HPCA Work Clients Guide

Guide to ITA/BTS CAWG Report 10 for Clients and others not familiar with high pressure compressed air work

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Health & Safety in Works
In Association with the British Tunnelling Society Compressed Air Working Group

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PREPARED JOINTLY

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"HEALTH & SAFETY IN WORKS"

IN ASSOCIATION WITH BRITISH TUNNELLING SOCIETY

COMPRESSED AIR WORKING GROUP

British Tunnelling Society

1. HIGH PRESSURE COMPRESSED AIR

Work in High pressure compressed air is defined in Report 10 as "work in compressed air at pressures above historical statutory limits, which in most countries are between 3 and 4 bar (gauge), and which involves the use of breathing mixtures other than compressed natural air and can involve the use of saturation techniques".

This guide provides information for those new to the topic to better understand some of the concepts covered by Report 10.

2. BACKGROUND TO THIS GUIDE

In 2018, the second revision of ITA/BTS CAWG Report 10 "Guidelines for Good Working Practice in High Pressure Compressed Air" was published. This is a highly technical and prescriptive document which comprehensively covers undertaking high pressure compressed air (HPCA) work in tunnelling. It is intended primarily for use by those planning and undertaking HPCA work and who have knowledge of hyperbaric procedures and tunnelling techniques.

Following publication, it was felt that a simplified guide to HPCA work should be produced aimed at clients and their professional advisers with no prior knowledge of the technique but who encounter it at the planning or design stage of a project before an experienced contractor has been appointed. They should refer to the glossary of terms in Report 10 for clarification of terms used in this guide.

This guide does not advocate the use of HPCA but provides background information on hyperbaric principles and compressed air tunnelling procedures once the use of HPCA is being considered. In this respect, attention is specifically drawn to clause 1.3 of Report 10 and clause 9.2 below.

This guide addresses commonly held misconceptions over the breathing of non-air mixtures and experiencing saturation. In addition, the guide highlights the decisions which need to be made before work begins on site to ensure HPCA work can safely be undertaken or to allow adequate provision to be made for the installation of equipment for HPCA work as a subsequent contingency measure. This allows clients and their professional advisers to more fully appreciate what HPCA work entails and the provision which needs to be made for it. It allows them to be more confident in making decisions about whether to include the provision of full HPCA functionality or only to require the capability to undertake HPCA once the need for it has been identified by conditions on site. The guide is intended to complement Report 10 in this decision-making process.

There are no textbooks which cover in detail the topic of compressed air working in tunnelling. Therefore, reference must be made to industry guidance, standards and regulation. The British Tunnelling Society "Guide to the Work in Compressed Air Regulations 1996" provides comprehensive guidance on the basics of compressed air work up to statutory limits and is available to download at https://www.britishtunnelling.org.uk/?sitecontentid=FA7C416F-ECC1-44F2-BD6C-7C3B223146DB. Report 10 addresses the additional requirements for working at high pressures.

3. STATUS OF REPORT 10

Report 10 is guidance on good practice. It is not a standard however it does refer to numerous relevant standards. It is the only known document published to date on its topic. ITA and BTS CAWG recommend it is used on all HPCA contracts. It is also commended to regulatory authorities to inform enforcement or to be the basis for enforcement.

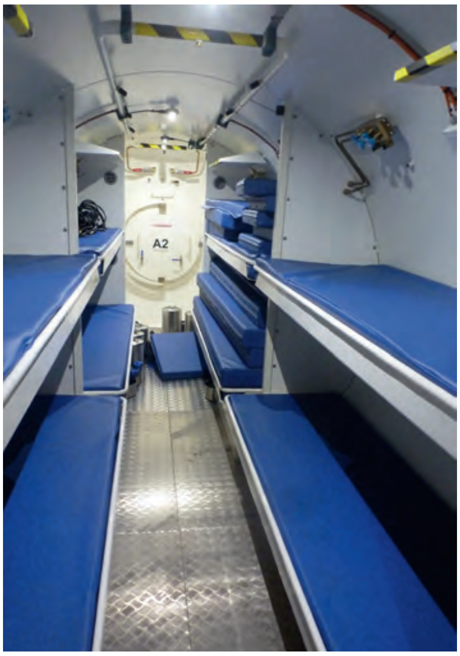

Figure 1 : Interior of habitat

Figure 2 : TUP shuttle being mated to TBM lock

4. STRUCTURE AND CONTENT OF REPORT 10

4.1. Glossary and terms of reference

Clients should refer to this as necessary. Some of the terms in the glossary are explained in more detail in this guide where it is felt this would facilitate their understanding by clients.

4.2. Clause 1 – Introduction

Clients should take due account of the contingency planning for HPCA work in clause 1.8.

4.3. Clause 2 – Legislation, standards, guidance etc.

Clients can find details of relevant information sources.

4.4. Clause 3 – Notifications, exemptions and approvals

Clients should familiarise themselves with this important clause before contacting the regulatory authority. Given that the regulator may not be familiar with HPCA work the client may have to draw the regulator's attention to this Guide, the Report 10 and to Clause 3. Much of the contact with the regulator prior to work beginning on site, is likely to relate to this clause.

4.5. Clause 4 – Organisation of works in HPCA

Clients should be cognisant of the planning of the works along with the main appointees required by this clause. Clients should also note the recommendations regarding planning for HPCA work from the earliest stages of planning onwards.

4.6. Clause 5 – Safe systems of work and operational procedures

Clients should be aware of the contents of clause 5.4 as the information in it is likely to inform early decisions over TBM design.

4.7. Clause 6 – Plant, equipment and gas supply

Clients should be aware of the contents of clause 6.1 as the information in it is likely to inform early decisions over TBM design

4.8. Clause 7 – Occupational health

Clients should be familiar with this clause.

4.9. Clause 8 – Hyperbaric procedures

Clients need to be familiar with this important clause as the information in it is likely to inform early decisions over exposure techniques to be used. Exposure techniques dictate the equipment required which in turn dictates the working space required.

4.10. Clause 9 – Record keeping

Clients should be aware of the importance of keeping proper records.

4.11. Clause 10 – Emergency procedures and fire

Clients should be aware that any emergency affecting the tunnel works whilst HPCA work is underway could cause them reputational damage. It could also lead to scrutiny of their role in ensuring the health and safety of those undertaking the work.

4.12. Clauses 11 – 13 and Appendices

Clients can treat these as “for information only” until a contractor has been appointed.

5. INDEPENDENT ADVICE

Clients without prior experience of HPCA work should engage specialist advisers from an early stage of the project.

6. REGULATION OF WORK IN COMPRESSED AIR

Many countries regulate work in compressed air and typically these regulations date from the 20th century. Often, they impose limits on the maximum working pressure. These limits are normally in the range 3.5 to 4.5 bar and reflect the requirements at the time the regulations were made and not the maximum pressure humans can safely withstand.

This potentially prohibits HPCA work in these countries unless some form of exemption, approval or variance can be obtained from the regulatory authorities. Detailed guidance on recommended procedures for this process are contained in Report 10.

As the procedure for obtaining regulatory approval can be time consuming it is recommended clients establish a dialogue with their national regulator as soon as the potential use of HPCA becomes known. Leaving this to after the contractor has been appointed can lead to delay.

In some countries there can be regulatory obstacles to acquiring bulk supplies of oxygen and helium or certain medicines. The client is advised to check whether such obstacles exist and are likely to impact on the project.

7. DOCUMENTATION FROM CONTRACTOR

The approvals/exemptions/variances/ procedure is likely to make considerable demands for documentation to be produced. Clients should therefore be careful not to place additional demands on contractors to produce unnecessary documentation at any stage of the HPCA work.

Figure 3 : TUP Shuttle at factory test

Figure 4 : Habitat control panel

8. PRINCIPLES OF COMPRESSED AIR TUNNELLING

8.1. How compressed air acts on the ground

Compressed air is used to counter the groundwater pressure acting on a tunnel face in permeable soil thus controlling water inflow and consequent stability/instability of the tunnel face. It is predominantly used in soft ground tunnelling below the water table. Fine grained soils are more responsive to the application of compressed air whereas in coarse grained material considerable air loss can occur through the ground. Further stabilisation measures such as a filter cake or bentonite membrane on the face may be necessary in more permeable soils.

8.2. Minimising exposure to compressed air

Clients should be aware that it is a legal requirement that all reasonably practicable measures should be taken to minimise the number of people exposed to pressure along with minimising the pressure and duration of each exposure, commensurate with minimising the overall risk to the health and safety of those exposed. This requirement should not be taken as a reason to avoid interventions for routine inspection and maintenance as to do so can lead to breakdown and the need for more extensive maintenance. The solution is the selection and execution of appropriate hyperbaric intervention techniques.

8.3. History of the use of compressed air

Compressed air is frequently used as a face stabilising medium in soft ground tunnels below the ground water table. It was first used in the mid-19th century. Until late in the second half of the 20th century the whole tunnel was pressurised with air and miners worked under pressure to hand excavate and support the ground to form the tunnel. Pressure was maintained by one or more bulkheads in the tunnel with passage of people and materials through airlocks in the bulkheads.

In the final quarter of the 20th century open face Tunnel Boring Machines (TBMs) took over from hand miners in excavating and erecting lining. On occasions these open face TBMs were installed within the pressurised tunnel. In both hand mining and TBM operations compressed air was used as a ground stabilisation technique to facilitate excavation.

As TBM technology progressed, closed face TBMs were developed incorporating a bulkhead with integral airlock(s) in the machine structure. Typically, these machines support the face by maintaining a pressure within the cutterhead and excavation chamber of the TBM ahead of the TBM bulkhead. The pressurising medium can be air as with air pressurised shields or excavated spoil as with earth pressure balance machines or slurry as with slurry TBMs. In all TBMs, periodic access for face inspections and cutterhead maintenance is required.

To maintain face support while accessing the face, the spoil or slurry is displaced by compressed air. Compressed air workers can then enter the cutter head or excavation chamber to undertake inspection or maintenance. This is a slightly different application of a traditional technique.

Compressed air can also be required for caisson sinking and shaft construction and very occasionally for groundwater control in rock tunnelling.

8.4. Alternative to compressed air for maintenance

Attention is drawn to clause 1.3 of Report 10. Options to avoid entry under compressed air for TBM maintenance include the formation of stabilised blocks of ground whilst those being developed include the use of robotic tool changers or tool change from within the spokes of the cutterhead under atmospheric pressure conditions.

Stabilised blocks of ground limit the locations at which maintenance can be undertaken whilst the robotic options being developed have limitations in terms of the size of TBM on which they can be undertaken; the extent of coverage of the cutterhead which can be achieved and the type of maintenance which can be carried out.

8.5. High pressure compressed air work

HPCA work was almost unheard of prior to the start of the 21st century. Since then a small number of tunnels at pressures of up to 15 bar have been built or are being planned. Nevertheless, this pressure is still significantly below that to which commercial divers routinely dive in offshore projects.

In HPCA work compressed air is still the pressurising medium at the face. However, for reasons which are set out in this Guide and Report 10, compressed air as a breathing mixture for workers becomes increasingly hazardous to their health and wellbeing as pressure is increased, to the point it becomes toxic and irrespirable. Hence those in the compressed air environment must breathe a non-air breathing mixture through masks attached by umbilicals to a gas supply manifold somewhere on the TBM.

8.6. Determining air pressure required

The air pressure required is related to the depth of ground water above the face. The simple rule of thumb is 1 bar of air pressure for every 10 m of groundwater. From its first use in the 19th century till the end of the 20th century the tunnelling industry found it unnecessary to work at pressures exceeding 3.5 to 4.5 bar and this was reflected in the regulations covering such work in many countries.

9. HYPERBARIC CONCEPTS

9.1. Absolute Pressure

Humans have evolved to survive in air at atmospheric pressure. For convenience when measuring pressure in most applications it is normal to measure pressure above atmospheric. At atmospheric pressure the gauges display a zero reading. Although strictly this should be referred to as "gauge" pressure the word "gauge" is normally omitted. However, in hyperbaric work it is absolute pressure – gauge pressure plus atmospheric pressure which is often important.

9.2. Partial pressure

Atmospheric pressure is made up of the pressure of oxygen, the pressure of nitrogen and the pressure of the other gases. The pressure of each individual gas is known as the partial pressure of that gas. Partial pressure is an important concept in hyperbaric work and many limits in hyperbarics are based on partial pressure.

9.3. Gas properties

9.3.1. Air

Air is a mixture of ~20% oxygen, ~79% nitrogen and ~1% other gases. Included in the other gases is a small percentage of helium. Hence, we already breathe helium in everyday life without experiencing any harmful effects.

9.3.2. Oxygen

Oxygen at atmospheric pressure is essential for life. It is not commonly understood amongst construction professionals that it is the partial pressure not the percentage of oxygen being breathed, which is important to sustain life. Extensive information on oxygen breathing is set out in clause 8.2 of Report 10.

9.3.3. Nitrogen

Nitrogen is an apparently harmless inert gases at least in air at atmospheric pressure. However, breathing elevated partial pressures of nitrogen results in two safety-critical adverse effects which become ever more pronounced as pressure increases. One is the narcotic effect which leads to human error and ultimately to loss of consciousness and death. Although some consider acclimatisation to narcosis can be developed by divers, it may just be that the divers have developed better coping strategies. The other arises from the relatively high density of nitrogen which when compressed makes breathing laborious. The effect on breathing, normally referred to as "the work of breathing", has been likened to breathing through a drinking straw. Further information on nitrogen narcosis along with the limits on inspired partial pressure of nitrogen are set out in Report 10. These limits are recognised as being somewhat conservative but nevertheless are considered to represent good practice.

9.3.4. Helium

Helium is another apparently harmless inert gas at least in air at atmospheric pressure. It is a low density inert gas which can be used to replace nitrogen in a breathing mixture and thus make breathing easier and reduce or eliminate the narcotic effect – see clause 8.4 of Report 10.

9.4. Breathing mixtures

Once the physiological properties of oxygen, nitrogen and helium are understood it is possible to design breathing mixtures, also referred to as mixed gas, to minimise the adverse effects of the individual component gases – see clauses 8.4 – 8.6 of Report 10.

9.5. Air as a hazardous gas

There is no specific pressure at which it becomes unsafe to breathe air. The harmful effects increase from atmospheric pressure upwards and are well documented as in Report 10. What limits to adopt are a matter for expert judgement. From the definition of HPCA, air breathing is acceptable up to 3.5 – 4.5 bar depending on national regulations. Above these pressures mixed gas should be used. The upper limit for breathing air in commercial diving is 5 bar. However, in offshore practice, air is seldom used above 3 bar, as saturation techniques are preferred because of the ready availability of equipment and their lower decompression illness (DCI) risk.

With regard to the limits on partial pressure of nitrogen, the guidance in Report 10 recognises that the construction industry has adopted a conservative approach towards working under the influence of narcotic substances. It would be inappropriate to allow someone to work in compressed air with a higher level of impairment due to nitrogen narcosis than the impairment resulting from the effects of drink or drugs. Additionally, the physical work undertaken in compressed air is considered to be more strenuous on average than that undertaken by divers. Hence consideration has also been given to limiting the work of breathing required.

Recommended good practice in Report 10 is to use mixed gas from 3.5 bar upwards as this is considered to represent the acceptable upper level of narcotic risk and work of breathing so far as is reasonably practicable. Clients should make it clear in the tender documents that air breathing at higher pressures will not be acceptable despite the cost savings possible. Foreseeably some contractors will propose the use of air up to 5 bar as in diving or even higher to save cost, but this should be resisted.

9.5.1. Saturation

Saturation is a physiological condition in which the partial pressures and proportions of gases in the body tissues are in dynamic equilibrium with those being breathed. Any change in either the composition of gas breathed and/or its pressure will result in a corresponding gas change in the tissues. That change is not instantaneous but takes place over time; the period to re-establish saturation depending on properties of the body tissues themselves.

9.6. Non-saturation exposure and saturation exposures

These are defined in Report 10. Because of the short duration of mixed gas non-saturation exposures not all body tissues are saturated before decompression begins. However, the length of time taken to decompress is still governed by the gas load in muscle tissue and body fat. The restrictions on subsequent exposures are to allow the residual inert gas which can remain in the body after return to atmospheric pressure to dissipate. If subsequent exposures begin before all tissue gas has dissipated, gas will accumulate in the tissues and lead to a progressively greater risk of DCI.

Mixed gas non-sat exposures are completed within a single working shift so the amount of productive work which can be carried out is in the range of 30 – 90 minutes depending on pressure. Hence non-sat exposures are not appropriate where considerable work is required under pressure. Non-sat exposures present a greater risk of DCI and because of their short duration the cumulative DCI risk for a given amount of work is very much higher. Report 10 limits the maximum pressure for mixed gas non-sat exposure to 8 bar on safety grounds. The requirement in commercial diving for the use of saturation techniques above an exposure pressure of 5 bar is to address the risks from in-water decompression. The higher limit in tunnelling recognises that HPCA work may be required in TBMs which are too small to accommodate the space envelope required by the shuttle.

With saturation exposures, saturation is re-established in all the body tissues after a few hours in storage and maintained until the final decompression is undertaken. A saturation decompression is done very slowly over a period of days and hence presents a much-reduced risk of DCI. This coupled with the significantly longer period of productive work per day makes saturation the preferred technique when frequent interventions and/or extensive work under pressure is required. Saturation techniques are not restricted to pressures above 3.5 bar – their use below 3.5 bar is a matter for commercial judgement.

9.7. Storage

This is the term for living in the pressurised habitat in saturation conditions. This is a very important part of the hyperbaric procedures and includes the provision of “hotel services” for those undertaking saturation work. It is necessary to provide food and drink, laundry, personal hygiene, as comfortable a living and sleeping environment as is possible in the circumstances, maintain a comfortable level of temperature and humidity and to maintain an environment which is free from bacterial infection.

9.8. Storage pressure

Ideally those undertaking saturation should be kept at a storage pressure which is the same as the working pressure on the TBM. However, it can be necessary to work at a different pressure to storage. Storage pressure should be chosen and adjusted to minimise the difference between storage and working pressure. It should also be chosen to avoid need to work at a pressure below storage pressure or to reduce storage pressure during a saturation run. Should either prove to be necessary the guidance in Report 10 on excursions and reduction in storage pressure should be adhered to.

9.9. Transfer under pressure

Transfer under pressure (TUP) is required for maintaining saturation whilst transferring people between the surface habitat and the TBM manlock. It is done in a transportable chamber (often called a shuttle) similar in many respects to a mobile manlock. The TUP process depends on being able to clamp the shuttle to the habitat and also to a mating flange or manlock on the TBM to maintain a pressurised environment in the shuttle.

It is very important to ensure there is sufficient space on the TBM to allow the shuttle to be transported from the rear of the TBM to the manlock. This is a responsibility of the contractor and TBM designer. This obviously dictates the size of TBM on which saturation exposures can be carried out. However, the fundamental issue is for the client to ensure the size of the tunnel is adequate to accommodate a TBM capable of supporting the TUP process. Where the size of the tunnel or saturation and TUP are not planned for at design stage it is unlikely there will be sufficient space or a clear pathway along the back-up, to accommodate the shuttle and allow TUP/saturation exposures to take place.

9.10. Gas reclaim

The recovery of exhaled gas and its purification to separate out the helium for re-use. This is a commercial decision by the contractor.

10. DECOMPRESSION PRINCIPLES

10.1. Exposure to pressures

The human body can withstand pressures above 15 bar provided the increase in pressure (compression) and the reduction in pressure (decompression) is done in accordance with well recognised procedures. Unlike exposure to noise or vibration it is not the exposure per se which is harmful but the inappropriate reduction in pressure which results in harm.

10.1.1. Compression

Compression in tunnelling work is typically undertaken at a rate of around 0.5 bar per minute. This is much slower than in diving. During compression the body is in a state of partial saturation until saturation has been re-established.

10.1.2. Decompression

Decompression on the other hand is a slow protracted process which typically takes hours or days to complete safely. During decompression the body is in a state of supersaturation resulting in the formation of bubbles in the tissues and bloodstream.

10.2. Gas take up and bubbles

The purpose of decompression is to control the formation of inert gas bubbles. Excess gas from the tissues is released into the bloodstream and hence to the lungs where it is expelled from the body through breathing. However, bubbles can lodge in the tissues and as pressure is reduced these bubbles expand become trapped and cause trauma which manifests as DCI.

10.3. Decompression tables

Decompression should be undertaken following a recognised decompression table (a time-pressure profile) to ensure the rate of gas release does not exceed the capacity of the lungs to release that gas back into the atmosphere. Whilst there are various decompression tables available for mixed gas use in diving, there are few tables available with a published history of use in mixed gas tunnelling exposures. This is particularly the case for trimix which is little used in diving.

Decompression tables are a compromise between prevention of DCI, making allowance for variations in human response to pressure and commercial expediency (minimising unproductive time). For this reason, decompression tables are not 100% effective at preventing the occurrence of DCI.

Getting regulatory approval for the decompression tables to be used is covered in clause 3 of the report. This can be a slow process. Clause 3 sets out recommended procedures. Hyperbaric trials should be avoided on cost grounds and additional monitoring of actual exposures undertaken instead.

10.4. Decompression following non-saturation exposures

Decompression following non-saturation exposures tends to follow a stepped pattern of rapid decrease in pressure followed by a soaking period at constant pressure. Such a profile is referred to as stage decompression. Oxygen or high oxygen breathing mixtures can be introduced in the final stages of decompression to increase its effectiveness.

10.5. Decompression following saturation exposures

Decompression following saturation exposures tends to be a long slow approximately constant reduction in pressure. Oxygen or high oxygen content breathing mixtures in the final stages of decompression are not normally used.

10.6. Decompression illness

Decompression illness is the collective name for a range of illnesses presenting a continuum of symptoms and severity resulting from decompression i.e. the removal of exposure to pressure. Because of human variation it is difficult to predict the occurrence of DCI.
The more commonly occurring dominant symptoms in tunnelling are pain affecting the limbs, often the lower limbs however occasionally neurological symptoms affecting the spinal cord or brain can dominate which may present as paralysis or loss of consciousness.
Bone necrosis (dysbaric osteonecrosis) is a chronic form of DCI which can manifest itself months or years after exposure. The terms “Type 1” and “Type 2” decompression sickness are no longer used within the hyperbaric medical community but remain common in tunnelling practice.

10.7. Decompression risk

DCI risk increases with increasing duration of exposure and/or exposure pressure. Decompression tables should give the same level of DCI risk over their full pressure and time range however many commercially available tables are less effective at higher pressures/ longer exposures. When assessing the effectiveness of decompression tables, it is the risk of DCI which should be considered not the actual incidence of DCI as this can be disproportionately influenced by variations in human susceptibility.

10.8. Treatment of DCI

Symptoms of acute DCI can normally be resolved through therapeutic recompression. Acute symptoms can sometimes be hidden or masked so that the decision to seek treatment can be subjective. Surgical replacement of affected joints is the normal treatment for bone necrosis. Use of the incident of acute DCI as a measure of effectiveness of decompression can be unreliable. An objective physiological monitoring procedure for DCI risk, should be adopted instead.

10.9. Post decompression air break

Even though therapeutic decompression is effective in relieving symptoms, there will be residual gas in the tissues on return to atmospheric pressure. Provided the quantity is within known limits it should not cause any ill health but will take time to dissipate. This why with all exposures, periods at atmospheric pressure are required between exposure to pressure. There is a greater likelihood of residual gas in the tissues after non-saturation exposures because of the less efficient decompression regimes used. Hence a period at atmospheric pressure is required between exposures.

11. PROCUREMENT

HPCA work is expensive because it is a high-risk activity which requires sophisticated equipment along with highly competent personnel to undertake it safely. Additionally, there is the cost of helium for use in the mixed gas. However, HPCA work can be the preferred option in terms of health and safety because of the flexibility it gives to carry out routine and reactive TBM maintenance other than at pre-planned locations.

Saturation requires much more equipment than non-sat but normally allows for more productive working. Non-sat requires less equipment but with the short productive working periods and restrictions on subsequent exposures can require large numbers of compressed air workers for continuity. Saturation can be cost effective overall.

As clients ultimately bear the cost, they need to be involved in the decision-making process regarding working patterns from an early stage of the project.

Clients should appreciate that deviations from the good practice in Report 10, are likely to have a negative impact on the health and safety of those undertaking what is high risk work activity. This is particularly the case when a tenderer proposes the use of air breathing up to around 5 bar or higher pressure in lieu of the more expensive but lower risk option of mixed gas.

Clients should always take account of competence when appointing a contractor. Accordingly, clients should consider contractor pre-qualification an essential part of the tender procedure.

When assessing tenders, a two-stage approach is recommended. Clients should consider fully the health and safety risk attached to the proposed working procedures of each tenderer including choice of breathing mixture and exposure technique before considering bid prices.

12. CLIENT DECISIONS REGARDING CHOICE OF EXPOSURE TECHNIQUE

The decisions which the client needs to ratify and act on in the planning, design and procurement of a project are :

Is HPCA going to be used during tunnelling operations?

- If "yes" - the type of exposure technique should be determined.
- For non-saturation exposures only
  - Provision must be made at TBM design stage for plant and equipment required.
  - Approaches should be made to the regulatory authority to discuss approvals, exemptions etc
- For saturation exposures
  - Tunnel diameter must be large enough to accommodate TBM with TUP capability.
  - Provision must be made at TBM design stage for plant and equipment required.
  - Approaches should be made to the regulatory authority to discuss approvals, exemptions etc
- If "possibly" - the type of exposure technique should be determined.
- For non-saturation exposures only
  - Provision must be made at TBM design stage for capability to install plant and equipment when required.
  - Approaches should be made to the regulatory authority to discuss approvals, exemptions etc
- For saturation exposures
  - Tunnel diameter must be large enough to accommodate TBM with TUP capability.
  - Provision must be made at TBM design stage for capability to install plant and equipment required.
  - Approaches should be made to the regulatory authority to discuss approvals, exemptions etc
- If "no" - then there should be the clear acceptance by the Client that there may be no option for retrofit once tunnelling has begun.
- If the client approves and accepts the use of any work under pressure they should be made aware of the medical staff and chamber operatives requirement needed to promote and ensure safe exposure and decompression.

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