached to the fixed pipework on the tunnel boring machine and, at intervals not exceeding 500 metres from the personnel lock, each face being worked; the medical lock attendant's station; and the medical lock.

8.27.2. The compressor attendant/underground plant attendant should also be able to communicate effectively with the lock attendant(s) throughout the time they could be required to assist with gas supply procedures.

8.27.3. Communications equipment in the personnel lock should be chosen for good speech quality and should preferably be explosion protected to standard E Ex ib 'intrinsic safety' or specifically manufactured for use in hyperbaric chambers.

8.27.4. A telephone connected to the public telephone network should be available in the office of the person in charge and the medical lock attendant's station. These telephones need to be available whenever people are working in compressed air or are in the medical lock. Cellular phones may be used but their reliable operation from the site location needs to be confirmed.

8.27.5. In general, voice communications equipment needs to be robust and reliable. A 'fire hardened' system may be required to maintain communication with personnel lock.

8.27.6. In addition, there needs to be a means of non-verbal communication, such as a tapping system using a metal object being struck against the airlock or bulkhead door and based on a pre-arranged code of signals, between lock attendants and people in the personnel locks under their control. A copy of the code should be prominently displayed both in the personnel lock and at the control panel.

8.28. Oxygen breathing systems

8.28.1. Oxygen breathing should be by means of a permanently or semi-permanently installed built in breathing system (BIBS) comprising an oxygen supply and masks either connected directly to the supply line or to breathing units connected to it with a discharge capability to free air on the surface or the tunnel ventilation system. BS EN 12110-1 effectively requires that the requirements for the oxygen breathing system should be agreed

between the TBM manufacturer and its user with statutory responsibility for the safety and compliance of the system on initial installation remaining with the TBM manufacturer.

8.28.2. A basic system based on twin hose masks connected to supply and discharge manifolds can be used. The second stage pressure regulator and demand valve are integral parts of the mask. Requirements for such systems are set out in BS EN 12110-1

8.28.3. Proprietary oxygen breathing systems are available which incorporate features to improve user comfort and acceptability. These features include breathing units attached to the chamber wall in which second stage pressure regulation and lung demand management is done. This allows the use of lightweight flexible tubes to connect the mask to the unit, thus reducing the weight and providing greater flexibility in the connections. Another feature available is the incorporation of a device for reducing the exhalation resistance in the discharge line. The device effectively induces a reduced pressure in the discharge line and thus reduces flow resistance particularly during use at low stage pressures. Requirements for such systems are set out in BS EN 12110-1.

8.28.4. Devices for reducing the exhalation resistance should be powered by compressed air taken directly from the air supply line to the control panel to prevent loss of pressure in the chamber or by some other power source. The detailed requirements for oxygen systems are covered in BS EN 12110.

8.28.5. Breathing units, masks, hoses etc. should be durable, robust and generally suitable for tunnel use. They should be easily removable for cleaning and sterilizing purposes. The contract medical adviser and hyperbaric supervisor should be consulted on system suitability and selection prior to procurement.

8.28.6. Mask selection should be overseen by the contract medical adviser in conjunction with the hyperbaric supervisor. Masks should be selected to give the best possible fit to maximise the delivery of oxygen to the user with inward and outward leakage minimised (see cl 8.28.10). Other selection criteria to be considered include functionality, user acceptance and resistance to displacement. They should be made from materials that are fully compatible with pure oxygen and easy to clean. Performance including breathing resistance should conform to the guidance in Report 10. Users should be advised to be clean shaven. Leakage of oxygen to the chamber atmosphere can increase fire risk and should be monitored (see clause 11.12 of Interim Technical Guidance 1)

8.28.7. Proprietary systems normally include self-contained control/connection boxes which permit the switchover of supply cylinders without disrupting flow along with first stage pressure regulation and excess flow control.

8.28.8. All control and adjustment of the oxygen system should be by the lock attendant from outside the personnel lock.

8.28.9. The system should be capable of supplying oxygen at a maximum pressure of 1.8 bar(g) to allow therapeutic recompression treatment to be carried out in the personnel lock in

an emergency such as someone collapsing in the vicinity of the lock immediately after leaving it.

8.28.10. The effectiveness of the oxygen delivery system should be checked at a frequency determined by the contract medical adviser, by measuring the concentration of oxygen in the discharge line close to the mask. The oxygen concentration should not be less than 85% by volume.

8.29. **Masks for mixed gas breathing**

8.29.1. Breathing mixture should be supplied through line fed masks. Full face masks with built-in communications capability within a helmet providing head protection are to be preferred.

8.29.2. Masks should be regularly inspected and maintained in accordance with the manufacturer's instructions. Inspection and maintenance records should be kept for each mask.

8.29.3. Masks should be cleaned using warm soapy water and disinfected in accordance with the manufacturer's instructions after each use.

8.29.4. Masks which become contaminated with oil or grease, including cosmetics, should be deep cleaned using an ultrasonic bath.

8.29.5. Masks should be bagged or otherwise protected when not in use.

8.30. Exhaust gas discharge

8.30.1. Oxygen breathing systems should be fitted with an overboard dump system. Exhaled oxygen should be dumped directly into the tunnel ventilation system or to free air on the surface outside the tunnel. For TBM locks the requirements of BS EN 16191 should be adhered to.

8.30.2. The point of discharge should be clearly marked and appropriately signed. It should be remote from the intake to any compressors and protected from adverse weather. It should be high enough above ground level to be safe from tampering.

8.30.3. The air flow rate in the tunnel ventilation system should be at least 100 times greater than the flow rate of discharge of oxygen to it.

8.30.4. When mixed gas breathing in being undertaken, vented gas from the locks or working chamber should be discharged directly into the tunnel ventilation system or other ventilated space either in the tunnel or on the TBM.

8.30.5. Where technically possible and economically viable, exhaled breathing mixture should be captured in a helium reclaim system.

8.30.6. Where the flow in the tunnel ventilation system is insufficient to maintain required levels of dilution, all vented gas from locks and the working chamber including exhaled

oxygen or mixed gas discharged from the locks or working chamber should be collected in an exhaust ventilation system which extracts to the surface.

8.30.7. In the event of the tunnel ventilation system or any exhaust ventilation system into which exhaled gas is discharged not operating, work in compressed air should be brought to an orderly stop. No further routine entry into compressed air should take place. Oxygen decompression should be suspended and decompression should continue in accordance with emergency decompression procedures using air. Those in the working chamber should return to the personnel lock for decompression. Those undertaking saturation exposures should return to the TUP shuttle for transportation back to the surface.

8.30.8. The personnel lock should be flushed through with air after every oxygen decompression.

8.31. Atmospheric monitoring and ventilation

8.31.1. When oxygen decompression is being undertaken, additional atmospheric monitoring will be required in the tunnel to detect any increase in oxygen concentration. The system should utilise fixed detector heads. Instrumentation for monitoring oxygen concentration at atmospheric pressure should comply with BS EN 50104:2002. There should be a digital readout, from the detectors in the tunnel, on the surface and at the lock attendant's station. Where the airlock or working chamber is an integral part of a tunnel boring machine, the display should also be at the tunnel boring machine operator's control panel for detector heads on the tunnel boring machine. Alarms should be set at an oxygen concentration of 23% by volume. The alarm should be both audible and visible and should indicate in the tunnel and on the surface. The atmospheric monitoring system should be intrinsically safe.

8.31.2. Oxygen detector heads should also be located in the vicinity of the oxygen storage area within the backup equipment and close to the point of oxygen discharge from the overboard dump into the tunnel ventilation system.

8.31.3. Any increase in oxygen concentration in the general body of air in the tunnel, above that in natural air, should be investigated.

8.31.4. The tunnel ventilation system should be capable of maintaining a minimum air supply in the vicinity of the airlock and any gas cylinders in the tunnel, of 100 m^3 per minute.

8.31.5. The point of discharge of gas from locks or the working chamber when mixed gas breathing is being undertaken should also be monitored for oxygen concentration.

8.32. Electrical requirements

8.32.1. Electrical equipment in airlocks should meet the requirements of the current edition of BS EN 12110. There should be no electrical equipment in a personnel lock except what is required for the safe operation of the lock itself. Such equipment should normally be powered from an extra low voltage system but should not exceed 60 v to earth.

8.32.2. All electrical equipment for use in the personnel lock should be capable of operating safely in an oxygen enriched atmosphere and under fluctuating atmospheric pressure up to the working pressure of the lock.

8.32.3. Electrical equipment in an airlock should be to a high level of ingress protection to prevent water ingress during cleaning of the lock. Below chamber axis level it should be protected to level IP67 so that it is not adversely affected by washing the chamber, above axis level electrical equipment should be to at least level IP66.

8.32.4. Although oxygen is not a potentially explosive gas, elevated levels of oxygen reduce the ignition energy required to ignite other materials. Consequently, all electrical equipment in the personnel lock should be explosion protected as this gives a high degree of mechanical protection to the equipment and reduces the risk of sparks or hot particles being ejected.

8.32.5. The level of protection should be such that the equipment is suitable for use in Zone 1 hazardous areas with gas group 2b as defined in BS EN 60079-14 or an equivalent standard.

8.32.6. Lighting in TBM locks should meet the requirements of the current version of BS EN 12110.

8.32.7. Lighting of in-tunnel locks should preferably be from outside the lock. Where adequate levels of lighting in the personnel lock cannot be achieved from outside, light fittings may be provided in the personnel lock. Switches for lighting circuits should be located outside the personnel lock. The use of cold LED lighting should be preferred.

8.32.8. For in-tunnel locks, the lock attendant's station should be lit to a level of at least 200 lux at any valve, gauge or other control equipment. The interior of personnel locks should be lit to a level of 120 lux at floor level. In-tunnel materials locks should be lit to a level of at least 10 lux at floor level. Where there is personnel access to the material lock the lighting level at floor level should be 120 lux.

8.32.9. Electric cables in a personnel lock should be selected to give maximum mechanical protection and should be sheathed in an LSF/LSOH material. Glanding should be appropriate to the protection classification of the equipment and the cabling used.

8.32.10. For in-tunnel locks, all electrical circuits in the personnel lock should be earthed and protected by suitable miniature circuit breakers and a 30mA residual current device where appropriate.

8.32.11. Communications equipment in the personnel lock should operate from an extra low voltage supply.

8.32.12. Electrical installation work on any airlock should be supervised and carried out by those with experience of explosion protected electrical installations.

8.33. Other plant and equipment

8.33.1. Plant and equipment not associated with the compressed air installation, but which will be used in compressed air as part of the tunnelling operation, should be capable of withstanding the maximum air pressure envisaged and also any reversal of load resulting from decompression.

8.34. Surface habitat – general requirements

8.34.1. At present there is no British or European standard covering habitats for use in diving or as part of HPCA work in tunnelling. Nevertheless, many of the requirements of BS EN 12110 will be relevant in tunnelling. One diving industry standard to which reference can be made, is Norwegian Standard NORSOK U100 "Manned Underwater Operations" (currently in edition 5, corrected version 2016-05-09). Until a relevant British or CEN standard is published, the guidance below should be followed.

8.34.2. The habitat should provide living accommodation, sleeping accommodation along with hyperbaric toilet/washing/showering facilities for those in saturation. The number of chambers along with their size, layout and number of compartments will depend on the complexity of the saturation operations being undertaken and thus the number of occupants to be accommodated.

8.34.3. The habitat should be located on the surface close to the access to the tunnel.

8.34.4. The habitat should comprise one or more PVHOs housed in a weatherproof structure(s) which together act as a hyperbaric living facility. In addition, the habitat requires to be supported by facilities for life support and the provision of hotel and medical services for those in the habitat. The habitat and its ancillary services should be set within a secure compound.

8.34.5. When saturation exposures are being undertaken concurrently on more than one TBM, separate chambers should be provided for the saturation workers on each TBM. Multiple chambers can be interconnected via a wet pod.

8.34.6. The habitat should preferably have a headroom of 2.2 m above the deckplate or chamber invert however the minimum headroom should be 2 m. If no deckplates are used the chamber invert should be covered in a non-slip material bonded to the shell.

8.34.7. The engineering design principles, fabrication, construction, fitting out and equipping of the habitat and emergency chamber should follow the requirements for airlocks intended for use with mixed gas BS EN 12110-2.

8.34.8. Each chamber should have a capacity of at least 4 persons. The habitat should provide at last 4 m^3 of useable volume per person. The volume should be divided sensibly between the living and sleeping accommodation which should be separated by a non-flammable ventilated privacy partition. Where seats are arranged along both sides of a chamber they should be staggered to allow greater leg room for occupants.

8.34.9. Living quarters should contain seats and a folding table. Sleeping quarters should contain bunks at least 2.0 m x 0.7 m. It should be possible to accommodate horizontally, a person on a stretcher of 2 m minimum length within the living or sleeping quarters.

8.34.10. The habitat compartments should be designed for easy cleaning. Surfaces should be coated in an appropriate material which is fire retardant and a low emitter of VOCs. The colour(s) should be chosen to optimise illumination but with user acceptance in mind.

8.34.11. At least one of the compartments of the habitat should form an entry compartment as in BS EN 12110-1 unless entry can always be achieved though the wet pod.

8.34.12. There should be a means of docking a TUP shuttle to at least one compartment.

8.34.13. Where a wet pod is provided there should be the capability to dock at least one TUP shuttle to it also.

8.34.14. All docking flanges should conform to the requirements of BS EN 12110 – 2 (see also interim technical guidance 3 clause 7) For shuttles without adjustable undercarriage, there should be a means of ensuring correct alignment prior to clamping.

8.34.15. There should be a supply lock for transferring food, medical supplies and consumables etc into each compartment and the wet pod. It should be big enough to allow passage of consumables for the CO/CO_2 scrubbers. It should conform to the requirements of BS EN 12110 – 2.

8.35. Surface habitat - wet pod

8.35.1. The main hyperbaric toilet/washing/showering facilities should be in a separate chamber or compartment (wet pod) to the living/sleeping accommodation. The wet pod should also be capable of providing emergency life support to the occupants of any living/sleeping chamber connected to it until they can be evacuated under pressure to the emergency chamber. It should be possible to isolate the wet pod by a pressure resisting door from any other chamber connected to it. The wet pod should have a separate supply lock for transferring food, consumables etc.

8.35.2. The wet pod should provide the same headroom as a living chamber. Previous experience has shown that a minimum useable volume of around 6 m^3 is sufficient. Docking flanges should conform with BS EN 12110 - 2.

8.36. Surface habitat - emergency chamber

8.36.1. The compressed air contractor is required to make provision for the transfer under pressure of all those in saturation to an alternative fully functioning emergency pressurised chamber in the event that occupation of the habitat becomes untenable.

8.36.2. The capability to provide the full range of life and welfare support to those in the emergency chamber should not be compromised by the event which rendered occupation of the main habitat untenable.

8.36.3. The guidance principles in clauses 8.34 to 8.49 apply to the alternative chamber.

8.37. Provision of emergency medical care for persons in saturation

8.37.1. It should be possible to provide emergency medical care for persons in saturation to a standard equivalent to that in DMAC 28 as recommended in Report 10.

8.37.2. There should be a chamber compartment meeting the requirements of section 6 of DMAC 28. This may either be in the emergency chamber or be a compartment of the living habitat.

8.37.3. The advice of the contract medical adviser on this matter should be followed.

8.38. Surface habitat - control panel

8.38.1. There should be a single control panel from which the pressure, temperature, humidity, of all living/sleeping compartment(s) and wet pod(s) (if fitted) can be monitored and controlled. The supply of air, breathing mixture or oxygen to any chamber or manifold should be monitored and controlled from there also. One set of controls for the fire suppression system should be accessible at the panel.

8.38.2. There should be a separate panel of similar capability for the emergency chamber.

8.38.3. It should be possible in an emergency to control each chamber from controls on the chamber.

8.38.4. There should be two air outlets at each panel for masks for the operators for use in an emergency.

8.38.5. There should be voice communications with compartment occupants along with the capability to observe living compartments and medical treatment areas from the panel.

The chambers should be designed so that any valves or gauges on them can be operated or viewed from floor level - see “zones within field of vision and actuation areas – standing” in EN 894-4. Where valves or gauges cannot be operated or viewed from floor level, raised platforms should be provided. Raised platforms should be designed to prevent falls from them.

8.39. Surface habitat - environment control

8.39.1. The heat exchange medium should be water based. There should be at least two environmental control units supplying the hot and cold water. Each unit should be capable of supplying the entire habitat on its own.

8.39.2. There should be separate environmental control units for the emergency chamber or a single unit supplying the chamber along with the capability of supplying the emergency chamber from the habitat supply.

8.39.3. Each compartment should have at least two heating/cooling devices. It should be possible to maintain the environment in any compartment at a temperature which is considered comfortable by the occupants in the range 22 to 33 ^{0}C and between 40% and 60% RH or other limits to be agreed between the saturation workers and the CMA.

8.39.4. Noise in a chamber should be kept to a minimum with the noise in the sleeping quarters not exceeding 60 dB(A) with the partition door shut.

8.40. Surface habitat - water supply

8.40.1. Potable water supplied to the habitat compound should be sourced directly from the public mains water supply. As an additional precaution against bacteriological infection, water should be passed through a UV steriliser before being used.

8.41. Surface habitat - enclosure.

8.41.1. The habitat should be located in a building or other weatherproof enclosure such as one or more ISO containers, which provide a stable thermal environment for the habitat.

8.41.2. The floor should be constructed from an easy-clean solid material.

8.41.3. The building/enclosure should also provide office and welfare accommodation for the life support and medical teams supporting the habitat along with associated washing/showering/toilet facilities. In addition, the environmental control equipment, potable water filtration plant and waste disposal facilities for the habitat should be located in the compound. Food preparation and laundry facilities for the habitat will be required and can be co-located in the compound. The building/enclosure should be sufficiently large to allow free movement around the habitat and access including access for operation, shuttle movement, maintenance and casualty removal. The building or enclosure should be designed to be easy to keep clean.

8.42. Surface habitat - secure compound

8.42.1. The chamber building and gas storage area should be set within a secure compound with access restricted to personnel connected with the HPCA work. In addition to the recommendations of paragraph 6.41 of ITA Report 10, the secure compound should be lit at night and be under CCTV surveillance.

8.42.2. The compound and gas storage area should sit on a hard standing on which delivery vehicles and forklift trucks can operate.

8.42.3. Recommendations for the gas storage facility are set out in clause 6.40 of Report 10.

8.42.4. Access to the compound from the main site access should be by an all-weather roadway with signage as necessary. The contractor should assess the need for access control, bearing in mind the need to ensure rapid access for emergency vehicles.

8.42.5. The compound should be protected against flooding.

8.43. Surface habitat - gas distribution panel

8.43.1. A gas distribution panel should be securely mounted in the habitat building. The panel should be supplied with gas from the primary, secondary and emergency gas supplies in the gas storage facility. From the panel, gas should be supplied under control by the control panel to each compartment of the habitat. Any risk of common mode failure in the construction or operation of the panel should be assessed and mitigated.

8.43.2. It should be possible to shut off each incoming gas supply line at the panel. Separately it should be possible to shut off an individual gas supply to an individual chamber. as well as each outgoing supply line to a compartment. Gas leaving the panel should have been regulated to a maximum pressure of 40 bar(g).

8.44. Surface habitat – power supply

8.44.1. There should be a power supply and back-up power supply to the secure compound which should feed all electrically powered equipment in the compound. Additionally, safety critical equipment associated with the habitat or emergency chamber should have a dedicated uninterruptible power supply capable of operating the equipment for at least 24 hours in the event of total power loss.

8.45. Surface habitat - protection against fire

8.45.1. The habitat building and emergency chamber building, if separate, should each have a fire suppression system such as a water mist or sprinkler system protecting all internal spaces and any enclosed roof space.

8.45.2. The requirements of BS EN 12110-1 in respect of fire suppression in chambers should be complied with in respect of the habitat, wet pod and emergency chamber. Additionally, an appropriately sized, hyperbaric fire extinguisher should be provided in each compartment.

8.45.3. The project fire risk assessment should extend to the habitat and emergency chamber building along with the gas storage area.

8.45.4. There should be a fire suppression system covering the gas storage facility.

8.45.5. Any vehicles used regularly for the handling of gas cylinders in the storage compound should meet the requirement of cl 24.6 of BS 6164:2019 and be fitted with an on-board fixed fire suppression system as required by BS 6164:2019 cl 13.3.3.

8.46. Surface habitat - chamber atmosphere monitoring

8.46.1. The atmosphere in each compartment should be monitored. A respirable atmosphere should be maintained through removing contaminants by chemical scrubbing with recirculation and oxygen make up as required. The scrubbing system should also provide ventilation circulation flow in each compartment.

8.46.2. Levels of atmospheric contamination in a compartment should not exceed those applicable in saturation diving. Guidance can be found in the current edition of Norwegian Standard U 100 “Manned underwater operations”.

8.46.3. Where scrubbers are fitted there should be at least two scrubber units per gas scrubbed, in any compartment. Each scrubber should be capable of servicing the compartment on its own. At least one spare scrubber cartridge should be kept in a compartment for each type of scrubber. Scrubbers for CO and CO2 may be a combined unit or separate units for each gas.

8.46.4. Where necessary a scrubbing system to remove VOCs should be available in each chamber. The exposure limits in HSE publication EH75/2 should be adhered to.

8.46.5. Where necessary an odour scrubbing system should be provided.

8.46.6. Hyperbaric exposure limits are set out in HSE publication EH75/2. Further information on exposure limits is given in Norwegian Standard NORSOK U100 “Manned Underwater Operations” edition 5 clause 5.3.2.6.

8.46.7. The following alarms should be available at the control panel

8.46.7.1. An audible and visible high and low O_2 alarm

8.46.7.2. An audible and visible high CO and CO_2 alarm

8.46.7.3. An audible and visible high N_2 alarm

8.47. Communications

8.47.1. There should be voice communications between the control panel and each compartment. In addition, there should be the capability for CCTV monitoring of each compartment however privacy in sleeping areas should be respected. There should be Wi-Fi connectivity via a router mounted outside the habitat. Tablets, phones etc should not be charged inside the habitat.

8.48. Gas storage and reclaim

8.48.1. Recommendations for the gas storage facility are set out in 6.40 of Report 10.

8.48.2. For sustainability reasons helium reclaim should be undertaken where commercially worthwhile. However, it is recognised that on small projects helium reclaim can be uneconomical.

8.48.3. Ideally, for sustainability reasons, helium should be reclaimed from both the habitat atmosphere and from the saturation workers breathing system.

8.48.4. In accordance with the recommendations in Report 10, reclaimed helium from the habitat should be returned to the gas mixing plant for reuse.

8.48.5. However, it is now possible to recycle helium in the tunnel directly from the exhaled breathing mixture via a second hose from the mask. When this technology is utilised, exhaled gas should be scrubbed, analysed, have the oxygen content adjusted and the final mixture reanalysed before being injected into the breathing mixture circuit upstream of the personnel lock control panel on the TBM. Analysis should include O_2, CO, CO_2, He/N_2 content with the results available at the control panel.

8.49. Maintenance and certification

8.49.1. The contractor should set up and maintain a planned preventative inspection, certification and maintenance system (PPICM) for all hyperbaric equipment on the contract. Extensive relevant guidance on the frequency of inspection and the competence required to undertake such inspection of hyperbaric plant and equipment is set out in the IMCA publication D 018 "Code of Practice for The Initial and Periodic Examination, Testing and Certification of Diving Plant and Equipment Rev. 1 – June 2014" and IMCA publication D 053 "DESIGN for the Hyperbaric Reception Facility (HRF) forming part of a Hyperbaric Evacuation System (HES)" Rev. 0.1 – October 2018.

8.49.2. All work carried out on the habitat and emergency chamber should be recorded in the system.

8.49.3. All PVHOs making up the habitat or emergency chamber should be tested in accordance with the requirements of BS EN 13445 and copies of the test certificates lodged in the PPICM system.

8.49.4. All pipework (and hoses) carrying gas or fluids to/from the habitat or emergency chamber should be functionally tested after assembly to 1.5 times their normal working pressure and be shown to be leak tight. Test certificates should be lodged in the PPICM system.

8.49.5. All pipework carrying oxygen or a gas mixture with more than 23.5% oxygen by volume should be oxygen cleaned to IEC/TR 60877:1999. Certificates of cleanliness should be lodged in the PPICM system.

8.49.6. Calibration certificates for all gauges and gas analysis equipment should be lodged in the PPICM system.

8.49.7. A commissioning/compliance audit of the hyperbaric system to confirm that all necessary pipework, valves, gauges, controls/control functions, ancillary systems etc have been installed and are known to be tested and functional should be undertaken on site before the habitat is occupied for the first time.

8.49.8. A functional test of all habitat systems at maximum pressure/maximum flow should be undertaken on site before the habitat is occupied for the first time. Test certificates should be lodged in the PPICM system.

8.50. TUP shuttles

8.50.1. These should conform with EN 12110-2 and have an entry compartment and a main compartment. There should be at least one shuttle per living compartment, each capable of holding the entire crew of the compartment.

8.50.2. The hard standing around the habitat enclosure should extend all areas required for shuttle lifting and movement. It should be capable of supporting all relevant crane and transport vehicle loads.

8.50.3. All lifting of the shuttle should be undertaken in accordance with personnel lifting requirements.

8.51. Transfer of TUP shuttle through TBM.

8.51.1. The requirements for raising a shuttle from its tunnel transport vehicle to the shuttle path on the TBM, moving it along the shuttle path and raising it to the docking position with the personnel lock are set out in the revision of EN 16191:2014. Until that is published as a prEN, the guidance in Interim technical guidance 3 should be followed. 16191.

Regulation 9 Appointment of contract medical adviser

(1) The compressed air contractor shall appoint a contract medical adviser to give advice to him on all aspects of health relevant to the work in compressed air undertaken.

(2) Nothing in paragraph (1) shall prevent the appointment of an appointed doctor to be the contract medical adviser.

9. Guidance relevant to Regulation 9

9.1. Pressure-related health hazards

9.1.1. The hyperbaric environment is one in which there is potential for serious harm to health arising from the effects of pressure or from contaminants in that environment.

9.1.2. At (low) pressures below 0.7 bar(g), work in compressed air is comparatively free from harm. Decompression illness is extremely rare and bone necrosis (osteonecrosis) is thought not to occur. As the working pressure increases, decompression illness and osteonecrosis are the potentially serious complications of intermediate pressure exposures. With high pressure exposures the risk of oxygen toxicity and nitrogen narcosis are controlled through the choice of breathing mixture and the use of saturation techniques significantly reduces the risk of decompression illness and bone necrosis.

9.1.3. Barotrauma can arise in any air-containing cavity in the body which is in direct connection with the surrounding atmosphere. Barotrauma can arise from compression to even low pressures. The risks to health involve pressure changes to, principally the ears, sinuses and lungs. Failure to equalise pressure across a bodily structure can result in physical damage

to that structure; for example, a burst eardrum could arise from a too rapid compression, particularly in the presence of an infection of the nose, throat or chest. Medical surveillance, reporting of temporary unfitness (see regulation 16) and adherence to the correct compression procedures all have a role to play in preventing this form of harm.

9.1.4. Acute decompression illness is a disease which occurs during or within the 24 hours following the decompression process. Research has shown that in tunnelling it predominantly occurs as 'pain only' decompression sickness (formerly known as Type 1 or by descriptive terms such as 'bends' or 'niggles'). It usually involves pain around the joints, or in a small minority of cases, as serious decompression sickness (formerly known as Type 2 decompression sickness or descriptive terms such as 'chokes' or 'staggers'). This is potentially a life threatening condition which may affect the central nervous system, including the vestibular system in the ear (which is responsible for balance), the heart or the lungs. Medical surveillance can help identify individuals who may be at greater than normal risk of decompression illness.

9.1.5. Osteonecrosis is a chronic illness normally affecting the long bones and their joints (see 10.9). Research has linked an enhanced risk of osteonecrosis to having experienced pain only or Type 1 decompression sickness.

9.1.6. Decompression illness, barotrauma and osteonecrosis are all conditions which were previously reportable to HSE but are no longer reportable under the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 2013 as specific disease entities (see Appendix 4). However, the compressed air contractor should continue to record instances of such conditions.

9.1.7. Dysbarism is a prescribed industrial disease (A3) for which statutory compensation may be paid. In this context, dysbarism includes decompression illness, barotrauma and osteonecrosis. (https://www.gov.uk/government/publications/industrial-injuries-disablement-benefits-technical-guidance/industrial-injuries-disablement-benefits-technical-guidance#prescribed-diseases).

9.2. Non pressure-related health hazards

9.2.1. Construction work also poses hazards to health which can result, for example, in dermatitis, noise-induced hearing loss, musculoskeletal problems, chemical toxicity arising from exposure to gas, vapour, fume or liquids or hand arm vibration syndrome. The hyperbaric environment can exacerbate or in some other way change the response to exposure to construction-related occupational health hazards. Prevention requires a high standard of occupational health practice and it is for this reason that the compressed air contractor is required to appoint a contract medical adviser.

9.3. Health and health surveillance

9.3.1. Health surveillance refers to all activities related to the identification of occupational diseases and in practice is overseen by the contract medical adviser.

9.3.2. As part of the overall responsibility the contract medical adviser is to advise the compressed air contractor on all aspects of health relating to work in compressed air the contract medical adviser should also provide occupational health advice to the principal contractor on health risk assessment and controls and the medical co-ordination of any clinical findings by the appointed doctor(s). Advice on health extends to the treatment of ill-health arising from compressed air work.

9.4. Medical surveillance

9.4.1. Medical surveillance refers only to the examination of all those proposed for work in compressed air and the certification of their medical fitness of work in compressed air.

9.4.2. Medical surveillance is required by Regulation 10 and should be undertaken by an appointed doctor.

9.5. Contract medical adviser

9.5.1. The contract medical adviser is responsible to the compressed air contractor for advising on all aspects of occupational health relating to the work in compressed air. In addition, the contract medical adviser should liaise with the person in charge, the hyperbaric supervisor and the hyperbaric plant supervisor to provide professional occupational health input to the organisation of the work in compressed air, the choice of decompression procedures, the development and implementation of the management plan and the health and safety plan, and the planning and implementation of emergency procedures.

9.5.2. The role of the contract medical adviser differs from that of the appointed doctor in that the contract medical adviser, in being responsible for advising on all aspects of occupational health relating to the work in compressed air, has a remit which is wider than medical surveillance alone. Although it is open to employers to propose any suitably qualified doctor for appointment to undertake the medical surveillance of their employees, it is strongly recommended that, to provide medical continuity, the contract medical adviser should be selected for this role, resulting in one practitioner having both responsibilities.

9.5.3. A contract medical adviser should have practical experience of work in compressed air and of occupational health in the construction industry and possession of a higher specialist qualification such as Membership of the Faculty of Occupational Medicine (MFOM) is likely to be a minimum requirement. It is recommended that a contract medical adviser should also be an appointed doctor (see clause 10.3).

9.5.4. A contract medical adviser should be able to advise the compressed air contractor about the risks which might arise from other health hazards arising from the work activity and about any health surveillance which may be necessary for those exposed to these hazards. They should also advise the compressed air contractor on how to deal with accidental injury or non-occupational ill health occurring in the workings. This should extend to mental health issues including any stress or anxiety associated with work in compressed

air. A contract medical adviser will need to have a broad understanding of occupational health hazards hence the requirement in clause 9.5.3 for possession of a formal qualification in occupational medicine equivalent to specialist GMC registration such as membership of the Faculty of Occupational Medicine. For saturation exposures the contract medical adviser will need to be able to advise on the mental health aspects of saturation work. A contract medical adviser will require the knowledge of hyperbaric medicine and casualty handling techniques. In practice, experience of the health care of compressed air workers is limited to a small number of practitioners. Those who come new to the field may wish to make arrangements to consult an experienced practitioner on an occasional basis.

9.5.5. The contract medical adviser will act as the medical director (terminology as used by the NHS service specification reference for the role of Medical Director in the UK for HBO treatment facilities. https://www.england.nhs.uk/wp-content/uploads/2018/11/1766-HBOT-Service-Specification.pdf) of the site hyperbaric medical treatment facilities (medical lock) and may also double as the hyperbaric duty doctor and thus should have appropriate professional experience to ensure competence for the supervision of site hyperbaric oxygen treatments of decompression illness and the operation of a non-hospital based hyperbaric treatment facility.

9.5.6. The contract medical adviser will have responsibilities for advising on the medical aspects of site emergency procedures including trauma and experience, training or qualifications in pre-hospital immediate care and casualty evacuation would be desirable.

9.5.7. Also, the contract medical adviser should advise the compressed air contractor on:

9.5.7.1. compression and decompression procedures including the selection of appropriate decompression tables;

9.5.7.2. exposure periods and multiple exposure;

9.5.7.3. familiarisation procedures;

9.5.7.4. hyperbaric treatment facilities and procedures;

9.5.7.5. incidence of decompression illness;

9.5.7.6. emergency procedures covering hyperbaric emergencies and emergencies in the compressed air environment;

9.5.7.7. first aid and welfare including heat stress and oral fluid replacement;

9.5.7.8. the provision of information, instruction and training;

9.5.7.9. maintenance of records;

9.5.7.10. general occupational health topics in the context of hyperbaric exposure.

9.5.7.11. overall supervision and monitoring of all health surveillance activities.

9.5.8. In addition, for high pressure compressed air work, the contract medical adviser should advise the compressed air contractor on:

9.5.8.1. choice of exposure technique – non-saturation or saturation;

9.5.8.2. formulation of gas mixtures;

9.5.8.3. minimising narcotic effects and the work of breathing;

9.5.8.4. chamber hygiene and cleanliness;

9.5.8.5. provision of food and drink.

9.5.8.6. overall wellbeing of those in saturation.

9.5.9.The contract medical adviser should also be responsible for advising on the professional control and supervision of all medical services on site, and for professional liaison with off-site medical services including notified hospitals and the ambulance service. In practical terms, the contract medical adviser will oversee the work of the hyperbaric supervisor and medical lock attendants and also be responsible for supervising the treatment of all acute cases of decompression illness arising from the contract. The contract medical adviser should advise on the determination of the treatment regimes to be used for the execution of treatment of decompression illness and also for ensuring that all cases of decompression illness are medically examined as soon as practicable after they are notified to the site. The contract medical adviser must be able to provide the compressed air contractor with advice on current best practice in the identification of risk to the health of those being exposed to compressed air and in the prevention of decompression illness or any medical aspects related to working under pressure.(for example identification /control of nitrogen narcosis, oxygen toxicity).

9.5.10. The contract medical adviser should supervise the collation of records of both normal and therapeutic compressions and decompressions, including manlock registers and recording pressure gauge records; prepare end-of-contract summaries and liaise with the compressed air contractor regarding the preservation of original records for a period of 40 years. The contract medical adviser should ensure that written diagnoses of all cases of hyperbaric illness which were previously reportable to HSE are still provided to the relevant employers.

9.5.11. The contract medical adviser needs to consider what other physical, chemical or biological hazards may exist for those involved in the contract and provide appropriate advice to the contractor regarding the prevention of ill health from these causes. The contract medical adviser can also act as a focus for liaison between the site and the HSE Medical Advisers.

9.5.12. Work in compressed air can be undertaken on a 24-hour basis using several shifts. The contract medical adviser must ensure that they, or a competent deputy, are available for

consultation at all times when work is done under pressure and for a period of 24 hours after the last person has been decompressed.

9.6. Selection and monitoring of decompression tables

9.6.1. Tables with an extensive and proven history of satisfactory performance do not need to be verified before being used. When determining the effectiveness of new or unproven decompression tables or investigating anomalies in otherwise proven tables, DCI and its incidence can be an unreliable measure. The subjective nature of DCI along with small numbers of exposures mean that traditional statistical analyses should not be the primary control measure. Alternative techniques for assessing the effectiveness of decompression, such as physiological monitoring of individuals post-decompression, should be adopted (see clause 11.8). The contract medical adviser should review any physiological monitoring being undertaken to ensure it is being undertaken in accordance with established protocols.

9.6.2. The contract medical adviser should use the monitoring results to actively review the effectiveness of the chosen decompression procedures and based on that monitoring, decide whether further measures need to be taken to improve the effectiveness of decompression procedures. The contract medical adviser should make recommendations to the compressed air contractor on the measures to be implemented.

9.6.3. The contract medical adviser should monitor individual cases of decompression illness for predisposing factors which could render that individual unfit for further work in compressed air. This may include the need for further specialist medical investigations or tests that are required to reach a medical conclusion on fitness for role or confirm the clinical status following decompression illness or any occupational injury or illness.

9.6.4. Active monitoring of the health of workers in this way will be one of the main responsibilities of the contract medical adviser. Those working in compressed air should be actively encouraged to report any symptoms of ill health. Less formal means of monitoring the health of the workforce such as anonymous reporting of symptoms should also be available.

9.6.5. The contract medical adviser has clinical responsibility for all treatments for decompression illness. Using the terminology of the British Hyperbaric Association "*Code of good working practice for the operation and staffing of hyperbaric chambers for therapeutic purposes"* published by the Faculty of Occupational Medicine, the contract medical adviser will act as the medical director of the facilities and may also double as the hyperbaric duty doctor. The contract medical adviser or a competent deputy needs to be available during all periods when treatments may be needed. The initial treatment of decompression illness is recompression and this should not be delayed. It is important that cases are adequately assessed as soon as possible after initial presentation. Treatment will normally be initiated after an assessment by the medical lock attendant and discussion with the contract medical adviser. It is essential that the contract medical adviser is familiar with the workplace and aware of the work being undertaken. The

contract medical adviser should have a deputy if the site is geographically remote or for when the contract medical adviser is unavailable. Similar consideration should be given to the deputy being an appointed doctor as for the contract medical adviser. Current guidance on the running of hyperbaric facilities can be found in the "European Code of practice for hyperbaric oxygen therapy" published in 2004 (https://pdf4pro.com/view/a-european-code-of-good-practice-for-6b94e.html).

9.6.6. Contract medical advisers act as professional advisers to the hyperbaric supervisor and their medical lock attendants. In this capacity, they should maintain an overview of the collation and maintenance of exposure records and the completion of the compressed air worker's health and exposure record. The contract medical adviser should liaise with the appointed doctor when both roles are not being untaken by the same person.

9.6.7. Contract medical advisers need to advise compressed air contractors about the risks which might arise from other health hazards being undertaken as part of the work activity as well as about any health surveillance which may be necessary for those exposed to these hazards. They should also advise the compressed air contractor on how to deal with accidental injury or non-occupational ill health occurring in the workings. This should extend to mental health issues including any stress or anxiety associated with work in compressed air. For this activity contract medical advisers will need to have a broad understanding of the occupational health hazards of construction along with a knowledge of casualty handling techniques. In practice, experience of the health care of compressed air workers is limited to a small number of practitioners. Those who come new to the field may wish to make arrangements to consult an experienced practitioner on an occasional basis.

9.7. Allocation of responsibility between occupational health professionals

9.7.1. Where the contract medical adviser is not the sole occupational health professional involved in the project, e.g. general occupational health surveillance of the workforce is undertaken by others, the contract medical adviser shall have primacy in all matters relating to occupational health in compressed air. It is a responsibility of the compressed air contractor to ensure that the contract medical adviser has access to all the relevant health records in order to discharge his responsibilities towards people exposed to compressed air. The contract medical adviser is expected to liaise, where relevant, with the other occupational health professionals over general occupational health issues arising from the work in compressed air.

Regulation 10 Medical surveillance

(1) Every employer shall ensure that each of his employees who works in compressed air is under adequate medical surveillance by an appointed doctor or employment medical adviser; and where an employee is to be assigned to work in compressed air, the medical surveillance shall be commenced before he is so assigned.

(2) The medical surveillance required by paragraph (1) shall include examinations at such suitable intervals as the appointed doctor or employment medical adviser may require having regard to the pressure to which the employee has been or will be subjected in the course of work in compressed air and, in any event, at intervals of not more than 12 months.

(3) The employer shall ensure that -

(a) a health record, containing particulars approved by the Executive, is made and maintained in respect of each of his employees who is engaged in work in compressed air; and

(b) the record or a copy thereof is kept in a suitable form for at least 40 years from the date of the last entry made in it; and

(c) as soon as is reasonably practicable after an employee of his has ceased to work on any project, a copy of the relevant part or parts of the record made under sub-paragraph (a) of this regulation is provided to that employee.

(4) Where an appointed doctor or employment medical adviser has certified in the health record of any employee that, in the professional opinion of the appointed doctor or employment medical adviser, the employee should not be engaged in work in compressed air or that he should only be so engaged under conditions specified in the record, the employer shall not permit the employee to be engaged in work in compressed air except in accordance with the conditions, if any, specified in the health record unless that entry has been cancelled by an appointed doctor or employment medical adviser.

(5) Where an employee is subject to medical surveillance in accordance with paragraph (1) and an appointed doctor or employment medical adviser has certified by an entry in his health record that medical surveillance should be continued after his work in compressed air has ceased, the employer shall ensure that the medical surveillance of that employee is continued in accordance with that entry while he is employed by the employer unless that entry has been cancelled by an appointed doctor or employment medical adviser.

(6) Every employee who is or who has been engaged in or who is to be assigned to work in compressed air shall -

(a) when required by his employer and at the cost of his employer, present himself during his working hours (or such other time as may be agreed by that employee) for such medical surveillance procedures as may be required for the purposes of this regulation; and

(b) furnish the appointed doctor or employment medical adviser with such information concerning his health as the appointed doctor or employment medical adviser may reasonably require.

10. Guidance relevant to Regulation 10

10.1. Medical surveillance – general requirements

10.1.1. One of the measures which limits the risk to health is the proper medical surveillance of workers who are, or who will be, exposed to compressed air. Medical surveillance is intended to limit risks to health by ensuring that only individuals who are considered fit to work in compressed air do so. Only people whose presence is essential should enter compressed air workings. This need can be challenged at the time of medical surveillance to discourage casual visitors from entering pressurised workings.

10.1.2. All people who work in compressed air are therefore required to be subject to medical surveillance provided by an appointed doctor or employment medical adviser.

10.1.3. Medical surveillance should be undertaken before each worker is initially exposed to increased pressure. For work in compressed air, it also covers the assessment and certification of continuing fitness of all workers at a suitable frequency; the maintenance of accurate and comprehensive clinical records; the provision of workers with information on the health effects associated with work in compressed air and the submission of statistical returns on request.

10.2. General duty to make arrangements for medical surveillance

10.2.1. All employers whose employees will work in compressed air have a duty to ensure that all employees who work in compressed air are under adequate medical surveillance. Surveillance will, in all cases, include a pre-exposure medical examination. Thereafter, a full medical examination is required to be repeated at least once in every period of 12 months during which a person is employed to work in compressed air.

10.2.2. Medical surveillance will not be considered adequate unless further assessments are also made:

10.2.2.1. at a frequency related to the working pressure;

10.2.2.2. following any significant illness or incapacity causing an inability to work; or

10.2.2.3. following any episode of ill health related to work in compressed air.

10.2.3. Appropriate frequency for such assessments of fitness are:

10.2.3.1. once every three months for work taking place at pressures up to but not including 1.0 bar(g),

10.2.3.2. monthly when pressures are 1.0 bar(g) or over,

10.2.3.3. more frequent assessments may be required at the appointed doctor's discretion when the work involves arduous physical activity or mixed gas applications.

10.3. Appointed doctor

10.3.1. Medical surveillance of compressed air workers has to be undertaken by appointed doctors (or employment medical advisers). The statutory function of the appointed doctor in a compressed air contract is limited to the certification of continuing medical fitness.

10.3.2. A doctor who wishes to become an appointed doctor to carry out medical surveillance of compressed air workers needs to be competent in occupational medicine and also to have specialist knowledge of hyperbaric medicine. Possession of a qualification such as the Diploma in Occupational Medicine is likely to be a minimum requirement. Knowledge of hyperbaric medicine can be gained from appropriate courses in diving medicine such as that equivalent to the level of training as an HSE Approved Medical Examiner of Divers (AMED) or from relevant courses specific to compressed air work which may be organised in the future.

10.3.3. The formal appointment allows HSE to set standards and monitor performance and quality as well as to collect statistics. An appointed doctor has a contractual responsibility to the employer of the person who is examined but also has responsibilities to HSE.

10.3.4. Information on the procedures for appointment of doctors by HSE is given at https://www.hse.gov.uk/doctors/information.htm.

10.4. Duties of the appointed doctor

10.4.1. HSE's general guidance for appointed doctors is given at https://www.hse.gov.uk/doctors/index.htm . HSE guidance for appointed doctors under the WCA Regulations is set out at "Guidance for appointed doctors on the Work in Compressed Air Regulations 1996" (MS35), see https://www.hse.gov.uk/pubns/ms35.pdf.

10.4.2. The role of the appointed doctor is set out in MS35 and comprises:

10.4.2.1. The role of the appointed doctor is set out in MS35 and comprises –

10.4.2.2. examine all those proposed for work in compressed air and certify medical fitness before each worker is initially exposed to increased pressure;

10.4.2.3. assess and certify continuing fitness of all workers at a suitable frequency;

10.4.2.4. maintain accurate and comprehensive clinical records;

10.4.2.5. provide workers with information on the health effects associated with work in compressed air;

10.4.2.6. submit statistical returns on request.

10.4.3. With the individual's consent their general practitioner may be informed that examination for work in compressed air has taken place, and of the resulting assessment of fitness;

10.4.3.1. Records should be kept in accordance with the requirements of the General Data Protection Regulations (GDPR).

10.5. Content of medical examination

10.5.1. For detailed requirements for medical examinations reference should be made to the current edition of HSE publication "Guidance for appointed doctors on the Work in Compressed Air Regulations 1996 – Medical surveillance of workers undertaking work in compressed air" https://www.hse.gov.uk/pubns/ms35.pdf.

10.6. Combination of roles

10.6.1. It is not intended that there should be a duplication of medical practitioners involved in providing services on any one contract. The particular designations indicate differing roles and responsibilities and it will usually be the case that the duties of the contract medical adviser and the appointed doctor will be carried out by the same individual.

10.6.2. Although it is open to employers to propose any doctor appointed under the WCA Regulations to undertake the medical surveillance of their employees, it is strongly recommended that, to provide medical continuity, the contract medical adviser should normally always be selected for this role, resulting in one practitioner having both responsibilities.

10.6.3. A possible exception is for an employer whose geographical base is distant from the site of the work and who may involve a local appointed doctor to make pre-exposure examinations. Where more than one appointed doctor is involved in a contract, the contract medical adviser will need to co-ordinate their activities including the development of any formal occupational health plans or strategies to deal with specific health hazards that have arisen.

10.6.4. If more than one appointed doctor is involved in a contract, the contract medical adviser will need to provide information about the nature of the contract and the intended work to the other appointed doctors and advise the other doctors regarding the fitness standards which will be accepted, any clinical governance issues relevant to the project and provide specialist professional advice or support for individual clinical case management when required.

10.7. Medical facilities

10.7.1. Appropriate medical facilities should be arranged by the compressed air contractor. Usually these will be close to or on the tunnel construction site where office space or accommodation is often limited.

10.7.2. Appointed doctors should have the facilities needed to conduct examinations effectively and with courtesy and compliance with HSE requirements.

10.7.3. Two medical examination rooms are the ideal to facilitate technician tests and a doctor's medical examination room. MLA/hyperbaric supervisor/lock attendant office facilities should also be provided and can be sited alongside/with the medical facilities where site location space is limited. Appropriate patient waiting space should also be provided.

10.7.4. Other facilities required include:

10.7.4.1. premises which comply with national health and safety and fire regulations

10.7.4.2. efficient reception arrangements, even when another medical is in progress

10.7.4.3. a clean, warm and adequately furnished waiting area/consulting room which enables confidential conversation to take place

10.7.4.4. hand washing facilities in the consulting room

10.7.4.5. arrangements for urine sampling which are discreet, clean, have hand washing and toilet facilities and which do not involve samples being carried through patient areas

10.7.4.6. adequate lighting, in terms of brightness and colour balance, for examination and vision testing

10.7.4.7. arrangements for audiometry and fitness testing either on site or readily accessible.

10.7.4.8. any infection control and clinical waste disposal requirements are met.

10.7.4.9. email and IT facilities

10.7.4.10. lockable facilities for confidential medical records/form storage

10.7.5. All such medical facilities should be assessed prior to start-up by the appointed doctor/contract medical adviser and hyperbaric supervisor to confirm their suitability for use and that current statutory and good clinical requirements are met.

10.8. Assessment of continuing fitness for work

10.8.1. A thorough annual medical examination and the reporting of minor illnesses which may affect fitness for work will help to ensure that individuals are not at risk of hyperbaric illnesses as a result of underlying medical conditions. However, it is considered advisable that the continuing fitness of individuals for work in compressed air should be monitored by the appointed doctor during the course of a contract.

10.8.2. The monitoring needs to comprise a review of the health of the individual along with information on sickness absence records, compressed air work history and any reported

discomfort or ill health arising from exposure to compressed air. The review needs to take place at the compressed air site where detailed records of exposure are available and where information can be obtained from lock attendants, people in charge and individual workers. The review may include an examination of the ears, nose and throat, or other systems, at the discretion of the doctor.

10.8.3. Appropriate intervals for such assessments of fitness are once every three months for work taking place at pressures below 1.0 bar(g); and monthly when pressures are 1.0 bar(g) or over. More frequent assessments may be required at the appointed doctor's discretion when the work involves arduous physical activity, mixed gas or saturation applications.

10.9. Additional medical examinations

10.9.1. Examination should also be made of any worker whose continuing fitness for work in compressed air is called into question. No one should be further exposed to compressed air following an episode of decompression illness without having a medical assessment by the appointed doctor.

10.9.2. The appointed doctor should ensure all workers certified fit for work in compressed air are made aware of the health risks of such work.

10.10. MRI screening

10.10.1. Although not required by HSE guidance for appointed doctors, it is open to the contract medical adviser to advise that screening for dysbaric osteonecrosis should be undertaken where medically indicated.

10.10.2. Consideration of the medical need for MRI screening should take account of previous episodes of pain-only DCS and the length of a person's career in compressed air tunnelling especially if working in locations where oxygen decompression was not undertaken routinely.

10.10.3. In recent years the routine radiological screening of long bones for dysbaric osteonecrosis has ceased due to concerns over radiation and Magnetic Resonance Images (MRI) have replaced X-rays for all routine screening of dysbaric osteonecrosis. Some radiological examinations for dysbaric osteonecrosis may still be carried out after an individual "risk-benefit" clinical analysis has been completed.

10.10.4. When acting on the advice of the contract medical adviser, MRI screening should be arranged by the compressed air contractor. In these circumstances all payments for MRI screening are the responsibility of the compressed air contractor and the facility undertaking the screening as well as the individual worker should be aware of this.

10.10.5. The contract medical adviser should ensure that all workers being screened are briefed on their individual MRI results (specifically in terms of negative or positive results for dysbaric osteonecrosis). However, MRI long bone and shoulder/knee joint examinations

frequently highlight other findings that may not be of any clinical significance and these should be fully explained to avoid unnecessary anxiety.

10.10.6. An appropriate screening protocol including MRI if clinically justified, should be developed by the contract medical adviser as part of any final or "exit" screening procedures and this should be implemented on completion of compressed air work exposures.

10.10.7. Recommendations for radiological skeletal surveys for the detection of osteonecrosis were published by the Medical Research Council Decompression Sickness Panel in "Radiography" June 1981, pp 141-143. The Medical Research Council Decompression Sickness Panel was eventually disbanded, and its role taken over by the BTS Compressed Air Working Group. An updated copy of "Radiographic Appearances of BONE LESIONS in Compressed Air Workers" can be downloaded from the BTS website. The BTS Compressed Air Working Group continues to monitor screening methods for dysbaric osteonecrosis including MRI and CT scanning, and this guidance will be reviewed periodically.

10.11. Screening for Osteonecrosis

10.11.1. For those who will work at pressures of 1.0 bar(g) or over the possibility of osteonecrosis should be considered. Long-bone screening is not required as part of routine surveillance of compressed-air workers for pressure exposures below 1 bar(g). However long-bone assessment is indicated in cases of suspected dysbaric osteonecrosis.

10.11.2. Those who work in compressed air at pressures of 1.0 bar(g) or over, run the risk of developing dysbaric (or aseptic) osteonecrosis, a chronic degradation of the bones. When this occurs part of the normal bone structure is replaced by new, weaker bone. Most bone necrosis occurs in the shafts of the long bones where it is symptomless and causes no disability. Less commonly, the site of the bone damage is close to a joint surface in the shoulder or hip where there is a danger that the joint surface will collapse (juxta-articular lesions) as a result of wear and tear. This creates a painful joint with only limited movement for which surgical joint replacement is the only treatment.

10.11.3. The Contract Medical Adviser should review a worker's previous history of work to assess if there is a history of exposure to compressed air or occurrence of Type 1 decompression sickness when determining if pre-exposure screening of the long bones to identify any pre-existing disease is necessary.

10.11.4. For workers who have been exposed to a pressure of 1.0 bar(g) or over it is good clinical practice for the Contract Medical Adviser to consider MRI screening of the long bones soon after exposure to compressed air ceases (or after 12 months by radiological examination if deemed necessary or MRI scan is contra-indicated) as part of routine health screening. This is particularly relevant for example, for workers who intend to continue a

career working in compressed air or who have experienced episodes of decompression illness during the course of work.

10.11.5. If the person concerned continues to be with the same employer on the date when the follow-up examination is recommended to take place, the employer should arrange for this to be done by the contractor medical adviser. The contract medical adviser may also, with the worker's consent, notify their general practitioner of the need for follow-up screening via the National Health Service if not completed through the contract medical adviser during project employment.

10.11.6. Workers experiencing pain only (Type 1) decompression sickness should also be considered for MRI scanning as part of the assessment of their fitness to return to work.

10.11.7. It is also open to the contract medical adviser to recommend to the compressed air contractor, MRI screening of long bones on the basis of individual clinical need at any time during the work in compressed air.

10.12. Health record

10.12.1. The results of medical surveillance are required to be recorded in a Health Record which is maintained by the employer for each worker. The Health Record will contain personal details of the worker and space to record the date, type and result of each medical assessment. The result may be that a person is fit to work in compressed air, fit to work subject to certain restrictions or is unfit to work either temporarily or permanently in compressed air. The Health Record will need to contain information on the items listed in clause 10.15.

10.12.2. The Health Record is the employer's statutory record of the results of medical surveillance and will be retained by the employer at the end of a contract for a period of 40 years. The appointed doctor will retain the detailed clinical records. Individual employees should be given a personal "Compressed air worker's health and exposure record" which summarises the results of their medical surveillance, their hyperbaric experience and also the training which they have received. The health section in the individual health and exposure record will duplicate the employer's health record. Personal copies of the compressed air worker's Health Record describe part of an individual's medical history and workers may find it useful to bring the record to the attention of their general practitioner. Under regulation 10(3)(a) the Health and Safety Executive has approved the particulars to be contained in a Health Record and can approve future changes.

10.12.3. All Medical Records, forms and certificates need to be stored with adequate security in locked containers.

10.12.4. The results of medical surveillance are required to be recorded in a clinical examination record which is maintained by the appointed doctor for each worker. The clinical examination record will contain personal details of the worker and the relevant

examination findings of initial and interim health surveillance checks after each medical assessment, and the copies of MRI reports (where relevant).

10.12.5. When paper records are used the compressed air contractor is responsible for providing appropriate storage facilities - normally a lockable filing cabinet held securely in the medical examination facilities on site with appropriately restricted access and in accordance with the requirements of the contract medical adviser.

10.12.6. Data protection legislation should be followed for electronic clinical examination records. Such data must be stored, processed and destroyed securely, confidentially and appropriately as laid down in the Data Protection Act 2018, which implements the EU GDPR legislation.

10.12.7. In all cases records should be maintained and stored in strict compliance with the ethical, legal and medical confidentiality requirements of the Faculty of Occupational Medicine and General Medical Council.

10.13. Work restrictions specified in the health record

10.13.1. Restrictions which may be placed include those on the maximum pressure to which a person should be exposed; the maximum duration of exposure per shift; the number of entries to be made per day or date of next assessment. Any restrictions relating to the use of breathing mixtures or undertaking saturation exposures should also be noted. Employers are required to ensure that any such restriction is brought to the attention of the compressed air contractor so that lock attendants can be notified. Any list of those fit to enter compressed air needs to be clearly marked to indicate that a restriction applies to the person concerned, and a note of the nature of the restriction retained.

10.14. Availability of medical records

10.14.1. HSE's current guidance for appointed doctors, MS35(rev1) notes at clause 19 that "Where the findings of an earlier medical examination by another appointed doctor are available, the current appointed doctor can use discretion to decide whether to accept those findings as proof of fitness. In making a decision, they should consider the time since the medical examination and whether the findings are complete. If necessary, they should conduct another examination".

10.14.2. It is recommended that the findings of an earlier medical examination by another appointed doctor within the immediately preceding four weeks may be accepted as proof of fitness if no restriction has been made. For work at pressures below 1.0 bar(g) this period can be extended to 13 weeks. Where longer periods have elapsed, a fresh examination should be made, the content of which will depend on the intended working pressure and the availability of information from the previous medical examination. HSE recommends that appointed Doctors should co-operate in making the results of previous medical surveillance available thus minimising unnecessary examinations. Records should be held on site to facilitate this.

10.15. Maintenance of compressed air worker's health and exposure record

10.15.1. Employees have a personal responsibility to safeguard their health and exposure record and to present it to their employer so that it can be updated and checks made prior to entry into compressed air. All lists of personnel fit to enter the workings need to be kept up to date.

10.15.2. An individual's compressed air worker's health and exposure record should be retained by the compressed air contractor until work in compressed air is completed or the person leaves employment. During that time, it needs to be readily available to the person named on it or his or her employer.

10.15.3. At the end of a contract or when workers leave employment, their compressed air worker's health and exposure records are required to be returned to them updated to include:

10.15.3.1. name and details of the appointed doctor or employment medical adviser;

10.15.3.2. details of all medical surveillance;

10.15.3.3. details of exposures, decompressions and any decompression illness.

10.15.4. The compressed air contractor may wish to obtain a signed receipt from the individual acknowledging that this has been done.

10.16. Duty to submit to medical surveillance

10.16.1. As the medical examination has an important role in the prevention of hyperbaric illness, no person can be exposed to compressed air without first having undergone medical surveillance. All people who intend to work in compressed air will, therefore, have to submit to medical examination by an appointed doctor (or employment medical adviser) and to co-operate fully, particularly in the provision of accurate information about any relevant medical condition, or past history of illness arising from exposure to compressed air.

Regulation 11 Compression and decompression procedures

(1) The compressed air contractor shall ensure that compression or decompression of any person engaged in work in compressed air is carried out in accordance with any procedures approved by the Executive.

(2) The compressed air contractor shall ensure that no person shall be subjected to a pressure exceeding 3.5 bar except in an unforeseen emergency.

(3) The compressed air contractor shall ensure that no person shall be subjected to the procedure of decanting except in an emergency.

(4) The compressed air contractor shall ensure that an adequate record of exposure is made and maintained in respect of the times and pressures at which work in compressed air is undertaken and that the record or a copy thereof is kept in a suitable form for at least 40 years from the date of the last entry made in it.

(5) The compressed air contractor shall ensure that an individual record of exposure containing the information specified in paragraph (6) is made and maintained in respect of each person who undertakes work in compressed air and that the record or a copy thereof is kept in a suitable form for at least 40 years from the date of the last entry made in it.

(6) The record referred to in paragraph (5) shall contain the date, time of entry, duration and maximum pressure of each exposure and decompression details of each exposure to which the person to whom the record relates is subjected.

(7) The compressed air contractor shall ensure that, as soon as is reasonably practicable after a person has ceased to work on any project -

(a) the employer of that person is provided with a copy of such part or parts of the record made pursuant to paragraph (4) as relate to that person; and

(b) that person is provided with a copy of such part or parts of the record made pursuant to paragraph (5) as relate to him.

(8) An employer who is provided with a copy of a record pursuant to paragraph (7) shall ensure that the record or a copy thereof is kept in a suitable form for at least 40 years from the date of the last entry made in it.

11. Guidance relevant to Regulation 11

11.1. **Selection of compression and decompression procedures**

11.1.1. Tables which are new or unproven should not be used on site until it has been established that they are likely to be acceptably safe (see Report 10 section 3). Once selected for use on site, their effectiveness in practice should be demonstrated.

11.1.2. Guidance on establishing the effectiveness of decompression tables through the use of physiological monitoring is set out in cl 11.8.

11.1.3. The Compressed Air Contractor should have selected appropriate procedures for compression and decompression as part of the safe system of work required by Regulation 7 and in doing so have taken account of guidance relating to Regulation 11 also.

11.1.4. HSE no longer has approved procedures under Regulation 11(1) which contractors are required to use. Compressed air contractors should therefore select procedures which have a proven record of effectiveness or undertake appropriate testing of procedures to demonstrate their effectiveness in providing a safe system of work for those who are entering and working in compressed air under their control.

11.1.5. Annex 2 sets out procedures which were published in earlier versions of this guidance and may still be used for air mode exposures if they provide a safe system of work for the operations being undertaken. Other decompression procedures may be considered for use.

11.1.6. The compression and decompression of people should only take place in a personnel lock under the control of a competent lock attendant in accordance with the selected procedures.

11.1.7. Everyone entering compressed air needs to be made aware of the responsibilities of the lock attendant.

11.1.8. Anyone who chooses to ignore any of the procedures for compression and decompression, or to flout the authority of the compressed air contractor as exercised by the lock attendant should be disciplined appropriately.

11.2. New starts and familiarisation

11.2.1. No-one without previous experience of air mode compressed air work or of commercial air diving should undertake work involving the use of breathing mixtures.

11.2.2. Those with no previous experience of compressed air work need to have a 'lock test' in which they experience the compressed air environment as part of their assessment for suitability for this type of work. This should be overseen by the hyperbaric supervisor or contract medical adviser.

11.2.3. For intermediate range exposures of 1.0 bar(g) and over, familiarisation shifts should be worked by all those new to work in compressed air.

11.2.4. It is normal practice for familiarisation shifts to be timed so that decompression occurs with other members of the shift.

11.2.5. During compression and decompression to working pressures, new starters need to be accompanied in the personnel lock by a colleague competent to advise them on procedures to be followed.

11.2.6. The contract medical adviser should advise on matters of familiarisation.

11.2.7. In determining the familiarisation procedures, the contract medical adviser should consider the working pressure, the nature of the work to be done in compressed air as well as the work environment.

11.2.8. The contract medical adviser should also consider whether additional familiarisation is required to accommodate subsequent increases in working pressure or changes in temperature and whether a re-familiarisation procedure is required for workers following a period of absence from work in compressed air.

11.2.9. Inadequate physical fitness is thought to contribute to the occurrence of decompression illness. If the work to be done on any particular contract involves a change in work patterns, e.g. the introduction of manual excavation, it is advisable to make provision for familiarisation to the change to more arduous physical labour.

11.2.10. Those undergoing non-saturation exposures involving the use of breathing mixtures should undergo at least one familiarisation shift.

11.2.11. Those undergoing saturation exposures should be made familiar with the habitat, the personnel lock and working chamber on the TBM as well as with TUP procedures.

11.2.12. Anyone who is unfamiliar with the tunnel environment and tunnel safety including those with commercial diving experience but new to the tunnelling environment should have appropriate induction training to familiarise them with the tunnel environment and the personal safety competences required for it. This should be in addition to any hyperbaric familiarisation required.

11.3. Compression – non saturation exposures

11.3.1. The lock attendant should ensure that the procedure for compression selected by the compressed air contractor is followed and that those undergoing compression have been briefed on it.

11.3.2. No one who, due to illness, is unfit for work in compressed air should be compressed.

11.3.3. Exceptionally there are people who have episodes of 'pain only' decompression illness (e.g. 'niggles') and suppress it by getting back into compressed air each day. Whenever such behaviour is suspected, the person needs to be excluded from work in compressed air and referred to the compressed air contractor and contract medical adviser immediately.

11.3.4. For record-keeping purposes, it is recommended that the starting time of all 24-hour periods be defined as the start of dayshift on the contract, e.g. 07.00 hours.

11.4. Limits on exposure, including multiple exposures

11.4.1. People exposed to low or intermediate pressure compressed air need to spend at least 12 consecutive hours at atmospheric pressure in any 24-hour period.

11.4.2. Except in an emergency, no one should work in compressed air at pressures up to 0.7 bar(g) for periods of time longer than 8.5 hours in any 12-hour period.

11.4.3. Except in an emergency, it is recommended that no one undergoing non-saturation exposures should be exposed to a maximum working pressure of between 0.7 bar(g) and 3.45 bar(g) for an exposure period including decompression of longer than 8 hours. If necessary, to ensure the safety of the tunnel, this may be extended to a total exposure period of 8.5 hours to allow shift change-over at the face.

11.4.4. For high pressure non-saturation exposures, the guidance in Report 10 clause 8.11 should be followed. Only a single exposure per shift is permitted.

11.4.5. For exposures during which the working pressure has varied e.g. as a result of tidal fluctuations, the limits on exposure period and decompression required should be determined on the basis of maximum working pressure experienced during the exposure.

11.4.6. Multiple exposures to compressed air at pressures of 0.7 bar(g) or over in any working shift should, where possible, be avoided. However, people such as the clients' representatives, engineers and maintenance staff, do undergo multiple exposures but should be limited to three periods in the working chamber and at not more than 3.45 bar(g) pressure, in any 8-hour period. Thereafter, they will need to spend at least 12 hours at normal atmospheric pressure. The total exposure to compressed air in the 8-hour period should not exceed the maximum permissible exposure for that pressure, were it to be experienced in a single exposure. The appropriate decompression regime after multiple exposures is:

11.4.6.1. the first exposure period - a normal decompression for that exposure;

11.4.6.2. subsequent exposure periods - normal decompression for which the exposure period is the total exposure period for that working shift excluding any time spent earlier in that shift on decompression, at the maximum pressure experienced during the shift;

11.4.6.3. when deriving decompression times for multiple exposures, the maximum pressure of any of the up-to-three exposure periods will determine the pressure component of the table to be used.

11.4.7. On a site where there is more than one point of entry to, or egress from, work in compressed air, the compressed air contractor will need to operate a system of record-keeping and information transfer to ensure that each lock attendant is fully aware of the pressure and duration of any previous exposure(s) to compressed air during the current shift.

11.5. Decompression

11.5.1. Normally for intermediate pressures the decompression procedure chosen by the compressed air contractor should include an oxygen breathing period with air breaks. If necessary, the compressed air contractor should also identify an emergency air decompression regime for use in the event of failure of the oxygen system. Decompression should be carried out by the lock attendant strictly in accordance with the

chosen decompression regime and in the event of any interruption to the oxygen decompression procedure the lock attendant should continue the decompression in accordance with the chosen emergency air decompression regime.

11.5.2. With most decompression regimes oxygen breathing occurs during the latter stages of pressure reduction. However, it is known that bubbling continues for some time after atmospheric pressure has been reached.

11.5.3. The technique of post decompression surface oxygen breathing is no longer used in UK but could prove a useful adjunct to air decompression tables in locations where there is not the capability for safe staged oxygen decompression. The technique involves the extension of the decompression process to include the routine administration of oxygen at either atmospheric pressure or at raised pressure of up to 1 bar(g) for a period of around 30 minutes within the first hour following the initial return to atmospheric pressure. The technique could be considered acceptable if shown to meet the criteria for effectiveness of decompression in clause 11.8. This technique should only be used where it is not possible to administer oxygen during the pressure reduction phase of the decompression.

11.5.4. The following procedure for decompression should be considered for adoption.

11.5.4.1. Prior to decompression commencing, the lock attendant should check that the volume of oxygen immediately available for use is sufficient for the decompression, any subsequent therapeutic treatment and the decompression of a rescue team and any tender accompanying a casualty. The lock attendant should also carry out a functional test on the BIBS system and flush the chamber with air on completion.

11.5.4.2. All sources of oxygen supply should be connected but their valves should be shut until required for use.

11.5.4.3. Immediately prior to the commencement of oxygen breathing, the appropriate cylinder valves should be slowly and carefully opened under the direct control of the lock attendant.

11.5.4.4. At the start of the first oxygen breathing period, the lock attendant should instruct people being decompressed to put on masks. Oxygen breathing should be undertaken with appropriate air breaks, as required by the chosen decompression regime.

11.5.4.5. The lock attendant should regularly monitor the oxygen pressure in both the high pressure supply and low pressure supply at the control panel. The lock attendant should change over cylinders as required. Normally it should be possible to do this without disrupting flow, if not it should be done at times of zero flow in the system.

11.5.4.6. In the event of the personnel lock atmosphere becoming enriched above 23% oxygen by volume, the lock attendant should ventilate the chamber until the oxygen concentration returns to below 22% and advise the hyperbaric supervisor.

11.5.4.7. In the event of any fire in the tunnel, airlocks or working chamber, the lock attendant should immediately advise the hyperbaric supervisor, shut off the flow of oxygen to the personnel manlock and initiate the appropriate emergency procedures. If relevant, the oxygen supply should also be shut off at the surface.

11.5.4.8. In the event of failure of the atmospheric monitoring or ventilation system, the lock attendant should immediately advise the hyperbaric supervisor, shut off the flow of oxygen to the personnel lock and complete the decompression on the emergency air table until the relevant system has again become operative.

11.5.4.9. In the event that the oxygen concentration in the general body of air in the tunnel should rise above 23%, the oxygen supply to the personnel lock should be turned off at the point of high pressure supply and the decompression completed as an emergency air decompression. The hyperbaric supervisor should be advised of the incident.

11.5.4.10. On completion of the decompression, the lock attendant should ensure all valves on the oxygen supply system are shut off and that appropriate cleaning, flushing and maintenance of the personnel lock including the BIBS is carried out.

11.6. Decompression following use of breathing mixture

11.6.1. The compressed air contractor should select an appropriate decompression regime and emergency decompression regime for use with the relevant breathing mixture(s) before commencement of the work in compressed air. The contractor should be able to demonstrate the chosen regime meets the effectiveness criteria.

11.6.2. Decompression should be carried out strictly in accordance with the chosen decompression regime. In the event of an interruption to the decompression procedure, the lock attendant should advise the hyperbaric supervisor and continue the decompression in accordance with the predetermined emergency decompression regime (see Report 10 clause 7.9).

11.7. Decompression – general precautions

11.7.1. If an electronic control system is used to control the decompression, the lock attendant or life support supervisor will need to ensure that the decompression procedure is accurate. In the event of failure of the electronic system, it will be necessary for the lock attendant or a life support technician to control the decompression manually and ensure that the hyperbaric supervisor or life support supervisor is regularly informed of progress.

11.7.2. The hyperbaric supervisor or life support supervisor along with the contract medical adviser need to be informed in the event of someone collapsing or being taken ill during decompression.

11.7.3. If ear block occurs during decompression, a small increase of pressure of 0.1 bar may be sufficient to relieve the problem.

11.8. Effectiveness of decompression - physiological monitoring

11.8.1. Whenever it needs to be established that tables are effectively safe in practice the guidance in clause 11.8 should be followed. This applies also to high pressure compressed air work (see Report 10 section 3),

11.8.2. One method of demonstrating the effectiveness of the decompression tables selected, is by the use of Doppler monitoring based on the Kisman Masurel scale. The monitoring site chosen should be carefully considered. Whilst precordial monitoring by experienced observers is preferred during the initial stages of proving the effectiveness of a table, monitoring of the sub-clavian vein can be used for routine monitoring once the table has been shown to be effective.

11.8.3. The monitoring should follow the recommendations in “Consensus guidelines” for the use of ultrasound for diving research” by Møllerløkken A, Blogg SL, Doolette DJ, Nishi RY, Pollock NW. and published in Diving and Hyperbaric Medicine. 2016 March; 46(1):26-32.

11.8.4. Other techniques may become available during the lifetime of this document and will be equally acceptable if they meet the “Consensus guidelines” criteria in clause 11.8.

11.8.5. Unless the information is already available, trials should be undertaken as required to establish appropriate endpoints for the monitoring. The endpoint for monitoring should be considered to be reached when at least four out of five (pro rata) of those monitored show both a downward trend in bubble scores and have two consecutive results at grade 2 or below. When bubble scores never exceed grade 2, the end point should be after monitoring has been undertaken for a minimum of 60 minutes following decompression and scores remain constant or are decreasing. Measurement intervals in the first 120 minutes following decompression, should be no greater than 30 minutes.

11.8.6. Initially and until the practical effectiveness of a table has been confirmed, monitoring should be undertaken following every use of the tables and persons exposed should be monitored at least once every two exposures. As confidence in the effectiveness of the table increases, the frequency of monitoring may be progressively reduced at the discretion of the contract medical adviser in consultation with the technician undertaking the Doppler monitoring. Once the tables have been shown to be effective, routine compliance monitoring to demonstrate the ongoing effectiveness of the decompression should be at a rate determined by the contract medical adviser but of no less than 10% of exposures spread uniformly across all those exposed and each occasion on which exposures are undertaken. The contract medical adviser should request an increase in monitoring frequency as appropriate, if the pressure or period of exposure is increased or

if there is a deterioration in the routine monitoring results and take appropriate action thereafter to ensure the effectiveness criteria are met.

11.8.7. A decompression regime should be considered effective if one or other of the criteria below is met:-

11.8.7.1. not more than 20% of results exceed Grade 2 with insignificant number of Grade 4s and insignificant DCI rate, or

11.8.7.2. for the first 120 minutes of monitoring following decompression, a Kisman Integrated Severity Score (KISS) should be determined and should not exceed 50.

11.8.8. The criteria apply equally to air, heliox or trimix exposures. The criteria represent what is considered by the Compressed Air Working Group of the British Tunnelling Society to represent an acceptably low risk of DCI, however because of human variation and inter/intra individual response to pressure exposure they do not ensure that DCI will never occur. Any cases of DCI which do occur should be comprehensively reviewed by the contract medical adviser and lessons learned acted upon.

11.8.9. Where tables have been shown to be effective on other contracts, the initial level of monitoring undertaken can be closer to that set out above for the routine monitoring of proven tables.

11.8.10. The monitoring should follow the recommendations in "Consensus guidelines" In particular recommendations 7 and 8 set out the following requirements:-

11.8.10.1. Recommendation 7 - Standard parameters to report include time to onset of non-zero grades, time to maximum grade reached, and maximum grade for individual subjects. In addition, median grade, grade range, and mode can be reported; all measured zero grades should be included.

11.8.10.2. Where possible, raw data should be reported. Bubble grade data are most appropriately analysed non-parametrically.

11.8.10.3. Recommendation 8 - Measurements should be recorded and preserved for future review. This includes audio and visual files, as appropriate for the technology employed.

11.8.10.4. These recommendations ("Consensus guidelines for the use of ultrasound for diving research" by Møllerløkken A, Blogg SL, Doolette DJ, Nishi RY, Pollock NW.) hold for all monitoring sites and should ensure consistency of previous recording and reporting with UK compressed air doppler measurements over the past 20 years.

11.8.10.5. If time/resources are limited, it is recommended that pre-cordial remains the priority and should be performed in preference to sub-clavian. Ideally both sites should be interrogated and should verify each other, particularly if the "flex" or "exercise" recording can be made as well. These data will all add to a fuller picture of

the systemic gas emboli load and assist the development of safer decompression tables over time.

11.9. Emergency decanting

11.9.1. Emergency decanting procedures should only be considered for low and intermediate pressure applications and should be set out in advance by the contract medical adviser in conjunction with the hyperbaric supervisor as part of the overall site emergency procedures which the compressed air contractor should prepare.

11.9.2. In some emergency situations it is preferable to remain under pressure in the personnel lock or working chamber and this should be assessed as part of the tunnel emergency procedures. Decanting at low or intermediate pressure should only be carried out as a means of evacuating the tunnel in an emergency, e.g. following fire or inundation of the workings. In such an event all those in the working chamber should return to the personnel lock immediately and be decompressed to atmospheric pressure as rapidly as the situation demands. The hyperbaric supervisor should ensure that the appropriate emergency procedures are then implemented.

11.9.3. Those decanted should be immediately transferred to the medical lock and be recompressed to the working pressure; held at this pressure for ten minutes; and then be decompressed to atmospheric pressure in accordance with a therapeutic treatment table.

11.9.4. The contract medical adviser should be informed immediately the decision to decant is made.

11.9.5. Given that in long tunnels the personnel lock could be a considerable distance from the surface medical lock, decanting as classically understood would not be possible and a form of accelerated emergency decompression would be required instead.

11.9.6. Guidance on accelerated emergency decompression from saturation are set out in clause 10.2 of Report 10. Further medically relevant information can be found in "Accelerated Emergency Decompression from Saturation in Commercial Diving Operations" Report of a Workshop held on 13 April 2011 in London, UK. see http://www.dmac-diving.org/guidance/DMAC-Workshop-20110413.pdf.

11.10. Keeping of decompression records

11.10.1. For low or intermediate pressure exposures, the compressed air contractor is required to keep all decompression records on site for the duration of the work in compressed air. Thereafter, compressed air contractors are required to arrange for the records to be kept, for example, at their registered offices or that of any successor company for a further 40 years. During that time the records need to be accessible to HSE. Individuals, or their agents, whose names appear in the records should have access to their own records. A copy of the decompression tables used should be kept with the records. The records should be kept in a non-paper form such as microfiche or electronic storage medium. In addition, each employer is required to keep a copy, provided by the

compressed air contractor, of the records relating to their employees and retain them in a similar manner.

11.10.2. For non-saturation exposures with breathing mixtures, records of pressure and time of use along with composition of breathing mixtures used should be kept as part of each exposure record.

11.10.3. **Records for saturation exposures**

11.10.3.1. For saturation exposures the compressed air contractor should ensure a daily log is kept from first compression to end of final decompression for each saturation run, detailing with times, all changes in pressure and gas used to affect these changes, nominal composition of breathing mixtures used, use of masks/umbilicals, all interventions and excursions, activity in habitat, health checks, chamber, shuttle and TBM lock atmosphere checks along with adjustments made, docking manoeuvres, unusual or adverse events, and other relevant information.

11.10.3.2. In respect of gas supplies, records should include quality checks on gas delivered to site and on gas put into service, gas analysis data from control panel suppling habitat, shuttle, locks or umbilicals and daily volumes used.

11.10.3.3. In respect of personnel, records for each shift of persons in saturation, persons undertaking interventions or excursions, lock attendants, life support personnel and supervisors for habitat, shuttle and TBM locks.

11.10.4. Records from contracts run by a joint venture formed from a number of UK and/or non-UK based companies need to be kept by all members of the joint venture.

11.11. Compressed air worker's health and exposure record

11.11.1. Employers should provide each of their employees with a personal health and exposure record. Copies of a logbook, *Compressed air worker's health and exposure record*, which contains the details required by the Regulations are available from HSE Books. Other layouts may be used but the minimum details needed are listed below.

11.11.2. The compressed air worker's health and exposure record needs to contain the following information:

11.11.2.1. personal details of the employee including name, national insurance number, date of birth, address (permanent);

11.11.2.2. details of the employer - name and address

11.11.2.3. contracts at which employee was exposed to compressed air

11.11.2.4. details of appointed doctor including name, address and telephone number;

11.11.2.5. details of contract medical adviser (if different) including name, address and telephone number;

11.11.2.6. details of medical surveillance;

11.11.2.7. date, type and result of each assessment, including any restriction imposed on the exposure of the employee

11.11.2.8. details of exposure including date, shift, maximum working pressure and working period for each exposure;

11.11.2.9. details of training;

11.11.2.10. date of the instruction and training required by regulation 15

11.11.2.11. sat and mixed gas.

11.11.3. The compressed air contractor should ensure that the compressed air worker's health and exposure record is completed and handed to the compressed air worker as soon as is reasonably practicable after that worker has ceased to work on the project.

11.11.4. Compressed air workers should be provided with the results of their medical and health surveillance, a record of their exposure to compressed air and details of training undertaken. The health section should duplicate the employer's health record and the exposure section should duplicate the individual exposure record.

11.11.5. This health and exposure record is the personal property of the compressed air worker who should keep it securely between contracts as they will need to present it to their employer when they next apply to work in compressed air. The employer will pass them to the compressed air contractor before such work is started.

11.11.6. Visitors to compressed air projects will need to give their compressed air worker's health and exposure record directly to the compressed air contractor prior to entering compressed air.

11.12. End of contract report

It is recommended that on completion of the compressed air work, the compressed air contractor should compile a comprehensive anonymised summary report covering the exposure history, the decompression tables used and any decompression illness experienced. For mixed gas exposures the gas mixtures used should be recorded and for saturation exposures a record of the storage pressures along with excursion pressures and times should also be included. A copy should be passed to the Client and the principal contractor. A copy of the report should also be made available in confidence to the BTS Compressed Air Working Group along with relevant comment on problems encountered through use of the guidance to allow BTS CAWG to monitor the effectiveness of this guidance.

Regulation 12 Medical treatment

(1) Every compressed air contractor shall ensure that adequate facilities are provided and maintained for the treatment of persons working in

compressed air and for the treatment of persons who have worked in compressed air within the preceding 24 hours.

(2) In the case of work undertaken at a pressure of 0.7 bar or above, the facilities referred to in paragraph (1) shall include -

(a) a medical lock;

(b) a person competent to operate that lock; and

(c) a person (whether the same or in addition to the person referred to in sub-paragraph (b) above) competent to provide medical assistance in respect of any condition arising from such work.

(3) In the case of work undertaken at a pressure of 1.0 bar or above, the facilities referred to in paragraph (1) shall include -

(a) a medical lock; and

(b) the presence of a person competent both to operate that lock and to provide medical assistance in respect of any condition arising from such work, which person shall be employed specifically for such purposes.

12. Guidance relevant to Regulation 12

12.1. Medical treatment - general provisions

12.1.1. Regulation 12 requires the compressed air contractor to make preparations for the medical treatment of anyone who is currently working in compressed air such as those in saturation or who has worked in compressed air within the previous 24 hours.

12.1.2. The facilities required are determined by the maximum working pressure and are set out in Regulations 12(2) and 12(3). Where the pressure in a working chamber is above 0.7 bar(g) but not above 3.5 bar(g), a medical lock will need to be provided and maintained. Above 3.5 bar(g) different provisions may be required depending on exposure techniques in use.

12.1.3. In practice, for intermediate pressure exposures, the requirements of Regulation 12 cover the making of preparations for the treatment of any cases of decompression illness which might arise from the work in compressed air.

12.1.4. This is separate from the need for the provision of first-aid arrangements in the pressurised workings.

12.1.5. In practice the incidence of decompression illness varies with the pressure at which work is undertaken along with the exposure techniques being used. Useful advice on the general operation and staffing of hyperbaric treatment facilities is contained in the "European Code of practice for hyperbaric oxygen therapy" published in 2004.. Annex 4

below gives information on the diagnosis, recording and evaluation of decompression illness.

12.1.6. Below 0.7 bar(g), the risk of decompression illness arising is extremely low. Only very rarely has decompression illness been reported below 0.7 bar(g). For work below 0.7 bar(g), in the very unlikely event of a case of decompression illness occurring, recompression should be undertaken in the personnel lock. However, the hyperbaric supervisor needs to be aware of the location and operational status of the nearest suitable off-site treatment facility and how to contact the facility operators. The person in charge, lock attendants and the contract medical adviser also need access to this information.

12.2. Medical locks – intermediate pressure exposures

12.2.1. The medical lock is best selected by the compressed air contractor in conjunction with the contract medical adviser. Unless requested otherwise by the contract medical adviser the lock should be of an appropriate size, have a headroom of at least 1.8m and consist of an inner (treatment) compartment and an outer (entrance) compartment. The maximum working pressure shall be sufficient to allow therapeutic recompression using US Navy Table 6 schedules (oxygen from 1.8 bar(g)) to be undertaken. The medical lock will normally be located on the surface near to the top of the shaft giving access to the compressed air workings.

12.2.2. Normally the medical lock should meet the requirements for personnel locks in BS EN 12110 as modified by clause 12.2. In addition, it should be equipped with a facility for supplying food, drink and medical supplies to people undergoing therapeutic treatment.

12.2.3. However, if considered appropriate by the contract medical adviser, a lock conforming with the principles of BS EN 14931:2006 “Pressure vessels for human occupancy (PVHO). Multi-place pressure chambers for hyperbaric therapy. Performance, safety requirements and testing” but with a maximum pressure capability meeting the requirements of clause 12.2.1 may be used.

12.2.4. The medical lock will need to be fitted out with suitable equipment, of fire-resistant materials, including a couch not less than 1.85 m long, mattresses, blankets and dry garments. There needs to be a means of verbal communication between each compartment of the lock and the person operating the lock.

12.2.5. The medical lock should be adequately ventilated and heated by means of a thermostatically controlled heating system based on with water as the heat transfer medium. The medical lock needs to be adequately lit by means of an external lighting system or by an internal LED system. The recommended level of illumination is not less than 350 lux at the couch surface.

12.2.6. The medical lock should be fitted with equipment to allow the administration of oxygen, by built-in breathing system (BIBS), to people being treated in the lock, and with a suitable supply of oxygen. The operational requirements for this system are the same as those for

oxygen systems in personnel locks. Fittings and oxygen for three masks to be in operation simultaneously in the medical lock should be sufficient for most contracts.

12.2.7. At least one medical lock needs to be provided for every 100 people working in compressed air per 24 hours.

12.2.8. The medical lock must be kept ready for immediate use while people are working in compressed air and for a period of 24 hours after the last person has been decompressed.

12.2.9. There should also be suitable accommodation for lock attendants/medical lock attendants to undertake record keeping and similar administrative duties. Co-location with the accommodation for medical examinations is to be preferred.

12.3. Medical - administering treatment

12.3.1. The administration of hyperbaric oxygen in the medical lock should be in accordance with the principles of the guidance in this document and under the clinical supervision of the contract medical adviser.

12.3.2. Although there is a possibility of 'pain only' decompression illness occurring between 0.7 bar(g) and 1.0 bar(g), a medical lock attendant is not required to be present as the frequency of cases of decompression illness should be low. However, the hyperbaric supervisor must ensure that someone is available on site who is able to competently perform the duties which would otherwise be undertaken by a dedicated medical lock attendant and who is able to initiate and manage recompression therapy under the direction of the hyperbaric supervisor or contract medical adviser.

12.3.3. Such a person could be the hyperbaric supervisor, a site engineer or a supernumerary lock attendant. He or she will have to have received some basic medical training, more than just first aid, and have knowledge of the presentation and treatment of decompression illnesses. He or she will need to be able to elicit and document basic symptoms and signs and record these and their response to treatment. The contract medical adviser will remain responsible for the management of the medical condition of the worker.

12.3.4. At pressures of 1.0 bar(g) or over, the risk of a case of decompression illness occurring increases and there is the possibility of this being the serious form of the illness. For this reason, it is necessary for the lock to be continuously manned by a medical lock attendant, both during the course of the work and for a period of 24 hours after the last person has been decompressed. The requirements for a medical lock attendant are given in clause 7.6.4.1.

12.3.5. The hyperbaric supervisor should ensure there is a person available who can act as medical lock tender (see clause 7.6.4.2) and enter the medical lock with the casualty if required to provide basic care and monitor their condition. The tender does not need to be a dedicated role but could be the medical lock attendant provided another person is available to operate the medical lock.

12.3.6. Clinical responsibility for all treatment rests with the contract medical adviser (acting as the hyperbaric duty doctor in the terms of the Faculty of Occupational Medicine Report). Treatment will usually begin on the initiative of the hyperbaric supervisor, life support supervisor or medical lock attendant, after discussion with the contract medical adviser. The casualty needs to be medically examined as soon as this is practicable.

12.3.7. Full clinical records need to be kept of the examination and treatment of all cases of decompression illness. A suitable checklist for the initial examination of the neurological system is given in Annex 3 It is important to document the state of the nervous system after all episodes of illness to ensure that any minor damage is detected. A suitable case sheet for summarising the features of a case of decompression illness is given in Annex 3.

12.3.8. Experience has shown that very occasionally decompression illness can occur during the final stages of decompression or within a few minutes after decompression has been completed on the return to atmospheric pressure. When such a DCI event occurs it is likely to be of the serious type requiring immediate recompression. The procedures in clause 12.7.6 or 12.7.7 should be initiated immediately.

12.4. Medical equipment

12.4.1. The contract medical adviser should ensure that sufficient medical equipment is available for use in the medical lock to enable a full clinical examination of an individual to be made. For low pressure work, statutory first aid requirements should suffice.

12.4.2. For intermediate pressure work, suitable medical equipment needs to be available to facilitate the resuscitation of a shocked casualty. The detailed list of equipment will need to be decided by the contract medical adviser, taking account of the recommendations in current resuscitation guidelines (e.g. trauma and cardiac life support guidelines from Resuscitation Council UK). Reference can also be made to the guidance in the current revision of DMAC 15 “Medical Equipment to be Held at the Site of an Offshore Diving Operation”. Additionally the physical remoteness of the lock from surface facilities and the geographical remoteness of the site should be taken into account.

12.4.3. All medical equipment should be suitable for use in hyperbaric environments and be capable of withstanding pressure changes from compression/decompression. Compliance with the full list of medications and equipment may not be necessary where alternative site arrangements can be made by the contract medical adviser - for example using local ambulance/paramedic/medical support. This will help to avoid storing unnecessary medical equipment and drugs on site and ensure the best resources are used when available.

12.4.4. A further consideration should be that for accidents involving moderate to severe trauma, pain relief with opiate-derived drugs can make matters worse especially when there is high risk of masking incipient DCI and affecting respiratory function. Any other than the basic analgesics are best left until the casualty is being evacuated for definitive treatment.

12.4.5. Where a medical emergency plan requires treatment support or trauma management inside the hyperbaric environment, and it is planned to use external emergency services staff - for example paramedics or ambulance or fire crews - then the contractor should ensure that specific roles and responsibilities and medical equipment requirements are clearly defined.

12.4.6. Any emergency services staff who are expected to enter the medical chamber to assist with emergency medical management in hyperbaric conditions should do so only after an appropriate site medical screening procedure has been completed, and this process should have been approved by the contract medical adviser and the relevant external emergency organisation as part of project emergency planning.

12.5. Medical lock - availability

12.5.1. Except for the lock testing of new starters and in emergencies, the medical lock should only be used for therapeutic recompression. When the medical lock is full or is being used to treat a patient for whom, in the opinion of the medical lock attendant, hyperbaric supervisor or the contract medical adviser, any unnecessary increase in medical lock pressure would have an adverse effect, then work in compressed air should cease until the medical lock is capable of accepting further patients.

12.6. Medical treatment - high pressure exposures

12.6.1. For non-saturation exposures above 3.5 bar(g), the provision of a medical lock and medical lock attendant as required under Regulation 13 should suffice. The contract medical adviser should advise on the maximum working pressure required for the medical lock along with the treatment facilities to be provided in it and the need for any treatment gases other than air or oxygen. The CMA should ensure the medical lock attendants are appropriately trained in any treatment protocols to be followed.

12.6.2. For saturation exposures the risk of decompression illness is likely to be lower than for non-saturation exposures but cannot be discounted totally (see Report 10 clause 7.9). In any case, the need to be able to treat casualties suffering from non-decompression related illness and injury remains.

12.6.3. For saturation exposures the provision of medical facilities needs to cover the treatment of saturation workers for any foreseeable illness or injury which could arise from their work whilst in saturation and to maintain them in saturation along with any necessary medical support until it is deemed appropriate by the contract medical adviser to decompress them – see Report 10.

12.7. **Medical treatment - recompression therapy**

12.7.1. In all cases, persons suffering from symptoms, however slight, which could be due to work in compressed air, should be encouraged to return for treatment. They should not try to treat themselves by taking alcohol and analgesics or waiting until the next shift in compressed air when some temporary relief of symptoms may occur. Anyone reporting

symptoms after decompression should be thoroughly assessed by the medical lock attendant in conjunction with the contract medical adviser as soon as possible after symptoms manifest themselves.

12.7.2. The initial treatment of all forms of decompression illness is recompression therapy. Where there is doubt about the origin of symptoms, then, after discussion with the contract medical adviser, and provided that there are no contra-indications, a single recompression may be informative.

12.7.3. Any recompression therapy should take into account the oxygen exposure already experienced by the person, including the effects of exposure to breathing mixtures during the working shift and any subsequent decompression. Limits on oxygen exposure are given elsewhere in this document.

12.7.4. Recompression therapy should be carried out in accordance with procedures set out by the contract medical adviser. Treatment regimes need to be based on the best available protocols. These could involve the use of recognised therapeutic oxygen tables such as US Navy Tables 6 or 6A or Royal Navy Tables or use of heliox treatment tables such as Comex 30. Guidance on treatment of DCI resulting from saturation exposures is given in Report 10 clause 7.9

12.7.5. Because the treatment of a serious case is more difficult than that of a 'pain only' case, it is important to decide which type of decompression illness is being dealt with. It should always be remembered that 'pain only' and serious decompression illness may occur together. If there is any doubt, the patient will need to be treated as suffering from the more serious illness.

12.7.6. If a person suffers from altered or loss of consciousness or otherwise becomes ill during decompression in the personnel lock, everyone in the lock needs to be recompressed at once to the working chamber pressure. The hyperbaric supervisor and the duty medical lock attendant should be informed immediately and a medical lock tender should be locked in to attend to the casualty. Such an event is foreseeable in principle, therefore the compressed air contractor in conjunction with the contract medical adviser and hyperbaric supervisor should prepare in advance a procedure for dealing with it. This procedure should set out how the rest of the shift can be decompressed in the usual way allowing for the now extended exposure period whilst the casualty can be decompressed in a way which does not trigger a second decompression illness event. The procedure to be adopted will depend on whether decompression takes place in a tunnel lock or in a lock attached to the TBM.

12.7.7. If a person suffers from altered or loss of consciousness or otherwise becomes ill immediately following decompression they need to be put back under pressure as quickly as possible. The contract medical adviser should determine in advance the criteria to determine whether recompression is undertaken in the underground lock or in the medical lock and the pressure to which the casualty should be compressed. Lock attendants should be advised of the criteria. As soon as such an event occurs the

hyperbaric supervisor and the duty medical lock attendant should be informed immediately.

12.7.8. All personnel locks should have the capability for oxygen to be administered in the lock at a pressure of at least 1.8 bar(g) in accordance with a recognised treatment schedule such as US Navy Table 6 as part of emergency recompression procedures.

12.7.9. If a suspected DCI event occurs during decompression as part of a saturation exposure, the relevant person under Report 10 clause 4.7.1 should be informed along with the duty medical lock attendant. Should the event occur in the shuttle, the shuttle supervisor should take control of the response until replaced by the responsible person under Report 10 clause 4.7.1.2.

12.7.10. A patient should not be transferred to a hospital lacking hyperbaric treatment facilities, until it is certain that the patient's residual symptoms can no longer be improved by recompression or are not caused by decompression illness.

12.7.11. If information is received that a compressed air worker is suffering from decompression illness at a place remote from the site, it may be more expedient for recompression treatment to be given elsewhere. In such cases, it may be helpful for the contract medical adviser to discuss the treatment of decompression illness arising from work in compressed air with the staff operating the remote recompression chamber. Those treating the casualty at the remote location should be informed of the recent exposure history undergone by the casualty.

12.7.12. Information about therapeutic recompression procedures is given in Annex 4. In case of difficulty, the contract medical adviser can seek assistance from one of the various helplines readily available through an internet search such as the British Hyperbaric Association (https://www.ukhyperbaric.com/hbot/emergency-treatment/).

Regulation 13 Emergencies

(1) The compressed air contractor shall ensure that no person works in compressed air unless there are suitable and sufficient arrangements for action to be taken in the event of an emergency.

(2) Without prejudice to the generality of paragraph (1), the arrangements required by that paragraph shall extend to -

(a) arrangements for ensuring that the requirements of regulations 30, 31 and 35(3) of the 2015 Regulations are complied with;

(b) the provision and maintenance of a sufficient number of suitable means of access;

(c) the provision and maintenance of suitable means of raising the alarm; and

(d) (where an airlock is required for the purpose of putting into operation an evacuation pursuant to regulation 30(1) of the 2015 Regulations) the maintenance of that airlock in such a condition as to be fit to receive persons in the event of an emergency having regard, in particular, to the air supply to and the temperature of that airlock.

13. Guidance relevant to Regulation 13

13.1. For the convenience of readers, the text of the 2015 Regulations quoted in (2)(b) above is set out below.

Regulation 30. Emergency procedures

(1) Where necessary in the interests of the health or safety of a person on a construction site, suitable and sufficient arrangements for dealing with any foreseeable emergency must be made and, where necessary, implemented, and those arrangements must include procedures for any necessary evacuation of the site or any part of it.

(2) In making arrangements under paragraph (1), account must be taken of—

(a)the type of work for which the construction site is being used;

(b)the characteristics and size of the construction site and the number and location of places of work on that site;

(c)the work equipment being used;

(d)the number of persons likely to be present on the site at any one time; and

(e)the physical and chemical properties of any substances or materials on, or likely to be on, the site.

(3) Where arrangements are made under paragraph (1), suitable and sufficient steps must be taken to ensure that—

(a)each person to whom the arrangements extend is familiar with those arrangements; and

(b)the arrangements are tested by being put into effect at suitable intervals.

Regulation 31. Emergency routes and exits

(1) Where necessary in the interests of the health or safety of a person on a construction site, a sufficient number of suitable emergency routes and exits must be provided to enable any person to reach a place of safety quickly in the event of danger.

(2) The matters in regulation 30(2) must be taken into account when making provision under paragraph (1).

(3) An emergency route or exit must lead as directly as possible to an identified safe area.

(4) An emergency route or exit and any traffic route giving access to it must be kept clear and free from obstruction and, where necessary, provided with emergency lighting so that it may be used at any time.

(5) Each emergency route or exit must be indicated by suitable signs.

Regulation 35. Lighting

(1) Each construction site and approach and traffic route to that site must be provided with suitable and sufficient lighting, which must be, so far as is reasonably practicable, by natural light.

13.2. Access and egress

13.2.1. Any working chamber, whether on a TBM or in a tunnel or shaft, needs to be accessible by at least two single compartment personnel locks or a personnel lock of two or more compartments. With the exception of when the locks (or compartments) are in use, it is necessary always to have one lock (or compartment) readily available for people to gain access to the working chamber and another lock (or compartment) available for the rapid escape of people in an emergency from the working chamber. When a lock is in use it should be possible in an emergency to complete compression and return the compartment being used for compression to allow rapid entry of emergency response personnel. it should be possible in an emergency to rapidly decompress a compartment being used for compression to allow rapid entry of response personnel. In the case of a compartment being used for decompression it should be possible in an emergency to rapidly compress a compartment being used for decompression to allow rapid escape of personnel from the workings.

13.2.2. Similar requirements for rescue and escape apply to shuttles whether docked with a personnel lock in the tunnel or stranded due to breakdown during transport hence 2-compartment shuttles are required. The entry compartment should meet the requirements for the entry compartment of a personnel lock in EN 12110-1.

13.3. **Emergency procedures in the health and safety plan**

13.3.1. In the event of any emergency occurring in the tunnel the intervention or excursion should be abandoned and those in the working chamber should return to the personnel lock for decompression or transfer under pressure as applicable.

13.3.2. Similarly in the event of any emergency on the surface which could threaten the surface installations supporting the work in compressed air, the intervention or excursion should be abandoned and those in the working chamber should return to the personnel lock for decompression or transfer under pressure as applicable.

13.3.3. The compressed air contractor's safe system of work and management plan (see 7.1.17.1) should include detailed procedures to be followed in the event of an emergency. These should take account of surface installations along with transfer under pressure procedures where relevant. Likely emergency scenarios which need to be considered

include fire, atmospheric contamination, leakage of oxygen or breathing mixture, transport accidents (including derailment, breakdown or collision, damage to oxygen cylinders), non-availability of normal means of access/egress in a shaft, personal injury or illness, loss of power, threat to the life support system for the airlock, blow-out or inundation and breathing de-oxygenated air or other contamination with toxic gasses including carbon monoxide or hydrogen sulphide.

13.3.4. The plan will need to include the site management structure, means of implementing the emergency procedures, liaison with the emergency services, removal of casualties from the pressurised workings, procedures for evacuation of the working chamber and airlocks (including emergency decompression and medical procedures), recovery of shuttles and protection of surface facilities. The planning arrangements will need to include the provision of a rescue team and any equipment necessary for use in an emergency. Target response times should be stated and need to be similar to those of the emergency services. A list illustrating possible emergency scenarios under high pressure conditions is set out in Report 10 clause 10.

13.3.5. A programme of practice drills to test the full range of emergency procedures must be held and the procedures reviewed in the light of the outcome of the exercises.

13.3.6. The programme should start before productive work in compressed air commences. Otherwise, the programme should begin as soon as possible work in compressed and further drills should be held regularly thereafter for all shifts. The frequency of the drills should be determined by the compressed air contractor in consultation with the hyperbaric supervisor..

13.3.7. As part of the emergency planning, relevant information on the compressed air set up should be included in the comprehensive information pack required by clause 4.2 of BS 6164:2019.

13.3.8. The plan should include the provision of an emergency breathing air supply and masks at each lock control panel for use by the lock attendant/medical lock attendant in an emergency.

13.3.9. Refuge chamber capacity underground should include provision for lock attendants and rescue personnel associated with the work in compressed air.

13.4. Emergency team fitness and training

13.4.1. Rescue work in an emergency as part of the emergency response team can be extremely physically and mentally demanding. The employer will have to consult with the contract medical adviser about the risk assessment for this kind of work. It may be necessary to require a substantially higher degree of fitness than is required for planned compressed air work. It should, in particular, assess the cardio-pulmonary demands of wearing breathing apparatus and carry out potentially very strenuous work. In deciding what that standard should be, employers and contract medical advisers should consider the fitness

standards for similar occupational groups such as mines rescue team members or firefighters.

13.4.2. When saturation exposures are being undertaken the rescue team should be fit, trained and prepared to undertake saturation decompression.

13.5. **Fire**

13.5.1. Further requirements in respect of fire are set out in Regulation 14

13.5.2. Fire risk under hyperbaric conditions can be even greater than in free air tunnels due to the enhanced mass concentration of oxygen, oxygen enrichment resulting from faulty oxygen breathing systems, the confined spaces involved and the need for decompression. In the event of a fire on the TBM outside the lock, people in the lock or working chamber could be prevented from escaping by virtue of the need for decompression. While people are working in such circumstances and particularly when oxygen decompression is being undertaken, all non-essential power systems on the machine need to be shut down and all maintenance or hot work suspended.

13.5.3. An extensive fire detection and suppression system will also be required. Requirements for the fire suppression system in locks and shuttles are given in BS EN 12110.

13.5.4. Additionally, power, communications and gas supply to the airlocks need to be maintained, as well as means to maintain the airlock at a safe temperature.

13.5.5. Additional fire risk mitigation measures protecting shuttles and surface facilities are set out in Report 10 section 10 and in BS EN 12110-2.

13.5.6. The means of raising the alarm in case of fire need to be 'fire hardened' so as to remain operable at all times.

13.6. Injury – evacuation of casualties

13.6.1. The contract medical adviser and hyperbaric supervisor/person appointed under Report 10 clause 4.7.1.2, should be involved in planning the extrication of a casualty from the working chamber to the point of reception of the casualty by the public emergency services. This will include the provision of appropriate equipment and planning for the transfer under pressure of the casualty if relevant, the decompression of the casualty and the provision of appropriate first aid treatment under pressure.

13.7. Self-rescuers

13.7.1. Self-rescuers are an essential part of a safe system of work in normobaric tunnelling. However, the need to avoid exposure to high partial pressures of oxygen limits their applicability in compressed air tunnelling. Commonly used self-rescuers in normobaric tunnelling provide the wearer with a supply of almost 100% pure oxygen within the first five minutes of use. Currently no manufacturer of self-rescuers intends them to be used in compressed air.

13.7.2. A prototype hyperbaric self-rescuer capable of use at pressures up to 3.5 bar(g) was developed with HSE funding, but the device was never CE marked or marketed due to perceived lack of commercial demand. Details of the device can be found in *Anthony, TG 'Generic modification of compressed oxygen self-rescuers for use in compressed air tunnels at pressures of 0.0 to 3.5 bar gauge' Proceedings of the 2nd International Conference on Engineering and Health in Compressed Air Work, Oxford 2002 Slocombe RT, Buchanan J, Lamont DR, eds, Thomas Telford 2003, London)*.

13.7.3. Overall, the availability of self-rescue devices for use in compressed air is poor. If a self-rescue device is required to allow return to the personnel lock, the use of a self-contained "bailout bottle" containing an appropriate breathing medium as in diving could be considered. The emergency second core of an umbilical in high pressure work can be considered to fulfil a similar purpose.

13.8. Emergency evacuation of habitat

13.8.1. Should the main habitation complex become uninhabitable such as due to fire, special arrangements and procedures are required to be in place to facilitate the evacuation all those in the habitat to an emergency chamber while keeping them under pressure.

13.8.2. One option is to ensure that the "adequate facilities" required by Regulation 12 and described in clause 12.6 are also capable of meeting the requirements for an emergency chamber required by Regulation 13 and clause 13.8.1.

13.8.3. Otherwise the emergency chamber can be by a standalone chamber, a chamber capable of being removed from the affected area to a safe location or an off-site facility. In all cases the chamber or facility should be capable of maintaining a suitable standard of life support and welfare for a minimum of 72 hours or the time required to undertake a full saturation decompression if longer.

13.8.4. The exact design of any equipment and the method of its deployment will depend on a number of factors including the facilities available, the number of persons to be evacuated and the location of the worksite. The design and location of emergency facilities should be determined by the compressed air contractor who should ensure sufficient physical separation between the emergency facilities and the main system to avoid it being compromised by the emergency event.

13.8.5. In all cases the compressed air contractor should ensure the means to evacuate persons under pressure can be undertaken in a way that avoids DCI incidents.

13.8.6. Whilst a pressurised transfer shuttle conforming to EN 12110-2 can be used for the evacuation process it does not constitute a fully functioning pressurised chamber.

13.8.7. Where the contractor opts for an off-site facility, it should be possible to complete transfer within 8 hours of the emergency arising. A trial evacuation should be undertaken successfully before saturation exposures begin on site.

13.8.8. The compressed air contractor should ensure that all necessary permissions are in place for the transport of a pressurised transfer shuttle containing MGSWs and that facilities

are available for the docking procedure. In particular compatibility of docking flanges and clamps is essential.

13.8.9. There are only very limited static off-site facilities available in the UK to support an off-site transfer and a very limited range of portable facilities also exist.

13.9. Emergency lock attendant cover

13.9.1. In addition to the need to be able to treat DCI at pressures below 1 bar(g) (see clause 12.3.2) it is foreseeable that either a lock attendant or medical lock attendant could become incapacitated in the course of their duties. In the case of the latter this could be inside the medical lock. An stand-in lock attendant is therefore required to operate the lock controls in an emergency.

13.9.2. A small number of site personnel should therefore be trained to act as stand-in lock attendants to undertake basic lock compression and decompression procedures (see clauses 7.6.6.7, 7.10.2.7, 7.11.9, 12.3.5). 7.11.9

Regulation 14 Precautions against fire

(1) The compressed air contractor shall ensure that there is provided in respect of work in compressed air any means for fighting fire required pursuant to regulation 32 of the 2015 Regulations and that any airlock or working chamber is operated and maintained in such a manner as to minimise the risk of fire.

(2) No person shall smoke or have with him any materials for the purpose of smoking when in compressed air.

(3) The compressed air contractor shall ensure compliance with paragraph (2).

14. Guidance relevant to Regulation 14

14.1. Fire behaviour in compressed air

14.1.1. Research has shown the extent to which the ignition energy required to start a fire is less in compressed air, materials burn more vigorously and with much greater radiant heat output. Material that is not combustible at atmospheric pressure can become combustible but not spontaneously combustible, with increasing pressure.

14.1.2. Information on fire behaviour in compressed air can be found in *Lamont, D.R., Buckland, I., Bettis, R.J., Jagger, S.F. and Hambleton, R.T., "Fire tests in a compressed air tunnel at up to 3 bar pressure", AITES – ITA World Tunnel Congress 1998 (Sao Paulo), Tunnels and Metropolises, Negro and Ferreira ed., Vol 1 Balkema Rotterdam 1998.*

14.1.3. Because of the potentially devastating effect of fire in a pressurised environment, wherever practicable, there should be no combustible material in the compressed air environment.

14.2. Fire precautions for locks and TBMs

14.2.1. For airlocks on TBMs and for shuttles, requirements and guidance relating to the fire suppression system are given in BS EN 12110-1 and Report 10 section 10. These should be rigorously adhered to.

14.2.2. Where the personnel locks are part of a TBM, there are specific requirements for fire suppression on the TBM. These are strictly not part of the work in compressed air but are nevertheless a safety critical aspect of the compressed air work. Fire suppression measures for the TBM should comply with BS EN 16191.

14.2.3. TBMs should conform to BS EN 16191 in respect of fire risk mitigation measures, including the use of HFDU fluids and the provision of a water spray curtain at the outbye end of the TBM. Pumps and motors need, where possible, to be enclosed to contain any high pressure discharge of oil, and fluid leaks should not be allowed to accumulate. Rigid hydraulic pipework is to be preferred where practicable. All lubricants and greases should also be of low flammability types.

14.2.4. Where the entire TBM is operating in the compressed air environment they should fully comply with the fire safety requirements of BS EN 16191.

14.3. Fire precautions for in-tunnel locks and working chambers

14.3.1. It is essential that airlocks and the working chamber are kept clean and free from all forms of combustible rubbish including waste timber, mineral oil and grease, paper, plastic, cloth and straw.

14.3.2. All tunnel plant and equipment passing through airlocks should also have onboard fire suppression systems suitable for use in the hyperbaric environment.

14.3.3. In conventional tunnelling by hand, a set of timber face boards and a small amount of straw in a closed metal container should be kept in the working chamber for face support.

14.3.4. Fire-fighting equipment should include a fire main throughout the airlocks and working chamber. Fire hoses should be located at regular intervals in the working chamber and in the personnel locks. It is strongly recommended that hoses and attachments be compatible with the local fire service's equipment. Further guidance on fire is contained in Br Hyperbaric Association publication "FIRE SAFETY GUIDELINES FOR MULTIPLACE HYPERBARIC TREATMENT FACILITIES" http://www.ukhyperbaric.com/wp-content/uploads/2019/03/BHA-Fire-Guideines-2018-OCR.pdf.

14.3.5. Portable extinguishers should be provided for tackling small fires and need to be suitable for use in hyperbaric environments.

14.4. Fire precautions - plant and equipment for air supply

14.4.1. All items of plant and equipment for compressed air supply above or below ground and for use in the compressed air workings, such as compressors, generators, electrical motors

and switchgear or hydraulic pumps should be protected by the full range of fire protection measures set out in BS 6164:2019. Equipment located in hyperbaric environments will require specialised firefighting equipment due to the nature of the hazard presented by them. The principle of "kill and quench" requiring two extinguishant systems to extinguish the fire (kill) and then to prevent re-ignition (quench) or a single extinguishant with both capabilities, is particularly important in compressed air workings.

14.4.2. Dry powder or gas extinguishers should be considered for fitting inside enclosures. However, there are several powder or gas extinguishing agents available, each with different characteristics, and care should be taken in the selection process.

14.4.3. Portable extinguishers should be provided for tackling small fires.

14.4.4. Flexible ventilation ducting should conform with BS 6164:2019 clause 15.

14.5. Fire precautions - electrical and battery equipment

14.5.1. The fire hazards presented by lithium or other high performance battery technologies should be specifically addressed (see BS 6164:2019) and expert advice on appropriate extinguishing methods obtained.

14.5.2. Electrical switchgear needs to be of a type that does not contain oil. All electrical enclosures should be fitted with inert gas or dry powder fire-suppression equipment which discharges directly into the enclosure and which, once activated, is capable of operating unattended.

14.5.3. Electrical cabling needs to be insulated with materials having low flame propagation and low smoke and zero halogen generation properties when subjected to fire.

14.5.4. The insulating sheath of such cables may have limited resistance to oil or water and needs to be regularly inspected to ensure its integrity.

14.5.5. Conveyor belting should conform with BS 6164:2019 clause 23

14.6. Burning and welding

14.6.1. The use of burning or welding equipment needs to be strictly limited and carried out in a safe manner under a permit-to-work procedure. Acetylene should not be used in pressurised workings (see The Acetylene Safety (England and Wales and Scotland) Regulations 2014). Cold cutting is to be preferred.

14.6.2. Flame-retardant high visibility overalls or clothing should be worn by all people working in compressed air. Relevant standards for protective clothing include BS EN ISO 11612:2015. Nomex or similarly fire-resistant overalls should be worn by those burning or welding. Nylon and similar garments should be excluded from the workings.

14.7. Prohibition on smoking and flammable materials.

14.7.1. The compressed air contractor is required to ensure that all people at work in compressed air are made fully aware of the prohibition on smoking materials and the reasons for it, and to rigorously enforce the prohibition. This includes electronic cigarettes and similar devices.

14.7.2. Substances which should not be permitted in the personnel lock include non-water based adhesives; aerosols; batteries with unprotected terminals; cleaning fluids - organic solvents; electrical equipment - non-essential; finely powered foodstuffs; materials for smoking including ignition sources or vaping; mineral oils, greases etc.

14.8. **Personal cleanliness**

14.8.1. All personnel should clean oil, grease and similar substances including cosmetic substances, from their skin and should change into clean flame-retardant clothing before entering the personnel lock or shuttle.

14.8.2. Dirty clothing should be bagged and taken through the materials lock for laundering prior to reuse or left in the intermediate chamber and removed later. Textiles which are not fire-retardant should be prohibited.

14.9. **Mixed gas storage underground**

14.9.1. There should be a water spray or high pressure water mist suppression system covering the location at which the vehicle(s) carrying the cylinders of breathing mixture park within the TBM backup equipment. This system should be capable of either manual or automatic operation in the event of a fire in the vicinity of the vehicle(s). The capacity of the water spray should be sufficient to operate the system for at least 15 minutes.

14.10. **Surface installations**

14.10.1. On the hard standing around the habitat building and surface gas storage areas, all flammable materials or activities likely to give rise to an ignition source, should be prohibited. Fire risk mitigation measures for the habitat building and gas storage area are set out in Report 10 clause 10.

Regulation 15 Information, instruction and training

The compressed air contractor shall ensure that adequate information, instruction and training has been given to any person who works in compressed air so that he is aware of the risks arising from such work and the precautions which should be observed.

15. Guidance relevant to Regulation 15

15.1. Information instruction training - general

15.1.1. It is essential that the compressed air contractor through the person in charge, the contract medical adviser, hyperbaric supervisor and persons appointed to the roles in 10.4.7 of Report 10 liaise with representatives of the workforce to ensure that the training carried out adequately addresses the risks on the project for the type of compressed air work being carried out and encourages a positive attitude towards health and safety in compressed air working.

15.1.2. The provision of information, instruction and training for all people undergoing non-saturation exposures in compressed air should be overseen by the hyperbaric supervisor in conjunction with the contract medical adviser. The compressed air contractor is responsible for ensuring that it is carried out to a standard which is appropriate for the circumstances of the project.

15.1.3. For a person who has not previously worked in compressed air it is anticipated that instruction and training for low or intermediate pressure exposures will take between a half and one day to complete. Experienced compressed air workers, who can provide proof of instruction and training by means of an entry in a compressed air worker's health and exposure record, may only require a refresher course and/or training in site-specific topics such as emergency procedures, rescue equipment and self-rescuers. Information, instruction and training also need to be provided for those who are new starters while the work in compressed air is under way. Refresher instruction and training need to be given periodically.

15.1.4. Details of the instruction and training received should be entered in the compressed air worker's health and exposure record (see 11.11.1).

15.1.5. Suitable topics to be covered by the information provided for work at any pressure, and in the instruction and training given include:

15.1.5.1. reasons for the use of compressed air; the medical reasons for the use of oxygen. For persons using breathing mixtures, reasons for the use of such mixtures;

15.1.5.2. risks to safety - e.g. fire, flood/inundation, blow-out; the safety risks associated with the use of oxygen and in particular the enhanced fire risk, and the need for high standards of cleanliness both personally and in the personnel lock and its equipment. The use of the HSE DVD "*The heat within: The effects of fires in tunnels"* (ISBN 978 0 7176 6411 5) should be part of this training;

15.1.5.3. site emergency procedures including use of emergency equipment - e.g. fire suppression systems in locks, fire extinguishers, rescue equipment and use of self-rescuers;

15.1.5.4. risks to health - decompression illness ('niggles', 'bends', 'chokes', 'staggers'), barotrauma, medical complications including over exposure to hyperbaric oxygen, osteonecrosis and their symptoms; the purpose of medical surveillance and the need to co-operate with this; heat illnesses and their recognition; the effects of cold. For those using breathing mixtures, the risks from exposure to high partial pressures of oxygen and nitrogen and the use of helium;

15.1.5.5. need for decompression - decompression tables (including details of the tables being used on the contract), oxygen breathing techniques, working pressure and shift length, problems of omitted decompression; the fact that bone damage can occur as the result of a single inadequate decompression and that it is essential to observe all the correct procedures carefully;

15.1.5.6. rules for compression and decompression including repeat compression and the need to remain on site after decompression, to take only gentle exercise, have tepid rather than hot showers, avoid diving or flying after decompression (see Regulation 18);

15.1.5.7. procedures for return to site out of hours, or if feeling unwell in lock;

15.1.5.8. the extent to which familiarisation occurs in compressed air work and its effects;

15.1.5.9. good working practice and postures - e.g. need to avoid constricting limbs such as by prolonged kneeling; the correct use of masks or hoods to ensure proper fit, the need to minimise leakage of gas from the masks and the need to inform the lock attendant immediately in the event of free flow of gas. It may be necessary to have an attendant in the manlock for the first few decompressions to ensure that masks are properly fitted and used;

15.1.5.10. authority and duties of compressed air contractor, person in charge, lock attendant, medical lock attendant, compressor attendant, appointed doctor and contract medical adviser;

15.1.5.11. strong emphasis on reasons for prohibition on drugs, alcohol, smoking;

15.1.5.12. reasons for unfitness for work in compressed air including colds, influenza, ear/nose/throat infection, pregnancy and illnesses that need to be brought to the attention of the employer;

15.1.5.13. importance of the compressed air worker's health and exposure record; and

15.1.5.14. wearing of badges, labels or devices.

15.1.6. Practical training should include a trial compression and ear clearing, i.e. the 'lock test' and emergency evacuation (see Guidance relevant to Regulation 13).

15.2. Information instruction training – high pressure

15.2.1. Considerable additional information, instruction and training along with evidence of an aptitude for close-proximity living will be required for work in compressed air involving saturation exposure techniques. Persons selected for such work should either hold a qualification on the list for "closed bell diving or saturation diving techniques" as set out in HSE's "List of Approved Diving Qualifications" dated 13th Feb 2020 or later (https://www.hse.gov.uk/diving/qualifications/approved-list.pdf) or have successfully completed an appropriate training course involving a period in saturation and hold a qualification from a recognised hyperbaric training organisation such as the French Classe 3 "Mention D" from INPP (https://inpp.org/institute/?lang=en). In both cases further training in personal underground safety, familiarisation with the tunnel environment, site specific training in the matters contained in clause 15.1.5 along with task training will be required.

15.2.2. All those undertaking mixed gas breathing should have knowledge of the effects of breathing oxygen, nitrogen, helium and carbon dioxide at high partial pressures, the effects of changing between breathing mixtures of different densities and an understanding of the principles of saturation exposure techniques.

Regulation 16 Fitness for work

(1) The compressed air contractor shall ensure, so far as is reasonably practicable, that every person who works in compressed air is under adequate medical surveillance and works only in accordance with the conditions, if any, specified in his health record.

(2) Notwithstanding paragraph (1), the compressed air contractor shall ensure that no person works in compressed air where the compressed air contractor has reason to believe that person to be subject to any medical or physical condition which is likely to render that person unfit or unsuitable for such work.

(3) A person engaged in work in compressed air shall report forthwith any medical or physical condition which he has reason to believe is likely to render him unfit or unsuitable for such work to the compressed air contractor and, in the case of an employee, to the employer.

16. Guidance relevant to Regulation 16

16.1. Fitness for work General

16.1.1. A list of those fit to enter the workings should be kept by the hyperbaric supervisor in conjunction with the appointed doctor. Lock attendants should have access to that list.

16.1.2. All people engaged in work in compressed air have a duty under this regulation to report both to their employer and to the compressed air contractor any illness or medical condition which may render them unfit for work in compressed air. where Normally that

report will be made to the compressed air contractor through contact with the appointed doctor or through the person in charge, contract medical adviser, hyperbaric supervisor, or to the lock or medical lock attendant. The list of those fit to enter the workings will need to be amended in the light of the report of unfitness.

16.1.3. People suffering from any ill effects which they consider may have arisen as a result of exposure to compressed air should, as soon as practicable, seek advice from the contract medical adviser, hyperbaric supervisor or medical lock attendant regarding their condition.

16.2. Temporary unfitness

16.2.1. The training which is given to all people working in compressed air will need to include an explanation of the types of illness which may render a person temporarily unfit. These include:

16.2.1.1. any systemic illness - including common respiratory or gastro-intestinal upsets;

16.2.1.2. any disease of the nose, sinuses, throat or ears which may prevent free passage of air;

16.2.1.3. any new medical treatment self-initiated or initiated by a registered medical practitioner;

16.2.1.4. any condition which results in self-medication or the acquisition of medication via the internet;

16.2.1.5. decompression illness (from work or sport diving); and

16.2.1.6. pregnancy (which is not compatible with work in compressed air).

16.2.1.7. Procedures for compression referred to in Regulation 11(1) do not permit the compression of people who have indicated that they may be temporarily unfit.

16.2.2. People suffering from any temporary unfitness which may have arisen as a result of exposure to compressed air should, as soon as practicable, seek advice from the contract medical adviser, hyperbaric supervisor or medical lock attendant regarding their return to work.

16.3. Return to work

16.3.1. Once a person has reported an illness likely to prevent entry to compressed air working, fitness to resume work in compressed air will need to be confirmed by an appointed doctor or an employment medical adviser.

16.4. Saturation – fitness for work

16.4.1. During saturation exposures, any questions over unfitness for work or about ill health effects due to work should be made known to the persons appointed under clause 4.7.1 of Report 10, the contract medical adviser or the medical lock attendant.

Regulation 17 Intoxicating liquor and drugs

(1) The compressed air contractor shall ensure that no person works in compressed air where the compressed air contractor has reason to believe that person to be under the influence of drink or a drug to such an extent that his capacity to carry out any task for which he is responsible is impaired.

(2) No person shall consume alcohol or have with him any alcoholic drink when in compressed air.

(3) The compressed air contractor shall ensure compliance with paragraph (2).

17. Guidance relevant to Regulation 17

17.1. **Prohibition of alcohol or drugs - policy**

17.1.1. The compressed air contractor needs to establish a drug and alcohol policy along with appropriate management procedures including testing protocols. It should be supported by site supervisors and lock attendants to prevent access to compressed air working by anyone considered to be under the influence of drink or drugs, and to prevent the taking of alcohol or drugs into compressed air. Lock attendants should have the authority of the compressed air contractor to refuse to compress any person whom they have reasonable grounds to believe is so affected. The person in charge and the contract medical adviser should immediately be informed by the lock attendant when someone has been refused entry to compressed air so that a formal investigation into the incident can be initiated and the person concerned given appropriate advice and support.

17.1.2. This prohibition, the reasons for it and the procedures which will be followed should be made clear to employees as part of the information, instruction and training provided. Site management is expected to use judgement and experience in looking for any indication that this regulation may have been breached.

17.2. Prohibition of alcohol

17.2.1. The effects of alcohol present a danger while working in compressed air for various reasons including:

17.2.1.1. unsafe behaviour may result, jeopardising the health and safety of the worker or others;

17.2.1.2. alcohol can increase the risk of decompression illness;

17.2.1.3. narcosis from alcohol could be indistinguishable from nitrogen narcosis

17.2.1.4. the effects of alcohol may mimic those of decompression illness, thus interfering with the diagnosis of this condition.

17.2.2. Historically, various studies noted that the incidence of decompression illness was elevated on the 'back' shift. It was thought that this could have been a result of the consumption of alcohol in the period prior to work commencing. Everyone working in compressed air should be discouraged from consuming alcohol prior to working in compressed air for a period sufficient to avoid the problems described in clause 17.2.1.

17.3. Prohibition of drugs

17.3.1. Prescribed or proprietary medication can also affect fitness for work in compressed air, and Regulation 16(3) is also relevant. An individual's capacity can be impaired either by the condition for which the medication has been taken or by the medication itself. Often little advice is given to the public about the possible effects of over-the-counter medication and for this reason it is important that workers should report temporary illness which results in self-medication or the need for prescribed drugs.

17.3.2. The lock attendant may need to obtain advice on such drugs from the contract medical adviser either directly or through the medical lock attendant. In cases of doubt, an individual should not be compressed. It is important that workers seek advice as early as possible about the potential effects of any medication which is prescribed for them or purchased.

17.3.3. The recreational use of prohibited drugs can also have effects which cause unsafe behaviour. Lock attendants and site managers should adhere to the company drug and alcohol policy as well as using their experience and judgement in dealing with such an incident. Again, in cases of doubt, a person should not be compressed, and the advice of the contract medical adviser obtained. For guidance, statutory limits applicable to unfitness to drive are set out in the Drug Driving (Specified Limits) (England and Wales) Regulations 2014 (as amended) and the Drug Driving (Specified Limits) (Scotland) Regulations 2019.

17.3.4. The narcotic effects of high partial pressures of nitrogen are considered not to be covered by this regulation but by Regulation 7. However the reasons behind the prohibition on alcohol and drugs and the limits tolerated on site should be borne in mind when considering the limits on nitrogen partial pressure exposure considered acceptable on site.

Regulation 18 Welfare

The compressed air contractor shall ensure that there are provided and maintained for the use of any person engaged in work in compressed air -

(a) such facilities as are required by Schedule 2 of the 2015 Regulations;

(b) suitable drinks for consumption during or after decompression;

(c) suitable food and drinks for consumption by any person receiving therapeutic recompression or decompression; and

(d) adequate and suitable facilities for remaining on the site after decompression.

18. Guidance relevant to Regulation 18

18.1. Welfare provision

18.1.1. The compressed air contractor is required to ensure that adequate welfare facilities are provided and maintained. With the dominance of TBM locks and the infrequent use of in-tunnel locks the interpretation of this regulation has changed. Also by extension, this regulation now includes the provision of "hotel services" for those undergoing saturation exposures.

18.2. **Welfare - sanitary conveniences and washing facilities**

18.2.1. Sanitary conveniences, washing facilities etc should be provided in accordance with the requirements of the CDM Regulations 2015 (Regs 4(2)(b), 13(4)(c), 5(11) and Schedule 2).

18.2.2. Toilets, normally of a portable chemical or incinerator type, should be provided underground. For TBM airlocks, a small portable chemical toilet should be available to be temporarily locked-in to the entry lock for use as required. Suitable arrangements should be made for privacy and for emptying the toilet.

18.2.3. It is essential to provide a means of hand cleaning or sanitising in the personnel lock or working chamber and in the vicinity of toilets. This is particularly important when working at pressures at which breaks are taken under pressure.

18.2.4. Because of the nature of the work, suitable and adequate shower and drying facilities will be necessary on the surface for those undertaking non-saturation exposures. Water supplied to the showers should be tepid as a hot shower could increase the risk of a person developing decompression illness.

18.3. **Welfare - facilities for remaining on site etc**

18.3.1. The purpose of remaining on site needs to be made clear to all those engaged in work in compressed air. After decompression from a working pressure of 1.0 bar(g) or over, people need to remain on site for at least 1 hour. If the working pressure was over 2.8 bar(g), people need to remain on site for 1.5 hours. During this period people should not engage in any arduous physical activity. The time can be used for showering and changing and for light duties only, e.g. record-keeping or minor maintenance tasks. This time can also be used for physiological monitoring if required.

18.3.2. All washing and welfare accommodation above ground should be heated, kept clean and be provided with seats and basic messing facilities.

18.4. Welfare provision of hotel services in saturation

18.4.1. As the welfare part of the safe system of work for those undergoing saturation exposures the compressed air contractor needs to provide "hotel services" i.e. food, drink, living/sleeping accommodation, laundry, toilet/washing facilities and general health care.

18.4.2. High standards of nutrition and hydration are necessary for the wellbeing of those at work. High standards of food hygiene throughout the food chain along with high standards of cleanliness in the habitat are necessary to minimise the risk of infection. This is covered in Report 10 clauses 6.4, 6.50 and 8.14. The contract medical adviser should be able to advise on these matters.

18.4.3. Although not specifically a requirement of Regulation 18, welfare facilities and working space including office-type accommodation should be provided for those managing, operating and servicing the surface habitat. This includes suitable accommodation for the contract medical adviser, medical lock attendants etc including accommodation for undertaking medical examinations.

18.5. Welfare - availability of food and drinks during recompression therapy

18.5.1. Hot food along with hot or cold drinks should be available to all those undergoing recompression therapy. The need to provide food will depend upon when recompression therapy takes place in relation to the end of the shift, and the duration of the therapy. The preferences of the worker undergoing recompression therapy should also be taken into account.

Regulation 19 Badge, label or other device

(1) Every compressed air contractor shall ensure that any person who works in compressed air at a pressure of 0.7 bar or above is supplied with a suitable and suitably worded badge, label or other similar device for the guidance of others should that employee be taken ill after leaving work and that the badge, label or device, as the case may be, contains such particulars as may be approved by the Executive.

(2) Every person to whom a badge, label or other device has been supplied in accordance with paragraph (1) shall wear that badge, label or device for 24 hours after leaving work in compressed air.

19. Guidance relevant to Regulation 19

19.1. Badge label etc

19.1.1. The badge, label or device is required to be worn in case the person collapses and is unable to indicate his or her history of work in compressed air. This should be explained to all people engaged in work in compressed air in the course of information, instruction and training.

19.1.2. The badge, label or device needs to be made of a durable material and worn next to the body. It should state clearly that the wearer is a person who has been exposed to work in compressed air and give the location and telephone number of the site medical lock to which a worker suffering from decompression illness should be referred. The contact telephone number of the contract medical adviser can also be given for use in emergencies.

19.1.3. Decompression illness is unlikely to occur more than 24 hours after leaving compressed air workings, but this is not an absolute cut-off point.

Regulation 20 Defence in proceedings

In any proceedings for an offence consisting of a contravention of regulation 14(3) or 17(3) it shall be a defence for any person to prove that he took all reasonable precautions and exercised all due diligence to avoid the commission of that offence.

20. Guidance relevant to Regulation 20

20.1. No relevant guidance

Regulation 21 Power to grant exemption

(1) Subject to paragraph (2), the Executive may, by a certificate in writing, exempt any person or class of persons from all or any of the requirements or prohibitions imposed by these Regulations, and any such exemption may be granted subject to conditions and to a time limit, and may be revoked by a certificate in writing at any time.

(2) The Executive shall not grant any such exemption unless, having regard to the circumstances and in particular to -

(a) the conditions, if any, which it proposes to attach to the exemption; and

(b) any other requirements imposed by or under any enactment which apply to the case,

it is satisfied that the health and safety of persons who are likely to be affected by the exemption will not be prejudiced in consequence of it.

21. Guidance relevant to Regulation 21

21.1. Application for exemptions

21.1.1. While the maximum exposure pressure permissible in Gt Britain under Regulation 11(2) is 3.5 bar(g), work in compressed air at higher pressures has been successfully undertaken elsewhere in the world. In order to undertake such work in Gt Britain it would be necessary to be exempted from Regulation 11(2) by HSE. Similar requirements apply under the Work in Compressed Air (Northern Ireland) Regulations 2004.

21.1.2. Any compressed air contractor who wishes to seek an exemption to the prohibition on work in compressed air above 3.5 bar(g) in Gt Britain (Regulation 11(2)) should contact HSE at WICAR@hse.gov.uk to start the application process. In Northern Ireland contact should be made with HSENI on mail@hesni.gov.uk.

21.1.3. During HSE's assessment of the exemption request, the applicant will need to demonstrate in considerable and wide-ranging detail that the exemption is necessary and that no one affected by the exemption will have their health and safety prejudiced as a result of the work.

21.1.4. Report 10 provides guidance on industry standards for high pressure work in compressed air and is a normative reference within BS 6164:2019. HSE will consider the individual proposals put forward for an exemption request.

Regulation 22 Revocations and modification

(1) The instruments specified in column 1 of Part 1 of Schedule 2 to these Regulations are hereby revoked to the extent specified in the corresponding entry in column 3 of that Schedule.

(2) The instrument specified in column 1 of Part II of Schedule 2 to these Regulations is hereby modified to the extent specified in column 3 of that Schedule.

22. Guidance relevant to Regulation 22

22.1. No relevant guidance

Schedule 1 Information to be contained in a notice given pursuant to regulation 6(1), 6(2) or 6(3)

Regulation 6(4)

Schedule

1 The fact that work in compressed air is being undertaken.

2 The location of the site of the work in compressed air.

3 The date of the commencement and the planned date of completion of the work in compressed air.

4 The name of the compressed air contractor and a 24-hour contact telephone number (or numbers) of that contractor.

5 The name, address and telephone number of the contract medical adviser.

6 The intended maximum pressure at which the work in compressed air is to be undertaken.

7 The planned pattern of the work in compressed air to be undertaken including details, where applicable, of shift and weekend working.

8 The number of workers likely to be working in compressed air in each shift.

Schedule 2 Revocations and modification

Regulation 22

Part I: Revocations

Schedule

(1) *Title of instrument*	*(2)* *Reference*	*(3)* *Extent of revocation*
The Work in Compressed Air Special Regulations 1958	*SI 1958/61*	*The whole Regulations*
The Work in Compressed Air (Amendment) Regulations 1960	*SI 1960/1307*	*The whole Regulations*
The Work in Compressed Air (Prescribed Leaflet) Order 1967	*SI 1967/112*	*The whole Order*
The Work in Compressed Air (Health Register) Order 1973	*SI 1973/5*	*The whole Order*
The Employment Medical Advisory Service (Factories Act Orders etc. Amendment) Order 1973	*SI 1973/36*	*In Part II of the Schedule, the entry in respect of - The Work in Compressed Air Special Regulations 1958*
The Construction (Metrication) Regulations 1984	*SI 1984/1593*	*Regulation 3, and in the list in regulation 1(2) and in Schedule 1, the entries in respect of - The Work in Compressed Air Special Regulations 1958*

Part II: **Modification**

(1) *Title of instrument*	*(2)* *Reference*	*(3)* *Extent of modification*
The Pressure Systems and Transportable Gas Containers Regulations 1989	*SI 1989/2169*	*In paragraph 8 of Part I of Schedule 2 for the words "the Work in Compressed Air (Special) Regulations 1958" substitute "the Work in Compressed Air Regulations 1996 (SI 1996/1656)"*

Annex 1 Application of the Pressure Systems Safety Regulations 2000

1. Where there is a pressure vessel and associated pipework (which includes pipes, hoses, bellows, filters and other pressure-containing components) and overpressure protective devices at a pressure above 0.5 bar(g), a pressure system, as defined in the Pressure Systems Safety Regulations 2000 (PSSR), will exist and the requirements in PSSR will apply.

2. A pressure system, as defined in PSSR, is a system comprising one or more rigid pressure vessels (air receivers, surge vessels), associated pipework and protective devices. If there is no pressure vessel, then there is no pressure system and PSSR will not apply. It will similarly not apply when the air pressure in the system is less than 0.5 bar(g).

3. Occasionally, hired mobile compressor units are used and tied in to existing pipework. A mobile compressor unit (above 0.5 bar(g)), which usually consists of compressor, coolers, air receiver and protective devices, is covered by PSSR as a mobile pressure system. It is the owner of the compressor unit who has responsibility for compliance, particularly with regulation 8 of PSSR which requires the pressure system to have a written scheme of examination certified as being suitable by a competent person (as defined in PSSR). Any further additions to the scope of this pressure system, such as existing pipework to which a mobile compressor unit may be connected on site, will also need to be considered as part of the overall pressure system and it is the user (as defined in PSSR) who has responsibility for compliance with PSSR for that part of the pressure system. The user in this case may be the compressed air contractor.

4. Normally, pipework would only require including in a written scheme of examination if:

   4.1. it is subject to a duty where its mechanical integrity is liable to be importantly reduced by corrosion, erosion, fatigue or other factors; and

   4.2. it is in such a service and location that failure, with a sudden release of stored energy, would give rise to danger.

5. Regarding site pipework, new or existing, which has to be connected to compressor units, the user should consult a competent person on what other pressure-containing parts (such as separators and driers) need to be included in a written scheme of examination.

6. Regarding the competent person, the PSSR Approved Code of Practice *Safety of pressure* systems gives detailed guidance (see the guidance in respect of regulation 2) on the necessary attributes of the competent body for drawing up or certifying written schemes of examination.

7. Any working chamber, tunnel, manlock or airlock in which people work in compressed air, being work to which the WCA Regulations apply, is excepted from the requirements of PSSR.

8. The PSSR apply to cylinders of oxygen, nitrogen or helium and to the gas supply pipework respectively.

Annex 2 Compression and decompression procedures for use at low and intermediate pressures.

1. HSE does not have any currently approved compression or decompression procedures. Consequently, the compressed air contractor should select procedures which provide a safe system for work for the planned work. The following procedures which were previously approved by HSE and were used in low and intermediate pressure compressed air work for many years remain available for use if relevant. It is now the responsibility of the compressed air contractor, taking account of the advice of the contract medical adviser and others, to select appropriate procedures to ensure compliance with Regulation 7.

2. Compression

   2.1. The procedure to be followed during compression is:

      2.1.1. increase the pressure in the personnel lock gradually to not more than 0.3 bar in the first minute after starting compression;

      2.1.2. maintain the pressure of 0.3 bar until the lock attendant has checked that no person in the lock complains of discomfort;

      2.1.3. thereafter, increase the pressure at a uniform rate not faster than 0.6 bar per minute and such that no one suffers discomfort.

3. If a person complains of discomfort at any time during compression, the compression should be stopped immediately. If the discomfort does not quickly cease, the pressure should be gradually decreased. If the discomfort does not cease during decompression, the person concerned should be released from the lock when atmospheric pressure is reached and referred to the contract medical adviser.

4. If a person appears to be suffering from deafness and vertigo during compression, the person concerned should be carefully decompressed as soon as possible, released from the personnel lock and referred to the contract medical adviser.

5. Decompression procedures

   5.1. Decompression following work in compressed air at low and intermediate pressures should be a stage decompression, normally including the breathing of pure oxygen for part of the decompression. Air breaks of 5 minutes duration at regular intervals of 25 – 30 minutes should be part of the decompression profile.

   5.2. For intermediate pressure exposures the maximum oxygen dose resulting from decompression should not exceed 400 OTU per day for 5 consecutive days to be followed by a break of 2 days at atmospheric pressure. Otherwise, the daily limit should be reduced to 300. A limit of 1800 OTU in any period of 7 days should apply. No more than 7 consecutive

days should be worked under pressure to be followed by a break of at least 2 days at atmospheric pressure.

5.3. In the event of a DCI treatment, for the worker treated, the oxygen dose of the treatment should be included in the 7 day limit (see HSE RR126 https://www.hse.gov.uk/research/rrpdf/rr126.pdf).

5.4. Decompression from pressures of less than 0.7 bar(g) should be at a rate of 0.4 bar per minute.

5.5. Decompression from pressures between 0.7 and 0.95 bar(g) should be carried out in accordance with Part 1 of the Tables. The compressed air contractor may use air or oxygen breathing at his discretion and thereafter should follow the relevant table from Part 1.

5.6. Decompression from pressures of 1.0 bar(g) and above should be carried out in accordance with Part 2 of the Tables.

5.7. If, for any reason oxygen breathing has to be aborted, then emergency air tables should be used. For pressures below 1.0 bar(g) the emergency air table to be used should be Table 1 of the 'Blackpool tables' without oxygen.

5.8. The emergency air tables for intermediate pressure exposures should be selected in advance in conjunction with the contract medical adviser and the hyperbaric supervisor. One set of such tables which can be selected for use is the Blackpool tables set out in this Annex but without the use of oxygen.

5.9. Decompression procedures should include:

5.9.1. checking that the recording pressure gauge is functioning correctly;

5.9.2. ascertaining the period during which workers have been exposed to compressed air, i.e. the period from the start of compression to the start of decompression, and the maximum working pressure to which they have been exposed. When two or more workers are being decompressed in the lock and their exposure periods or their maximum working pressure do not fall within the same range, the decompression procedure should be based upon the longest exposure period experienced by any one of the workers concerned and the maximum working pressure during that period.

5.9.3. determining the decompression table to be used, on the basis that pressures should be in increments of 0.05 bar with actual pressures being rounded up to the next 0.05 bar increment above the actual pressure; i.e. 0.66 bar(g) becomes 0.7 bar(g), 0.96 bar(g) becomes 1.0 bar(g) etc;

5.9.4. determining the appropriate stage pressures, times at stage pressures and periods of oxygen breathing from the decompression tables;

5.9.5. noting the starting time and starting the stop-clock where provided;

5.9.6. reducing the pressure at a rate of 0.4 bar per minute to, but not lower than, the first stage according to the decompression tables being used;

5.9.7. retaining that pressure for the number of minutes prescribed in the table, then reducing the pressure at the same rate as before to the next stage, and so on;

5.9.8. oxygen breathing at stops of 0.6 bar(g) and below as indicated in the tables;

5.9.9. for stops of 2 bar(g) and below the compartment pressure should be maintained at the nominal stop pressure +/- 0.025 bar.

5.9.10. ventilating the lock continuously or at intervals of up to 15 minutes including increasing the ventilation rate in response to any increase in oxygen or carbon dioxide concentration. The routine ventilation at a stage can be carried out balancing the flow through the inlet and outlet valves whilst maintaining the stage pressure. The inlet valve should be closed before reducing the pressure to the next stage. Pressure fluctuation due to ventilation should not exceed 0.05 bar.

5.10. If a person in the lock collapses or is taken ill during the decompression, the lock attendant needs to raise the pressure in the lock to the pressure in the working chamber and ensure that the hyperbaric supervisor is informed immediately.

6. Blackpool Tables with Oxygen

6.1. These tables were written for a total exposure from initial compression to end of decompression of up to 10 hours. Current guidance is that this period should not exceed 8 hours.

6.2. Part 1 Decompression from pressures of 0.7 - 0.95 bar(g).

6.2.1. The compressed air contractor may use either the oxygen or air decompression table. Where an 'Exposure Period' appears on two lines, the longer duration of 'Total decompression period (min)' should be used.

6.3. Oxygen decompression table

6.3.1. Oxygen should be breathed at stage pressures of 0.6 bar(g) and below (columns shaded and with bold type in tables). There should be an air break of five minutes after every 20 minutes of oxygen breathing. The rate of change of pressure should be 0.4 bar/minute.

Table	Maximum working pressure (bar(g))	Exposure period (h)	Time (minutes) at Stage Pressure of:									Total decompression period (min)	Line No.
			1.8	1.6	1.4	1.2	1.0	0.8	**0.6**	**0.4**	**0.2**		
A	0.7 - 0.8	0-3.0										2	1
		3.0-8.5										2	2
B	0.85 - 0.9	0-3.0										2	1
		3.0-8.5									**15**	17	2
C	0.95	0-3.0										2	1
		3.0-8.5								**10**	**10**	22	2

6.3.2. Air decompression table - Air only decompression: No oxygen breathing

Table	Maximum working pressure (bar(g))	Exposure period (h)	Time (minutes) at stage pressure of:									Total decompression period (min)	Line No.
			1.8	1.6	1.4	1.2	1.0	0.8	0.6	0.4	0.2		
D	0.7 - 0.8	0-3.0										2	1
		3.0-8.5										2	2
E	0.85 - 0.9	0-3.0										2	1
		3.0-8.5								20	30	52	2
F	0.95	0-3.0										2	1
		3.0-8.5								40	60	102	2

6.4. **Part 2 Oxygen decompression from pressures of 1.0 bar(g) and over**

6.4.1. Oxygen should be breathed at stage pressures of 0.6 bar(g) and below (columns shaded **and** with bold type in tables). There should be an air break of five minutes after every 20 minutes of oxygen breathing. The rate of change of pressure should be 0.4 bar/minute.

Table No.	Maximum working pressure (bar(g))	Exposure period (h)	Time (minutes) at stage pressure of:									Total decompression period (min)	Line No.
			1.8	1.6	1.4	1.2	1.0	0.8	**0.6**	**0.4**	**0.2**		
1	1.0 - 1.15	0-0.5										3	1
		0.5-1.0										3	2
		1.0-1.5										3	3
		1.5-2.0									**5**	8	4
		2.0-2.5									**5**	8	5
		2.5-3.0									**10**	13	6
		3.0-4.0									**15**	18	7
		4.0-8.5									**20**	23	8
2	1.2-1.35	0-0.5										4	1
		0.5-1.0										4	2
		1.0-1.5									**5**	9	3
		1.5-2.0									**10**	14	4
		2.0-2.5									**20**	24	5
		2.5-3.0								**5**	**20**	29	6
		3.0-4.0								**5**	**30**	39	7
		4.0-8.5								**5**	**35**	44	8
3	1.4-1.55	0-0.5										4	1
		0.5-1.0									**5**	9	2
		1.0-1.5									**10**	14	3
		1.5-2.0								**5**	**20**	29	4
		2.0-2.5								**5**	**30**	39	5
		2.5-3.0								**10**	**35**	49	6
		3.0-4.0								**15**	**40**	59	7
		4.0-8.5							**5**	**20**	**40**	69	8

Table No.	Maximum working pressure (bar(g))	Exposure period (h)	Time (minutes) at stage pressure of:									Total decompression period (min)	Line No.
			1.8	1.6	1.4	1.2	1.0	0.8	0.6	0.4	0.2		
4	1.6-1.75	0-0.5										5	1
		0.5-1.0									5	10	2
		1.0-1.5								5	15	25	3
		1.5-2.0								10	30	45	4
		2.0-2.5								15	40	60	5
		2.5-3.0							5	20	40	70	6
		3.0-4.0							5	25	45	80	7
		4.0-8.5							10	30	45	90	8
5	1.8-1.95	0-0.5										5	1
		0.5-1.0									10	15	2
		1.0-1.5								5	30	40	3
		1.5-2.0							5	15	35	60	4
		2.0-2.5							5	25	40	75	5
		2.5-3.0							10	30	40	85	6
		3.0-4.0						5	15	30	45	100	7
		4.0-8.0						5	20	35	45	110	8
6	2.0-2.15	0-0.5									5	11	1
		0.5-1.0								5	15	26	2
		1.0-1.5							5	10	35	56	3
		1.5-2.0							5	25	40	76	4
		2.0-2.5						5	10	30	45	96	5
		2.5-3.0						5	15	35	45	106	6
		3.0-4.0						10	20	35	45	116	7
		4.0-7.75					5	10	25	40	50	136	8
7	2.2-2.35	0-0.5									5	11	1
		0.5-1.0								5	20	31	2
		1.0-1.5							5	20	35	66	3
		1.5-2.0						5	10	30	40	91	4

Table No.	Maximum working pressure (bar(g))	Exposure period (h)	Time (minutes) at stage pressure of:									Total decompression period (min)	Line No.
			1.8	1.6	1.4	1.2	1.0	0.8	0.6	0.4	0.2		
		2.0-2.5						5	20	35	45	111	5
		2.5-3.0						10	25	35	45	121	6
		3.0-4.0					5	15	25	40	45	136	7
		4.0-7.25					10	20	30	40	55	161	8
8	2.4-2.55	0-0.5									5	12	1
		0.5-1.0								10	25	42	2
		1.0-1.5							10	25	40	82	3
		1.5-2.0						5	20	35	40	107	4
		2.0-2.5					5	10	25	35	45	127	5
		2.5-3.0					5	15	30	35	45	137	6
		3.0-4.0				5	5	25	30	40	45	157	7
		4.0-6.75				5	15	25	30	45	60	187	8
9	2.6-2.75	0-0.5									5	12	1
		0.5-1.0							5	10	35	57	2
		1.0-1.5						5	10	30	45	97	3
		1.5-2.0					5	10	25	35	45	127	4
		2.0-2.5					5	20	30	35	45	142	5
		2.5-3.0				5	10	20	30	35	45	152	6
		3.0-4.0				5	15	25	30	40	45	167	7
		4.0-6.5			5	10	20	25	30	45	70	212	8
10	2.8-2.95	0-0.5								5	5	18	1
		0.5-1.0							5	15	40	68	2
		1.0-1.5						5	20	35	45	113	3
		1.5-2.0					5	15	30	35	45	138	4
		2.0-2.5				5	10	20	30	35	45	153	5
		2.5-3.0				5	20	25	30	35	45	168	6
		3.0-4.0			5	10	20	25	30	40	45	183	7
		4.0-5.75			10	15	20	30	40	50	80	253	8

Table No.	Maximum working pressure (bar(g))	Exposure period (h)	Time (minutes) at stage pressure of:									Total decompression period (min)	Line No.
			1.8	1.6	1.4	1.2	1.0	0.8	0.6	0.4	0.2		
11	3.0-3.15	0-0.5								5	5	18	1
		0.5-1.0						5	5	20	40	78	2
		1.0-1.5					5	10	20	35	45	123	3
		1.5-2.0				5	10	20	30	35	45	153	4
		2.0-2.5			5	5	15	25	30	35	45	168	5
		2.5-3.0			5	10	20	25	30	40	45	183	6
		3.0-4.0		5	5	15	25	25	30	40	45	198	7
		4.0-5.0		5	15	15	25	30	45	55	100	298	8
12	3.2-3.45	0-0.5								5	10	24	1
		0.5-1.0						5	10	25	40	89	2
		1.0-1.5					5	15	25	35	45	134	3
		1.5-2.0				5	15	25	30	35	45	164	4
		2.0-2.5			5	10	20	25	30	40	45	184	5
		2.5-3.0		5	5	15	25	25	30	40	45	199	6
		3.0-4.0		5	15	20	25	30	30	40	45	219	7
		4.0-4.25	5	10	15	20	25	35	45	60	120	344	8

Annex 3 Diagnosis, recording and evaluation of decompression illness.

1. Decompression illness is a term which covers the range of medical complications which can arise as a result of exposure to hyperbaric environments. As such it includes the condition previously described as decompression sickness and the conditions of arterial gas embolism and barotrauma. As it is often difficult to make a diagnosis based on an accurate knowledge of the pathological mechanism of the presenting symptoms, a classification of decompression illness based on the features of the illness was introduced within the hyperbaric medical fraternity (reference - Francis T J R and Smith D (Eds), Describing dysbarism, Bethesda, Md.: Undersea and Hyperbaric Medical Society 1991). This classification is based on the evolution of the presenting symptoms, the nature of the manifestations, the time of onset of the condition, the gas burden and any evidence of barotrauma. The previously used terms of decompression sickness (DCS); DCS Type 1, "bends", "niggles"; DCS Type 2 remain common in industry use.

2. The reclassification describing decompression illness is based on various factors.

3. The presentation of acute decompression illness should be described in terms of the following:-

    3.1. Evolution – progressive; static; spontaneously improving; relapsing

    3.2. Manifestation – limb pain or girdle pain; cutaneous; neurological (including audiovestibular); pulmonary; lymphatic; constitutional (malaise, anorexia, fatigue); hypotension.

    3.3. Time of onset

    3.4. Gas burden (e.g. depth-time profile)

    3.5. Evidence of barotrauma (lung, sinus, ear, dental)

4. Under this classification, the conditions previously known as decompression sickness are now described as decompression illness and qualified by the nature of the manifestation. Those cases presenting with predominant features of limb pain would previously have been classified as Type I decompression sickness.

5. **Symptoms of 'pain only' decompression illness (previously Type I)**

    5.1. Workers have pain in one or more limbs. While not feeling or looking ill, they usually appear to be in pain. The pain may commence at any time from the later stages of decompression up to 24 hours after decompression, although occasional cases start later. Whatever the intensity of the pain, agonising (the 'bends') or slight (the 'niggles'), all cases should be treated. The severity of the pain can mask evidence of serious decompression illness.

6. **Symptoms of serious decompression illness (previously Type II)**

    6.1. In compressed air work, the most common serious manifestation of decompression illness is with neurological symptoms, including those from the audiovestibular system. In compressed air tunnelling the term 'serious decompression illness' is almost synonymous with

neurological decompression illness, although other possible effects are included in the description in paragraphs 5-8 which follow.

6.2. Workers usually feel and appear ill. Characteristically, the cardiovascular, neurological, respiratory or gastro-intestinal systems are affected. Occasionally they also complain of pains in the limbs.

6.3. The symptoms sometimes commence during the later stages of decompression, although generally within 45 minutes after decompression. The symptoms may be delayed for some hours, but this is uncommon.

6.4. A patient with serious decompression illness can present as follows:

6.4.1. loss of consciousness. This can occur during the later stages of decompression or soon after its completion;

6.4.2. collapse, with signs and symptoms of shock;

6.4.3. giddiness (the 'staggers');

6.4.4. difficult breathing (tightness of the chest or 'chokes');

6.4.5. visual symptoms (flashes of light, spots before the eyes or tunnel vision);

6.4.6. headache;

6.4.7. abdominal pains, with or without vomiting;

6.4.8. weakness or paralysis of limbs;

6.4.9. tingling or numbness of limbs.

6.5. The signs and symptoms of serious decompression illness are so varied that making a correct diagnosis might prove difficult. It is essential, therefore, that all workers with abnormal signs or symptoms who have been exposed to compressed air during the previous 24 hours should be recompressed immediately. If adequate recompression does not relieve some of the symptoms almost immediately, the diagnosis needs then to be reconsidered.

7. **Other signs and symptoms**

7.1. 9 In addition to the signs and symptoms already mentioned, certain other complications of decompression can be encountered:

7.1.1. a bluish mottling of the skin of the trunk. Sometimes called 'bruising', this can be associated with any of the symptoms already mentioned or it can occur alone;

7.1.2. irritation of the skin over the chest, neck or face. This can precede and accompany mottling; early cases respond to treatment by recompression;

7.1.3. localised swelling, usually in the neck and shoulder area. This results from gas in the subcutaneous tissues and can be seen to disappear on recompression. It requires no treatment unless painful, at which time the worker should be recompressed;

7.1.4. a 'squelching' noise on movement at the knee or shoulder joint. Clearly audible to other people, this is caused by gas in or around a joint. It appears to be of little consequence and disappears after a few hours.

7.2. The conditions described in paragraph 9, do not necessarily require treatment as decompression illness. They should, however, be taken into consideration when assessing a worker's fitness to continue working in compressed air. These symptoms may be accepted as evidence that, for the worker in question, the decompression procedure could have been inadequate. They should be included in the reports of decompression illness.

7.3. Nose bleeding is usually associated with a head cold, but should workers cough blood, even though the origin of the blood may be considered to be post-nasal, their lungs need to be investigated.

7.4. Deafness associated with decompression, affecting one or both ears, can result from an obstruction in the passage between the ear and the throat causing the ear drum to bulge outwards. This can be relieved by nasal decongestants or, if unsuccessful, specialist ear, nose and throat advice should be sought.

8. **Decompression illness initial assessment checklist**

8.1. All workers presenting symptoms of possible decompression illness should have these symptoms assessed and recorded. This should be done as soon as possible after symptoms are reported. Timing will depend on the nature and severity of symptoms. Assessment should not delay recompression therapy and may need to be done during this treatment. The checklist can be modified to suit the needs of individual contracts.

	Name
	Date
	Time of assessment
	Maximum pressure of last shift
	Duration of last shift
	Any other exposure to compressed air in last 24 hours
	Time since decompression
	Symptoms
	Worker's complaints - general
	Walking and balance
	Breathing
	Mental function - general
	Level of consciousness
	Vision
	Hearing

Peripheral numbness
- tingling
Pain - limbs
- other
Skin
Physical assessment
Vital signs: pulse rate
blood pressure
respiration rate

Neurological system	**Left**	**Right**
Pupils – size		
Reaction to light		
Reaction to accommodation		
Eye movements		
Nystagmus present		
Facial nerve, smile, clench teeth, equal		
Hearing		
Tympanic membranes		
Speech, quality		
Tongue, any deviation		
Co-ordination: finger nose test		
Eyes open		
Eyes closed		
Muscle strength		
Shoulder shrug		
Grip strength		
Raise arms to shoulder height		
Push with flexed arm		
Pull with flexed arm		

Straight leg raising		
Dorsiflexion of foot		
Plantarflexion of foot		

Reflexes: plantar arms legs		
Sensation: light touch arm leg pin prick arm leg		

9. **Recording and evaluating decompression illness**

9.1. The occurrence of a case or suspected case of decompression illness should be recorded in the lock attendant's register or the saturation against the person's exposure immediately preceding the event.

9.2. Full clinical records should be kept of the presentation and treatment of all cases of decompression illness or suspected decompression illness. For the purpose of providing a summary of this information, the case sheet that follows, devised by the former Medical Research Council Decompression Sickness Panel, Compressed Air Working Group can be of help.

9.3. Analysis of the circumstances surrounding each case of decompression illness is important in order to determine whether there were any preventable factors. On an individual basis these can derive from failure of familiarisation, temporary unfitness or inadequate decompression.

9.4. A check needs to be made on the adequacy of the decompression following all cases of decompression illness and on the results of physiological monitoring of the person concerned.

9.5. This should be done in conjunction with the contract medical adviser.

9.6. Where there is confidence in the effectiveness of decompression procedures and monitoring procedures have been properly followed, the continuing fitness for work of the individual should be reassessed.

9.7. Provided the effectiveness of the decompression procedures for the group remains acceptable no reduction in working period for that pressure is required.

9.8. Any reduction in working period will have the effect of increasing the number of shifts worked which in turn can increase the number of decompression illness events occurring. Shift length and the resulting number of shifts required to complete a job have to be carefully balanced. The contract medical adviser should provide the necessary advice to the compressed air contractor.

9.9. Shift length reduction should not be seen as a substitute for proper management and control of work in compressed air. However it should be introduced as a response to cases of decompression illness if all other controls are operating satisfactorily.

9.10. It is unlikely that sufficient exposures will be undertaken on most contracts to allow meaningful statistical analysis to be undertaken however Doppler monitoring can be used to provide data on which to make decisions about shift length.

9.11. Should analysis be required there are a number of measures of the incidence of decompression illness available. The measures currently preferred and their derivation were described in the Proceedings of the Institution of Civil Engineers, Paper 14384 Lamont DR and Booth R *"Acute decompression illness in UK tunnelling",* November 2006. The results for air decompression to the Blackpool Tables from 1984 – 2001 are set out in Table 1. To date no similar table for the Blackpool Tables with oxygen has been published.

Pressure / **Time**	**Single exposure risk factors %**				
	0 - < 2	**2 - < 4**	**4 - < 6**	**6 - < 8**	**>= 8**
< 0.7	0.00	0.00	0.00	0.00	0.00
0.7 – 0.95	0.01	0.03	0.06	0.20	0.21
1.0 – 1.25	0.03	0.02	0.20	0.24	0.39
1.3 – 1.55	0.00	0.22	0.81	1.07	1.69
1.6 – 1.85	0.05	0.89	2.41	1.92	1.63
1.9 – 2.15	0.22	1.11	1.85	19.05*	0.00*
2.2 – 2.35	0.79	0.23	2.84	No data	
2.4 – 2.7	0.00*	No data	No data	No data	
>2.7	No data	No data	No data		

Table 1 Single exposure risk factors

Note:These figures were derived from copies of records held by compressed air contractors and donated to HSE for research purposes.

* insufficient exposures to be statistically valid..

Compressed air worker's decompression illness case sheet

☑ *Please tick appropriate boxes*

Employer..... Date..... NI No.....
Full name of worker..... Works No.....
Contract..... Occupation..... Activity: manual/supervisor/sedentary.....
Age..... Height (cm)..... Weight (kg)..... Body mass index.....
Date of last medical assessment..... Result: fit/conditions.....

Have you had decompression illness before? Yes ☐ No ☐ If yes, how many times?.....
When?.....

Details of work in 8 shifts previous to this attack

Day	1	2	3	4	5	6	7	8
Date								
Maximum working pressure (bar)								
Working period								

Any decompression illness? Yes ☐ No ☐

Details of exposure immediately preceding illness
Maximum working pressure (bar)..... If multiple exposure, how many?.....
Date and time of start of last compression.....
Date and time of start of last decompression..... Time last decompression completed.....

Decompression tables used (give details)..... Was anyone else affected? Yes ☐ No ☐

Shift: Day ☐ Night ☐ Back ☐ Head cold? Yes ☐ No ☐ Chest cold? Yes ☐ No ☐

Pain only (bends)
How soon after decompression?..... Site of pain.....

Localised? Yes ☐ No ☐ Spreading? Yes ☐ No ☐ Any injury to affected part Yes ☐ No ☐

Excessive use of limb during shift? Yes ☐ No ☐ Any symptom other than pain?.....

Skin mottling? Yes ☐ No ☐ Skin irritation? Yes ☐ No ☐ Vomiting? Yes ☐ No ☐

Serious
Signs and symptoms.....

Circulatory? Yes ☐ No ☐ Respiratory? Yes ☐ No ☐ Visual? Yes ☐ No ☐ Neurological? Yes ☐ No ☐

Treatment (pain only or serious)
Time commenced..... Pressure of relief.....
Highest pressure used..... Time at that pressure.....
Method of decompression.....
Number of recompressions..... Time treatment completed.....
Residual symptoms.....

Evidence of recurrence after above treatment Yes ☐ No ☐

Treatment apparently successful Fit to work in compressed air again? Yes ☐ No ☐

Signed ..... Signed.....
Medical lock attendant Medical adviser

Example of Compressed air worker's decompression illness case sheet

Annex 4 Treatment of DCI

1. Management of the treatment of decompression illness is the responsibility of the contract medical adviser. Contract medical advisers should decide which treatment regime to use and advise the hyperbaric supervisor, persons with roles under Report 10 para 4.7.1 and the medical lock attendant accordingly. Advice on the treatment regime should extend to situations in which symptoms are not fully resolved.

2. Treatment regimes using oxygen have been published by the Royal Navy and the United States Navy in their respective diving manuals – see US Navy Diving Manual 7th edition (2017) available at https://www.navsea.navy.mil/Portals/103/Documents/SUPSALV/Diving/US%20DIVING%20MANUAL_REV7.pdf?ver=2017-01-11-102354-393.).

3. For many years in tunnelling, procedures for treating decompression illness arising from low or intermediate pressure exposures developed by the Medical Research Council Decompression Sickness Panel and published by the Construction Industry Research and Information Association in their Report 44, third edition 1982, *Medical code of practice for work in compressed air*, were used, apparently successfully.

4. At low, intermediate pressures and non-saturation high pressure exposures, the hyperbaric supervisor, or if unavailable, the medical lock attendant, should initiate therapeutic recompression immediately a potential case of decompression illness has been identified in accordance with procedures previously agreed with the contract medical adviser. These procedures should set out requirements for contact with the contract medical adviser over diagnosis, treatment, extension of treatment etc.

5. For DCI occurring in connection with saturation exposures the guidance in Report 10 clause 7.9 should be followed.

6. The contract medical adviser should assess the casualty on completion of treatment.

7. In the absence of advice from the contract medical adviser to the contrary, US Navy Table 6 should be used for treating decompression illness arising from tunnelling in compressed air at low or intermediate pressures. US Navy Table 6A may be used in specific cases where clinically indicated on the advice of the contract medical adviser.

8. Information about therapeutic recompression procedures is given above however in an emergency, assistance can be sought from the duty diving medical officer, Ministry of Defence (Navy).

9. Relevant research is set out in “Treatment of DCI in compressed air workers”, HSE Contract Research Report 320/2001 (https://www.hse.gov.uk/research/crr_pdf/2001/crr01320.pdf).

Annex 5 Record-keeping

1. Introduction

1.1. The Regulations require the making and maintenance of the records described in this appendix. The records which should be kept and those responsible for keeping them are:- medical surveillance – appointed doctor; health surveillance including treatment of DCI – contract medical adviser; exposure - compressed air contractor and individual employers. The compressed air contractor should also keep all recordings made in connection with post decompression physiological monitoring.

1.2. The results of medical surveillance are required to be recorded in a clinical examination record which is maintained by the appointed doctor for each worker. When paper records are used the principal compressed air contractor is responsible for providing appropriate site storage facilities during compressed air work activities -normally a lockable filing cabinet held securely in the medical examination facilities on site with appropriately restricted access in accordance with the requirements of the contract medical adviser.

1.3. Data protection legislation should be followed for electronic clinical examination records. In all cases all records should be maintained and stored in strict compliance with the ethical, legal and medical confidentiality requirements of the Faculty of Occupational Medicine and General Medical Council.

2. Clinical records

2.1. Appointed doctors are required to maintain accurate and comprehensive clinical records to meet normal professional standards and the terms of appointments made by HSE. Contract medical advisers should maintain clinical records of diagnosis and treatment of DCI and any other ill-health conditions arising from the work as well as records of any advice formulated and given to the compressed air contractor. This should include any review or assessments of the effectiveness of the decompression procedures.

3. Exposure records

3.1. Non-saturation exposure records should be kept electronically in a database or spreadsheet format which is compatible with commonly available office software packages. Appropriately formatted date and time fields should be used to record all dates and times. Current data protection requirements should be observed. All persons exposed should be advised that their data may be analysed for regulatory compliance purposes and should also be requested to consent to their data in anonymised form being used for research purposes.

3.2. The exposure record will need to contain details of the decompression tables being used along with personal details of the worker and a record of the exposures undertaken. The following data fields should be completed for each non-saturation exposure:

3.2.1.Unique site reference number for each worker;

3.2.2.*NI number;

3.2.3.*Employer;

3.2.4.*Surname;

3.2.5.*First name;

3.2.6.Date of exposure (in date format);

3.2.7.*Occupation;

3.2.8.Compression start time (in time format);

3.2.9.Decompression start time (in time format);

3.2.10. Exposure period (in time format);

3.2.11. Max exposure pressure;

3.2.12. Decompression table number;

3.2.13. Line number;

3.2.14. Comments (include record of any DCI in this field);

3.2.15. Location on site if multiple workings (e.g. Shaft 4A, Shaft 1 etc).

3.3. Alternatively for fields marked *, a separate summary spreadsheet or database can be provided to link that information to the unique site reference number used for each worker in the main exposure spreadsheet or database.

3.4. For saturation exposures the records recommended by clause 9.2 of Report 10 and clause 11.10.3.1 of this guide should be kept.

3.5. A part of the exposure record should be produced by the lock attendant each time a person is compressed and decompressed. The master copy (with appropriate secure backup) of the exposure record spreadsheet or database should be updated at least daily and kept by the hyperbaric supervisor.

3.6. The exposure record needs to contain each person's name, national insurance number and employer so that an individual exposure record can be compiled in respect of each person and an exposure record can be compiled in respect of all the employees of each employer.

4. Health records

4.1. Both employers' and personal health and exposure records will need to contain personal details of the worker and record the date, type and result of each medical assessment. Clause 7.2 below gives full details of the information needed.

4.2. The personal health record provided under Regulation 10(3)(c) is the property of the employee and should be provided to the appointed doctor for completion at the time of each

assessment. It may be convenient for the appointed doctor to retain the health records during the course of a contract.

5. The compressed air contractor

5.1. The compressed air contractor has to ensure that:

5.1.1. an adequate exposure record is made and maintained of the times and pressures at which work in compressed air is undertaken along with a time/pressure record of the decompression and that the records or copies of them are kept in a suitable form;

5.1.2. an individual exposure record is made and maintained for each person who undertakes work in compressed air.

5.2. In addition, as soon as is reasonably practicable, after a person has ceased to work on any project, that:

5.2.1. the employer of that person is provided with a copy of the parts of the exposure record that relate to that person;

5.2.2. that person is provided with a copy of the parts of the individual exposure record that relate to him or her.

6. The employer

6.1. Employers have to ensure that:

6.1.1. a health record (employers') is made and maintained for each of their employees who is engaged in work in compressed air and that the record or a copy of it is kept in a suitable form;

6.1.2. a copy of the relevant part of the health record is provided to the employee to whom it relates as soon as is reasonably practicable after that employee has ceased to work on any project; and

6.1.3. the record of exposures or a copy thereof provided to the employer by the compressed air contractor is kept in a suitable form.

7. The compressed air worker's health and exposure record

7.1. The Regulations require that compressed air workers are provided with a "compressed air worker's health and exposure record" which will summarise the results of that worker's medical and health surveillance, exposure to compressed air and training. This health and exposure record will be the personal property of the compressed air worker who should keep it securely between contracts.

8. **Keeping the records**

8.1. The compressed air contractor is required to keep all exposure records on site for the duration of the work in compressed air. Thereafter, the compressed air contractor and the employer should arrange for the records for which they are responsible to be kept for at least 40 years from the date of the last entry.

8.2. The health and exposure records can be kept in any convenient manner. They may be kept in a non-paper form such as microfiche or computer disc.

8.3. A copy of the decompression tables used needs to be included with the records.

8.4. The database function of a standard office software package is the preferred option for storing the records as spreadsheets offer insufficient flexibility for data sorting and analysis and are more easily corrupted.

9. Access to the records

9.1. BTS CAWG has considered this matter and has recommended that the records should be accessible to:

9.1.1. HSE;

9.1.2. individual compressed air workers, or their representatives, who can retrieve their own records by contacting their employers, providing their personal details (including NI number). They will also be required to give details of the individual contract(s) on which they were employed; and

9.1.3. compressed air contractors and employers, who can only retrieve records for their own contracts.

Interim technical guidance 1 - Airlocks for air mode exposures and oxygen decompression systems

1. Scope and Life-span of this guidance

1.1. This interim technical guidance is primarily aimed at TBM airlocks,

1.2. This interim technical guidance should be followed in conjunction with the requirements of BS EN 12110:2014 in respect of airlocks utilising compressed air as the pressurising and breathing medium along with requirements for oxygen breathing systems for decompression purposes. This interim technical guidance should be considered time-expired once the revised version of BS EN 12110:2014 has been published as a prEN.

1.3. Whilst the principles in this interim technical guidance can generally be applied to tunnel airlocks some of the detailed requirements are not technically feasible. Professional judgement should therefore be applied in interpreting its requirements in respect of such locks.

2. Design, fabrication etc

2.1. Airlocks and oxygen decompression systems on TBMs should meet the requirements of BS EN12110:2014 along with the additional requirements set out below.

2.2. The design, fabrication and testing of airlocks, as pressure vessels, should be done in conformity with BS EN 13445 parts 1 – 5.

3. Pipework, hoses, valves etc

3.1. Pipework should have a burst pressure of at least 4 times the maximum working pressure of the fluid contained. Following installation, pipework installations should be pressure tested to 1.5 times maximum working pressure.

3.2. For pipework of materials other than mild steel, joints should be made using compression fittings which are compatible with the material of the tube being used. For preference, double ferrule fittings should be used.

3.3. Hoses should have a burst pressure at least four times the maximum working pressure of any fluid. Following installation, hose installations should be pressure tested to 1.5 times maximum working pressure.

3.4. Valves can be divided into two categories – slow acting, normally multi-turn valves, for controlling compression and decompression of persons along with routing control of oxygen flow and fast acting, normally quarter turn valves, non-return valves etc, for other purposes.

4. Servo valves

4.1. Any servo-operated valve should be fitted with a manual override or bypass.

5. Gauges

5.1. Gauges can be divided into two categories – controlling gauges for compression or decompression of persons and indicating gauges for other purposes.

5.2. Gauges for controlling compression or decompression of persons should be mirror scale gauges. They should have a minimum scale diameter of 150 mm and be capable of being read to an accuracy of 0,05 bar. They should be accurate to 0.25 % of full-scale readout. There

should be a means of isolating a mirror scale gauge to allow for removal or for calibration purposes.

5.3. Gauges for indicating pressure should comply with BS EN 837-1 and be at least 63 mm in diameter.

5.4. All gauges should normally be selected so that the maximum working pressure in use would be approximately 75% of the full-scale reading.

5.5. Gauges used in oxygen systems (or mixtures containing 23.5% or more of oxygen) should be oxygen compatible.

5.6. Digital pressure gauges of equivalent accuracy may be used instead of analogue gauges. Digital gauges require an uninterruptible power supply capable of powering the gauge for at least 24 hours.

6. Pressure regulators

6.1. Pressure regulating devices should be fitted to compressed air and oxygen supply lines to reduce the downstream pressure to the maximum required for the line function. The pressure of compressed air from site compressors is already regulated at source.

7. Protection against inlet line breaks

7.1. It is good hyperbaric engineering practice to fit protection against sudden pressure loss as a result of inlet line breaks, to all inlet lines of 15 mm diameter and over. Protection devices should be fitted on both sides of the pressure vessel shell. Those fitted inside the shell should act automatically such as flap valves or non-return valves and be located adjacent to the penetration. Those fitted outside should normally fast acting and be fitted adjacent to the penetration or within 3 fittings lengths of the penetration and should be protected against mechanical damage where necessary.

7.2. This requirement should not be applied to the fire-fighting system.

7.3. Adjacent to the penetration there should be a marking with the purpose of the penetration.

7.4. Outflow lines over 15 mm diameter apart from those connected to pressure relief valves, shall be fitted with excess flow prevention valves.

8. Fire protection

8.1. Fire protection particularly on personnel locks is of the utmost importance.

8.2. All airlocks should be constructed from materials and components selected to minimize their flammability under increased air pressure and which are of low toxicity when burning.

8.3. There should be a water spray or water mist system discharging into each compartment of personnel locks. It should be capable of being operated from inside or outside of the compartment. The system design should be based on the performance requirements for the main compartment of a personnel lock.

8.4. Water spray systems should comply with BS EN 16081:2011 + A1 2013 as amended here. All parts of the system should be coloured or marked in such a way that they are immediately distinguishable from all other systems on the air lock (BS EN 16081 cl 5.8); (cl 5.10) conveying of the extinguishing medium should be done by a permanently-on gas pressure tank system exclusive to the extinguishing system; (cl 5.12) the “permanently-on” pressurising medium should be a gas which is respirable within the normal operating range of the chamber; (cl 5.13) the required supply of extinguishing medium should be calculated to ensure at least 2 minutes of flow of the extinguishing medium. The system when wet tested using water, in

accordance with 6.3.2 should meet the requirements of that clause. A hot test is not normally required.

8.5. Water mist systems should meet the requirements of NFPA 99 (National Fire Prevention Association "Health Care Facilities code"). They should also conform to the guidance in respect of marking. They should be operated by means of a permanently-on gas pressure tank system exclusive to the extinguishing system containing a gas which is respirable within the normal operating range of the chamber. The required quantity of extinguishing medium and gas to discharge it, should be calculated to ensure at least 2 minutes of flow of the extinguishing medium. The system when wet tested using water, should meet the requirements of clause 6.3.2 of BS EN 16081:2011 + A1 2013.

8.6. There should be a indication of the pressure of the pressurising medium displayed at the control panel for the lock.

8.7. The fire extinguishing system should also include either a hand-held extinguisher or a water hose inside the lock. All fire-fighting equipment should be suitable for the maximum working pressure of the air lock.

8.8. Means of operating the fire-fighting and other emergency provisions should be provided at the control panel.

8.9. It shall be possible to reduce the pressure in each compartment of the personnel lock from 2 bar(g) to atmospheric pressure in not more than 2 min in the event of fire by means of a valve outside the airlock.

8.10. A fire suppression system is not required in compartments of materials locks.

8.11. In-tunnel personnel locks should be fitted with a water spray or mist fire suppression system supplemented by fire hose/extinguishers as necessary.

9. Electrical supply

9.1. The power supply to TBM personnel locks should come from the main TBM power supply. Emergency power during unplanned outages should be supplied from the TBM emergency power supply.

9.2. The TBM standby power supply is only intended for use during TBM maintenance such as cable extension and not for hyperbaric interventions.

9.3. Electrical power for materials locks if required, should also be supplied from the TBM.

9.4. Compressed air interventions should be planned so as not to coincide with maintenance activity on the TBM.

9.5. In-tunnel locks should be supplied from the main tunnel power and emergency power supplies.

10. Control panel ergonomics

10.1. Panels shall be designed in accordance with the principles for interaction between controls and instrumentation set out in BS EN 894-1. Selection and layout of instrumentation and other displays shall be in accordance with BS EN 894-2. Selection and layout of valves and other control actuators on a panel shall be in accordance with BS EN 894-3. The layout of a panel shall be such that the lock attendant can operate control equipment whilst simultaneously observing the relevant instrumentation as required by BS EN 894-4.

10.2. Control panels shall be illuminated with a nominal intensity of at least 200 lux at the panel surface in accordance with BS EN 894-2. All valves and gauges not located at a control panel shall be lit with an intensity of 200 lux at the valve or gauge display. When operating

under emergency power (cl 5.2.7), lighting levels may be reduced to no less than 100 lux at the control panel and 15 lux in each compartment of the personnel lock at seat level.

11. Oxygen breathing system (including all gas mixtures with 23.5 % oxygen or more)

11.1. General

11.1.1. The oxygen built in breathing system (BIBS) should be capable of delivering oxygen at a pressure of at least 1.8 bar(g) to allow for therapeutic treatment to be undertaken in the lock in an emergency.

11.2. Oxygen supply from TBM

11.2.1. Oxygen should be supplied from an oxygen source remote from the lock but on the TBM, via the lock control panel to the BIBS manifolds or breathing units in each compartment of the lock. For air mode exposures only the oxygen supply to the breathing units can be adjacent to the lock and controlled through a separate control panel.

11.2.2. There should be a pressure regulator adjacent to each high pressure source reducing the pressure of the oxygen in the supply line downstream of the high pressure source to 40 bar(g) or less.

11.2.3. There should be gauges indicating the pressure upstream and downstream of the regulator.

11.2.4. It should be possible to changeover high pressure sources without disrupting the oxygen supply.

11.2.5. There should be an excess flow prevention device in the 40 bar(g) supply line.

11.2.6. It should be possible to switch from supplying oxygen to supplying air to the masks from the panel controlling the oxygen supply. Switchover may be activated by activation of the fire suppression system.

NOTE – this is a safety action to reduce the possibility of leakage of oxygen into the chamber and to maintain a supply of respirable gas to those in the chamber in the event the fire suppression system is activated.

11.3. Inlet flow controls – oxygen

11.3.1. There should be a non-return valve and a fast acting shutoff valve on the oxygen line immediately upstream of the control panel. There should also be a pressure gauge indicating the pressure of the oxygen supply upstream of the shutoff valve.

11.3.2. There should be a means of releasing pressure safely and bleeding off gas from the supply line downstream of the shutoff valve by means of a slow acting valve. Gas should be discharged into the TBM ventilation flow.

11.4. Oxygen supply adjacent to lock

11.4.1. There should be a primary and secondary high pressure source and it should be possible to change sources without disrupting flow to the lock.

11.4.2. First stage pressure reduction should be to a pressure of 40 bar(g) or less and be at the source with pressure indicating devices on both the high pressure and low pressure sides of the pressure reduction device. Back flow from one source to the other should be prevented by non-return valves. There should be an excess flow prevention device in the 40 bar(g) supply line.

11.4.3. Any dedicated control panel on the oxygen system should have a mimic diagram. Pipes, valves, gauges etc should be in accordance with this interim technical guidance.

11.5. Minimum requirements for BIBS

11.5.1. The BIBS supplying oxygen for decompression purposes in a personnel lock should incorporate as a minimum a supply manifold and discharge manifold in the lock. Masks incorporating a second stage pressure reduction mechanism and a lung demand valve, should be connected to both manifolds by means of pressure resistant hoses with seal-sealing quick couplings. The couplings on the manifolds should have removable caps to prevent ingress of dirt.

11.5.2. It should not be possible to cross connect supply and discharge hoses. Exhaled gas should be discharged to a ventilated area outside the chamber.

11.6. **Enhancements to BIBS**

11.6.1. User comfort can be improved by the use of proprietary systems which incorporate breathing units and/or an exhalation resistance reduction device.

11.7. Breathing units

11.7.1. Instead of a supply manifold and mask combination, a breathing unit provides second stage pressure regulation and a lung demand valve within a device attached to the lock compartment wall along with a connection to the discharge line. This allows masks to be connected to the unit by lightweight flexible non-pressure resistant tubes.

11.7.2. Requirements for breathing units include that failure of one unit should not disrupt flow to other units. For each unit there should be a shutoff valve on the oxygen supply to the mask. The mask connections should be self-sealing when disconnected and provided with caps to prevent dirt ingress when not in use. It should not be possible by design to cross connect supply and exhalation connections.

11.7.3. There should be a valve outside the lock to shut off the oxygen supply to the lock and provide a supply of breathing air (see 11.2.6).

11.7.4. There should be one standby breathing unit in a compartment.

11.8. **Exhalation resistance reduction device**

11.8.1. An exhalation resistance reduction device reduces the pressure in the discharge line and hence facilitates exhalation and the discharge of oxygen rich gas particularly at low chamber pressures.

11.8.2. The device should normally be powered by air pressure from the air supply to the lock however other power sources can be used.

11.8.3. Failure of the device should not increase the breathing resistance for other masks connected to it or lead to uncontrolled loss of air pressure in lock. There should be no discharge of oxygen or oxygen rich air into the lock. Excess pressure reduction in the discharge line should be prevented.

11.8.4. Adjustment and controls for the device should be located outside the lock.

11.9. Equipment requirements for oxygen

11.9.1. Pipework, hoses, valves, gauges etc should be in accordance with this Interim Technical Guidance.

11.10. Distribution network

11.10.1. The distribution pipework should be designed to give a theoretical flow rate of 75 l/min per person in accordance with cl 4.7.1 of EN 14931:2006.

11.10.2. Downstream of the control panel there should be slow operating valve to release pressure in any supply line.

11.11. **Oxygen discharge**

11.11.1. Exhaled oxygen should be fed into a dedicated line for discharge outside the personnel lock to a ventilated area. The discharge of oxygen into a lock compartment should be prohibited.

11.11.2. The discharge line should be capable of passing the design supply flow at all oxygen stage pressures for the decompression tables intended by the user.

11.12. **Oxygen monitoring**

11.12.1. Each compartment of the personnel lock should be equipped with at least one device to monitor the oxygen concentration by volume in that compartment. The concentration should be displayed at the control panel.

11.12.2. A warning device with an audible alarm should be provided to alarm when the oxygen concentration in the atmosphere of a compartment is 23.5% or more by volume.

11.13. Oxygen cleanliness

11.13.1. All pipework, hoses, gauges etc intended to convey gas containing 23.5% oxygen or more by volume should be oxygen cleaned in accordance with EN ISO 15001 before the lock is handed over to the user. Once cleaned, the ends of pipes and hoses should be sealed or capped.

11.13.2. A dated certificate confirming the oxygen cleaning carried out should also be given to the user.

11.13.3. Technical information on oxygen cleanliness can be found in “CLEANING OF EQUIPMENT FOR OXYGEN SERVICE Doc 33/18” published by the European Industrial Gases Association https://www.eiga.eu/index.php.

Interim technical guidance 2 - Mixed gas capability for personnel locks and pressurised transfer shuttles.

On TBMs or in-tunnel installations

1. Life-span of this guidance

1.1. This interim technical guidance should be followed in conjunction with the requirements of BS EN 12110:2014 in respect of requirements for the use of non-air breathing mixtures and saturation techniques in personnel locks. This interim technical guidance should be considered time-expired once the revised version of BS EN 12110:2014 has been published as a prEN.

2. **General**

2.1. The requirements of ITG 2 are in addition to the requirements in BS EN 12110:2014 and ITG 1.

3. Design etc

3.1. Personnel locks and shuttles should meet the requirements of BS EN 12110:2014 and any additional requirements set out in this guide.

3.2. The design, fabrication and testing of shuttles as pressure vessels, should be done in conformity with BS EN 13445 parts 1 – 5.

4. Pressure relief valve

4.1. Compartment shell valves on penetrations feeding pressure relief valves should be secured in the open position.

5. Pipes hoses, valves and gauges etc.

5.1. In addition to the requirements in BS EN 12110:2014 the following general guidance on pipes, hoses and valves for personnel locks should be followed.

5.2. Pipework

5.2.1. Pipework for oxygen or mixed gas should be fabricated from aluminium nickel silicon brass (copper alloy) tube to BS EN 12449 CW 700R, or austenitic stainless steel with a chromium nickel content of >22%, or from copper tube conforming to BS EN 13348.

5.2.2. Pipework should be jointed using compression fittings which are compatible with the material of the tube being used. Double ferrule fittings are to be preferred.

5.2.3. Pipework should withstand a burst pressure of at least 4 times the maximum working pressure of the fluid contained and should be pressure tested to 1.5 times maximum working pressure.

5.3. Hoses

5.3.1. The burst pressure of hoses should be at least four times the maximum working pressure of any gas they carry or four times the maximum pressure of any liquid they carry. Hose installations should be pressure tested to 1.5 times maximum working pressure.

5.3.2. Self-sealing quick couplings, if used, should conform to ISO 7241 series A and should be compatible with contents and for intended purpose. Self-sealing quick couplings should have a design pressure of 4 times the working pressure.

5.4. Valves

5.4.1. For airlocks rated at 5 bar(g) or over, any pipe of 15 mm diameter or more for the normal (non-emergency) outflow of gas from the chamber should have an automatic excess flow prevention valve.

5.5. Servo-operated valves

5.5.1. Servo valves should have a manual override or bypass.

5.6. Gauges

5.6.1. Mirror scale gauges should be used for controlling the compression and decompression of persons. They should have a minimum scale diameter of 150 mm and be capable of being read to an accuracy of 0.05 bar. They should be accurate to 0.25 % of full-scale readout. There should be a means of isolating a mirror scale gauge to allow for removal or for calibration purposes.

6. Pressure regulators

6.1. Pressure regulators should be fitted to all oxygen or mixed gas supply lines to reduce the pressure to the minimum required for undertaking the works safely.

7. Gas analysis

7.1. Gas analysis equipment should be fitted on all mixed gas lines supplying personnel locks both upstream and downstream of the control panel. Intermittent analysis capability is required upstream whilst continuous capability is required downstream. Connections should include means of isolation to allow for removal or calibration.

8. Protection against inlet line breaks

8.1. For protection against sudden pressure loss in the event of line break, all inlet lines of 15 mm diameter and over, should be fitted with cut off devices on both sides of the pressure shell to close the line. Those inside the shell should be fitted next to the shell and be self-acting such as flap valves or non-return valves. Those fitted outside should normally be fitted within three fittings length of the penetration and should be protected against mechanical damage.

8.2. This requirement does not apply to the fire-fighting system.

8.3. The purpose of the line passing through a penetration should be clearly marked adjacent to it.

8.4. Outflow lines over 15 mm diameter shall be fitted with excess flow detection and prevention. This shall not apply to pressure relief valves

9. Control functions

9.1. Shuttles should have a pressure gauge outside each compartment, allowing for the control of pressure in the compartment.

9.2. Shuttles should have separate slow acting valves outside each compartment for controlling the compression and decompression of the compartment. In order for it to be possible to operate the valves whilst observing the corresponding gauge, valves should be within 1 m of the gauge displaying the pressure in the compartment. Valves and gauges should be mounted on a control panel.

9.3. The valves and gauges should be lit with an intensity of 200 lux at the valve or gauge display in accordance with BS EN 894-2.

10. Fire protection

10.1. Personnel locks and material locks should be constructed from materials and components selected to minimize their flammability under increased air pressure and which are of low toxicity when burning.

10.2. There should be a water spray or water mist system discharging into each compartment of personnel locks. It should be possible to operate it from inside or outside of the compartment. The system design should be based on the performance requirements for the main compartment of a personnel lock.

10.3. Water spray systems should comply with BS EN 16081:2011 + A1 2013 but with the following amendments to it – (BS EN 16081 cl 5.8). All parts of the system should be coloured or marked in such a way that they are immediately distinguishable from all other systems on the air lock; (cl 5.10) conveying of the extinguishing medium should be done by a permanently-on gas pressure tank system exclusive to the extinguishing system; (cl 5.12) the "permanently-on" pressurising medium should be a gas which is respirable within the normal operating range of the chamber; (cl 5.13) the required supply of extinguishing medium should be calculated to ensure at least 2 minutes of flow of the extinguishing medium. The system when wet tested using water, in accordance with 6.3.2 should meet the requirements of that clause. A hot test should not be undertaken.

10.4. Water mist systems should meet the requirements of NFPA 99. They should also conform to the requirements of this clause in respect of marking. They should be operated by means of a permanently-on gas pressure tank system exclusive to the extinguishing system containing a gas which is respirable within the normal operating range of the chamber. The required quantity of extinguishing medium and gas to discharge it, should be calculated to ensure at least 2 minutes of flow of the extinguishing medium. The system when wet tested using water, in accordance with 6.3.2 should meet the requirements of clause 6.3.2 of BS EN 16081:2011 + A! 2013.

10.5. There should be a device for measuring the pressure of the pressurising medium and for displaying it at the control panel for the lock.

10.6. The fire extinguishing system should also include either a hand-held extinguisher or a water hose inside the lock. All fire-fighting equipment should be suitable for the maximum working pressure of the air lock.

10.7. Fire-fighting and other emergency provisions should be provided at the control panel. The external activation control of the fire-fighting system should be at the control panel or similar easily accessible location.

10.8. It should be possible to reduce the pressure in each compartment of the personnel lock from 2 bar(g) to atmospheric pressure in not more than 2 min in the event of fire by means outside the airlock.

11. Electrical equipment

11.1. It should be possible to connect the shuttle when stationery, to the TBM power supply. All electrically powered equipment on the shuttle should be controlled from the control panel.

11.2. Electrical installations in shuttles should be earthed.

12. Emergency Power Supply and Lighting

12.1. Shuttles should have an emergency self-contained power supply capable of powering all life support critical equipment on it for 12 hours. The power supply should be located outside the shuttle but mounted within the protective frame.

12.2. The emergency power supply should come into operation automatically when required. Lighting levels should be 15 lux in each compartment of the shuttle at seat level and at least 100 lux at any control panel.

13. Control panel operation

13.1. Instructions for the functional operation of the control panel of a personnel lock should be provided by the manufacturer. Instructions for procedural operation of the control panel are the responsibility of the user.

14. Shuttle – size and configuration

14.1. **Number** of **compartments**

14.1.1. Shuttles should consist of two directly interconnected compartments, a main compartment and an entrance compartment. It should be possible to use the entrance compartment as an entry lock in an emergency.

15. Dimensional requirements

15.1. Dimensions

15.1.1. The user should advise the TBM designer in advance of machine design, of the size and weight of the shuttle. In the absence of information the guidance in ITA report 20 should be followed.

15.1.2. Shuttles and their protective frames shall meet the following requirements.

Personnel lock	**Main compartment**	**Entrance compartment**
Minimum cross-sectional dimension	1.5 m diameter	As main compartment.
Minimum length	See 15..2 below	Compartment door must open clear of seats.
Minimum number of persons	3	2
Minimum volume per person	1 m^3	1 m^3

Table 2 — Dimensional requirements

16. Compartment lengths

16.1. The shuttle should be able to accommodate a casualty on a stretcher (of at least 1.85 m length) in the main compartment and clear of the closing door. Where fitted, the entry compartment shall accommodate 2 persons and still allow the outer compartment door to open/close.

17. Seats

17.1. Seats should either be in a single line or staggered so as not to be directly opposite each other.

18. Door openings, dimensions

18.1. When transfer under pressure is being undertaken the doors of a personnel lock used for docking, should be 800 mm in diameter. There should be a single observation window in the door.

19. Floor coverings

19.1. The floor of the shuttle should have a non-slip covering bonded to it.

20. Trunking

20.1. Personnel locks used for saturation exposures need to be fitted with trunking and a docking flange as shown in section 12 of Report 10. The trunking should be long enough to permit unobstructed operation of the docking clamp and interlock.

20.2. The trunking, flange and clamp should be considered part of the pressure vessel to which it is attached and should be designed, fabricated and tested accordingly.

21. Gas supplies from tunnel

21.1. Any system for supplying mixed gas for compression or breathing from the TBM should meet the requirements of BS EN 16191.

21.2. The requirements of this interim technical guidance apply from immediately upstream of the gas analysis point on the supply side of the control panel and via the panel to the lock.

21.3. For shuttles, this guidance applies from the external services connection panel on the protective frame. Feeds to the shuttle comprise include main and emergency mixed gas supply and a single supply of compressed air.

22. General principles for gas supply

22.1. Back flow should be prevented by non-return valves in each gas supply line.

22.2. Cross connection between lines should be prevented by design of the fittings. Interchange of masks for breathing mixture/compressed air with those for oxygen should be prevented by design of the fittings.

22.3. The initial regulation of pressure should be undertaken upstream of the point of connection on the TBM so that the pressure of the gas arriving at the control panel does not exceed 40 bar(g).

23. Breathing mixture supply

23.1. For any personnel lock compartment intended for use with mixed gas, there should be a primary, secondary and emergency breathing mixture supply. The primary and secondary supplies should feed a common inlet manifold. The emergency supply should feed a separate inlet manifold. These manifolds should provide separate main and emergency breathing

mixture supplies via the control panel for compression of each compartment of the personnel lock.

23.2. Breathing mixture should also be supplied from the respective inlet manifolds via the control panel to separate main and emergency manifolds in each compartment of the personnel lock, to which masks can be connected.

23.3. For any shuttle, there should be a main and emergency breathing mixture supply to the shuttle control panel. From the control panel there should be separate supplies to each compartment of the shuttle for pressurising that compartment. There should also be separate supplies to manifolds in each compartment to which masks can be connected.

24. Compressed air supply

24.1. There should be the capability to supply compressed air to the shuttle control panel and from the panel to each compartment of the shuttle for compression of the compartment.

24.2. There should also be the capability to supply compressed air to the control panel from where it can be switched to supply the BIBS manifold instead of mixed gas. The changeover valve should have two clearly marked positions only and it should not be possible to make the changeover without two separate actions. Again, backflow should be prevented by non-return valves.

25. Decompression oxygen supply

25.1. At the user's discretion there may be a supply of oxygen for decompression purposes. If so oxygen should be supplied via a dedicated manifold or via proprietary breathing units. Exhaled oxygen should be routed to an overboard dump as for personnel locks. Interchange of masks between mixed gas/air breathing and oxygen breathing should be prevented by design of the fittings.

25.2. If requested by the user, there should be a capability to supply other gas mixtures for decompression purposes through the control panel to the manifold supplying oxygen for decompression purposes.

26. Metabolic oxygen make-up

26.1. Any personnel lock or shuttle intended for use with mixed gas requires a metabolic oxygen make up supply. The metabolic oxygen supply should be from a source mounted externally on the personnel lock. The metabolic oxygen should be from a separate source to oxygen for decompression purposes. The flow should be controlled from the control panel and the discharge should be into a ventilation stream in the lock.

26.2. There should be a metering device on the supply line to prevent excess metabolic oxygen discharge into the personnel lock compartment.

27. Mixed gas inlet flow controls

27.1. Immediately upstream of the control panel on each mixed gas inlet supply, there should be a shutoff valve and further upstream a non-return valve.

27.2. Upstream of the valves there should be a sampling point for a gauge indicating the pressure of the incoming supply and for an analyser indicating the composition (% oxygen by volume and % helium by volume) of the incoming supply. The data from the gauge and analyser should be displayed on the lock control panel.

27.3. A gas analyser can potentially service more than one inlet supply as continuous monitoring of each supply is not always required.

27.4. There should be a slow acting device to release pressure safely and bleed off gas from each supply line downstream of the shutoff valve.

28. Manifolds

28.1. Each manifold to which masks can be connected in a personnel lock or shuttle compartment, should have at least one spare connection point. All connection points should be self-sealing and be capable of being capped when not in use.

28.2. The failure of one connection point should not result in the failure of all connection points simultaneously.

29. Design of breathing mixture supply pipework

29.1. Breathing mixture supply for compression

29.1.1. The breathing mixture supply for compression of a compartment should be sufficient to compress the compartment at a rate of 2 bar per minute for the first minute and 1 bar per minute thereafter.

29.2. Breathing mixture supply to masks

29.2.1. The breathing mixture supply to a manifold should be designed in accordance with EN 14931 to provide a nominally flow of 75 l/min at working pressure to each connection point. The total supply flow rate to the manifold may be reduced by the simultaneity factors “coefficient K” in table 3 of cl 4.7.1 of BS EN 14931.

30. Helium reclaim

30.1. It is recommended that a helium reclaim system be installed where economically advantageous to do so. The reclaim system should not adversely affect the performance of the breathing mixture supply system. All pipes, hoses, fittings etc connecting the reclaim system to the personal lock or shuttle should follow the guidance in this document.

31. Flushing of trunking

31.1. Where trunking is fitted to a personnel lock, there should be the capability to flush the trunking with air or breathing mixture as required. Control of flushing operations may be from the panel or locally at the trunking.

32. Alternative layout.

32.1. Because of space constraints on a shuttle, it may not always be possible to meet the requirements of this guidance in respect of layout of control panels and pipework etc. However, it should be possible to demonstrate that the level of reliability, functionality and control can be maintained with the alternative layout.

32.2. The ability of the lock attendant to exercise informed control over all functions from the control panel should not be compromised.

33. Control functions and information – personnel locks

33.1. The following control functions, capabilities or information should be available at the control panel of the personnel lock:

- the pressure and the composition (O_2 and He as % by volume) in each inlet supply line from the TBM gas supplies.

- valves to control the flow downstream of the panel in each supply line to each compartment,

- valves to control the de-pressurisation of each compartment.

- valves to control the flow downstream of the panel in each supply line to the intermediate chamber

- continuous readout of the pressure and composition (O_2 as % by volume and partial pressure, He as % by volume) downstream of the panel in each supply line to each compartment of the personnel lock and the intermediate chamber,

- high and low oxygen level alarms for each supply line with the capability to adjust alarm points at the panel

- the pressure in the intermediate chamber

- mirror scale gauges to indicate the pressure in each compartment and for the main compartment of the lock there shall also be a mirror scale gauge with a maximum full-scale deflection of 2 bar(g),

- the O_2 and He concentrations (O_2 as % by volume and partial pressure, He as % by volume) in each compartment.

- the CO and CO_2 concentrations (as partial pressure) in each compartment.

- the flow rate of gas being discharged from each compartment

- the temperature and humidity in each compartment.

- time both as real time and elapsed time with a display in hours, minutes and seconds, battery backup or clockwork;

- voice communications with each compartment with helium speech unscrambler capability. Any microphone should be placed for ease of use by the lock attendant;

- views of the interior of main compartment and intermediate chamber using CCTV.

- data recording device capable of recording the pressure and composition of compartment atmosphere including humidity, along with supply to each umbilical at 20 sec intervals.

33.2. When requested by the user, an electronic system for controlling pressure during decompression may be fitted.

33.3. Valves and analysers may be physically located at the control panel or operated remotely from the control panel.

34. **Control functions and information – trunking**

34.1. The following control functions and control information should be available at the trunking or at the control panel if requested by user:-

- the pressure in each supply line.

- pressure in the trunking

- valves to control the flow in each supply line to the trunking,
- slow acting valves to control the de-pressurisation of the trunking.

35. Communications

35.1. A microphone should be arranged in the compartment centre at a seated person's head level.

36. Ventilation and contaminant removal

36.1. When operating in non-saturation mode, there should be the capability to remove CO and CO_2 from the compartment atmosphere. Either there should be a supply of air/mixed gas air or a scrubbing system.

36.2. The supply of air or mixed gas should be at a rate of at least 50 l/min per person, measured at the chamber pressure. There should be a device to monitor ventilation rate. If automatically controlled, the ventilation should be performed with pressure variations less than ± 0,05 bar. The ventilation equipment shall be so designed that this range of fluctuation can also be achieved manually.

36.3. When operating in saturation mode, there should be an electrically operated device in each compartment for scrubbing carbon monoxide and carbon dioxide from the compartment atmosphere. There should be standby devices of similar capacity in each compartment. It should also be possible to remove volatile organic compounds and foul odours from the chamber atmosphere.

Interim technical guidance 3 – Requirements for pressurised transfer shuttles due to their mobility

1. Life-span of this guidance

1.1. This interim technical guidance should be followed in conjunction with the requirements of BS EN 12110:2014 in respect of pressurised transfer shuttles. This interim technical guidance should be considered time-expired once the revised version of BS EN 12110:2014 has been published as a prEN.

1.2. Pressurized transfer shuttles, "shuttles", should be treated as personnel locks with mixed gas capability (ITG 1 and 2 apply) along with mobility and the appropriate guidance followed.

2. Protective frame

2.1. The shuttle should be fitted within a protective frame to minimise the risk of impact damage and facilitate lifting. The protective frame can incorporate wheels to facilitate its movement and handling. The corners of the frame should be formed from castings to ISO 1161:2016. The frame should be fabricated in accordance with ISO 10885:2018 or stronger. Where appropriate there should be a protective non-flammable weather protection cover over the top of the frame.

3. Fire suppression

3.1. The fire suppression system for the shuttle should be permanently mounted within the protective frame and connected to the shuttle at all times the shuttle is in use. Whenever the shuttle is in use the fire suppression system should be pressurised.

4. Spare penetrations

4.1. There should be two spare penetrations of 40 mm minimum diameter in each compartment which until use should be sealed with a blind flange or threaded plug or cap.

5. Supply lock

5.1. There should be a supply lock on the main compartment. It should be at least 250 mm diameter x 350 mm long and be sufficiently large to allow the passage of chemical containers for any CO/CO2/VOC scrubbers installed in the shuttle. If the outer door of the supply lock opens outwards, it should be fitted with a pressure activated interlock to prevent unintentional opening when the lock is pressurised.

5.2. There should be a pressure gauge and a bleed valve fitted to the outside of the supply lock.

6. Chamber coatings

6.1. The interior of the shuttle should be coated with a flame-retardant epoxy paint which is low in VOCs.

7. Docking flanges

7.1. The main compartment of a shuttle should be fitted with a length of trunking terminating in a docking flange details of which are shown in section 12 of Report 10. In addition, there should be a docking flange or the capability to attach a docking flange at the other end of the shuttle.

7.2. The trunking should be 800 mm internal diameter and 30 mm wall thickness. The flange should be formed as an upstand around the end of the trunking 30 mm high by 30 mm wide giving an overall external diameter across the flange of 920 mm. The flange upstand should be tapered by 15 degrees to facilitate clamping as shown in figure 2 of Report 10.

8. **Docking clamp**

8.1. A clamping device should be fitted to the shuttle capable of forming and maintaining a pressure tight seal between the docking flange on the shuttle and the docking flange on a TBM personnel lock or habitat. The clamp can be power operated however it should always be possible to open or close the clamp manually such as in the event of failure of the powered system. The clamp should be prevented from opening when the trunking is pressurised, by a robust mechanical interlock mounted on the shuttle and activated by pressure in the trunking. The interlock should be clearly visible, and it should be immediately identifiable whether the interlock is engaged or disengaged.

8.2. The clamp should be treated as part of the pressure system and be designed, fabricated and tested accordingly.

8.3. Where a working chamber is formed by a bulkhead in the tunnel lining it is possible to use the shuttle as a 2-compartment personnel lock with the shuttle being clamped directly to a flange on a bulkhead. This precludes the provision of an intermediate chamber and is to be considered a method of last resort.

9. Alignment devices

9.1. To facilitate clamping there should be a means of ensuring the correct alignment of the shuttle and the lock to which it is to be clamped. This can be in the form of adjustment capability within the undercarriage of the protective frame around the shuttle or some form of guide frame on to which the shuttle can be driven. Tolerances in alignment should be provided by the shuttle manufacturer.

10. Wheel gauge

10.1. The normal wheel gauge for rail mounted shuttles should be 900 mm.

11. Prevention of unintended movement

11.1. Where the shuttle frame is wheeled, there should be a braking system or similar means for preventing unintended movement of the shuttle frame.

12. Lifting points

12.1. The protective frame of the shuttle should be fitted with lifting points. The load of the shuttle in service to be taken by the lifting points should include the weight of the shuttle, a full crew of occupants, the protective frame and all essential equipment mounted within the frame. This in-service load should be clearly marked on the lifting frame. A factor of safety of 10 should be applied to the maximum in-service load when designing lifting points. The protective frame and its lifting points should be designed for lifting persons and should be inspected, thoroughly examined and tested in accordance with requirements for personnel lifting equipment.

13. Transportation structure

13.1. It is necessary to lift and transport the shuttle within its protective frame (including the onboard fire suppression system) as part of the TUP procedure. During TUP the shuttle will

also need a power supply and a substantial supply of mixed gas. This can be done by mounting the shuttle and protective frame, a generator or other power supply suitable fire protected, gas quads and a suitably enclosed workstation for the supervisor within a transportation structure. The structure should be designed for lifting persons and should be inspected, thoroughly examined and tested in accordance with requirements for personnel lifting equipment.

14. Tie down points

14.1. Tie down points should be provided to secure the shuttle within its protective frame on any transport vehicle or platform used. Twist lock devices compatible with the ISO 1161 corner castings of the frame may be used.

15. Observation windows

15.1. There should be two observation windows at least 100 mm in diameter for each compartment of the shuttle and one observation window in each interconnecting or end door.

16. Thermal insulation

16.1. Any thermal insulation or covering around the shuttle should be non-flammable.

17. Shuttle atmosphere control

17.1. There should be a temperature and humidity control system on the shuttle capable of maintaining a temperature in the shuttle of between 25 ^{0}C and 35 ^{0}C with an accuracy of +/- 2 ^{0}C whilst in transit.

17.2. The humidity of the shuttle atmosphere should be controlled between 40% RH and 70% RH.

17.3. The contract medical adviser should liaise with those in the shuttle over temperature and humidity to ensure comfort and health.

18. Power during TUP operations

18.1. Powered externally same emergency power as lock.

19. External services connection panel

19.1. There should be a panel on the protective frame to which the external services to the shuttle can be connected. The panel and connectors should be located within the protective frame and be readily accessible. Connectors should be self-sealing and fitted with caps to prevent ingress of dirt when not in use. The connectors used, should each differ in diameter and type to minimise the risk of cross connection. Each connector should be clearly labelled on the panel with its function.

19.2. As a minimum there should be connections for main and standby compressed air, main and standby mixed gas, oxygen for decompression, water (flow and return) for the climate control unit, power and emergency power, and communications.

20. On-board Gas storage

20.1. As a minimum there should be fastenings for three 50 litre x 200 bar gas storage cylinders within the protective frame. Fastenings should be adjustable to accommodate cylinders of 200 mm to 250 mm diameter. There should be connections to the control panel for each cylinder with in-line non-return valves to prevent backflow. There should be a pressure reducer on each connection adjacent to the connection point reducing supply pressure to less than 40 bar(g).

21. Personnel restraint

21.1. Seat belts for use during lifting and travel, should be provided on each seat in the shuttle.

22. Shuttle BIBS Supply

22.1. Because of the limited space in a shuttle a common manifold may be used in the main compartment for the supply of compressed air or oxygen for decompression purposes, to masks. There should still be an overboard dump for the exhaled oxygen and back flow of one gas into another line shall be prevented by in-line non-return valves. In addition to the control valves required, there should be a switchover valve with the position for the respective gases clearly marked. The valve should be designed so that accidental switchover cannot happen.

23. Control panel(s)

23.1. The shuttle should preferably be fitted with a single control panel from which the shuttle supervisor can control the operation of the shuttle. Where space constraints require it the controls and instrumentation can be distributed across more than one panel provided good ergonomic layout can be maintained. Panels and all the controls and instrumentation on them should be contained within the envelope of the protective frame.

23.2. Design of the control panel design should take good ergonomic practice into account to allow the operator of the shuttle to operate the shuttle in the best conditions. Reference should be made to BS EN 894:2008 (all parts). The layout of the panel should allow the operator to operate control equipment whilst simultaneously observing the relevant instrumentation.

23.3. The control panel should be marked so that the function and switching direction of control equipment can be clearly recognized (see BS EN 61310-1:2008). The control panel should have a schematic identifying the layout and function of the controls and instrumentation.

23.4. Each panel should be illuminated with a nominal intensity of at least 200 lux at the panel surface.

24. Control functions and information

24.1. The following control functions and control information should be available to the shuttle supervisor from the shuttle control panel(s):

- the pressure and the composition (O_2 and He as % by volume) in each mixed gas inlet supply line to the panel.
- the pressure in each compressed air inlet supply line to the panel.
- valves to control the flow downstream of the panel in each compressed air or mixed gas supply line to each compartment both for compartment pressurisation and to manifolds,
- valves to control the de-pressurisation of each compartment.
- the pressure and composition (O_2 as % by volume and partial pressure, He as % by volume) downstream of the panel in each supply line both for pressurisation and to manifolds to each compartment of the shuttle,
- high and low oxygen level alarms for each supply line downstream of the panel with the capability to adjust alarm points at the panel
- mirror scale gauges to control the pressure in each compartment and for the main compartment of the shuttle there shall also be a mirror scale gauge with a maximum full-scale deflection of 2 bar(g). Digital gauges of equivalent capability may be used.

- the O_2 and He concentrations (O_2 as % by volume and partial pressure, He as % by volume) in each compartment.
- the CO and CO_2 concentrations (as partial pressure) in each compartment.
- the temperature and humidity in each compartment.
- controls for the environmental control system for the shuttle.
- time both as real time and elapsed time with a display in hours, minutes and seconds. A digital device with battery backup or a mechanical device can be used.
- voice communications with each compartment with helium speech unscrambler capability. Any microphone should be placed for ease of use by the lock attendant;
- data recording device capable of recording the pressure and composition of compartment atmosphere including humidity, along with supply to each umbilical at 20 sec intervals.

24.2. Valves and gas analysers may be physically located at the control panel or operated remotely from the control panel.

25. Testing

25.1. The shuttle should undergo and pass the following tests before being put into service:-

- the shuttle as a pressure vessel should be tested in accordance with BS EN 13445.
- the shuttle should be functionally tested by the manufacturer using maximum flow rates and at a pressure agreed with the user.

25.2. All test and calibration certificates for instrumentation should be recorded in the formal maintenance system (Report 10 clause 6.8).

26. Shuttle transfer on TBM

26.1. Transfer to/from transport vehicle

26.1.1. Equipment should be provided to transfer a shuttle to/from its tunnel transfer vehicle and the shuttle path in the TBM backup. Where this involves a vertical transfer, use of a hydraulic lifting platform is to be preferred over hoisting on ropes. All lifting operations should be designed personnel use and for a factor of safety of 10. For multi-point lifting, failure of lifting at one point should not lead to failure of lifting at another. Hydraulic lifting platforms shall conform with BS EN 1570. Devices shall be provided on the hydraulic platform to restrain or otherwise prevent unintended movement of the shuttle.

26.2. **Movement through TBM on shuttle path**

26.2.1. Equipment should be provided to move the shuttle mechanically along the shuttle path. Devices should be provided to prevent unintended movement or runaway of the shuttle. Where movement is by rail, the wheel gauge for rail mounting should normally be 900 mm.

26.3. **Transfer of shuttle vertically to/from shuttle path to docking position.**

26.3.1. Where necessary, it should be possible to transfer a shuttle vertically to/from its docking position with the personnel lock and the shuttle path on the TBM backup. Vertical movement should be done using a hydraulic lifting platform. Lifting operations should be designed for personnel use with a factor of safety of 10. Hydraulic lifting platforms shall conform with BS EN 1570.

26.3.2. The control station for the platform should be on the platform at the end adjacent to the personnel lock.

26.3.3. There should be a mechanical interlock on the lifting platform to prevent downwards movement of the loaded platform. The interlock when engaged should be held in place

by the weight of the platform and its load. It should take effect automatically when the platform is within 25 mm of its final height for docking. It should only be possible to release the interlock after raising the platform by at least 10 mm. it should be possible to restrain the shuttle or otherwise prevent unintended movement of the shuttle when it was on the hydraulic platform.

26.3.4. The load of the shuttle for transfer shall be the in-service load calculated according to cl 5.6.7.

26.3.5. The lifting equipment shall be thoroughly examined before initial use.

26.3.6. A dated certificate recording this examination shall be included in the instruction handbook.

Note : It is a requirement of EN 12110-2 that means should be provided to align the shuttle docking flange with the TBM docking flange and thereby allow the docking clamp to be closed. Means can include a docking alignment frame and guide rails on to which the shuttle can be driven.

26.3.7. Where a docking alignment frame is used it shall be supported by the shield structure and not by the airlock.

26.3.8. Where the means of alignment for docking is provided by height adjustment capability within the undercarriage of the shuttle access around the undercarriage should be provided when it is on the hydraulic platform

26.3.9. Access to manually operate the docking clamp shall be provided.

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