High Pressure Compressed Air

International guidance
The ITA/BTS CAWG Guidelines

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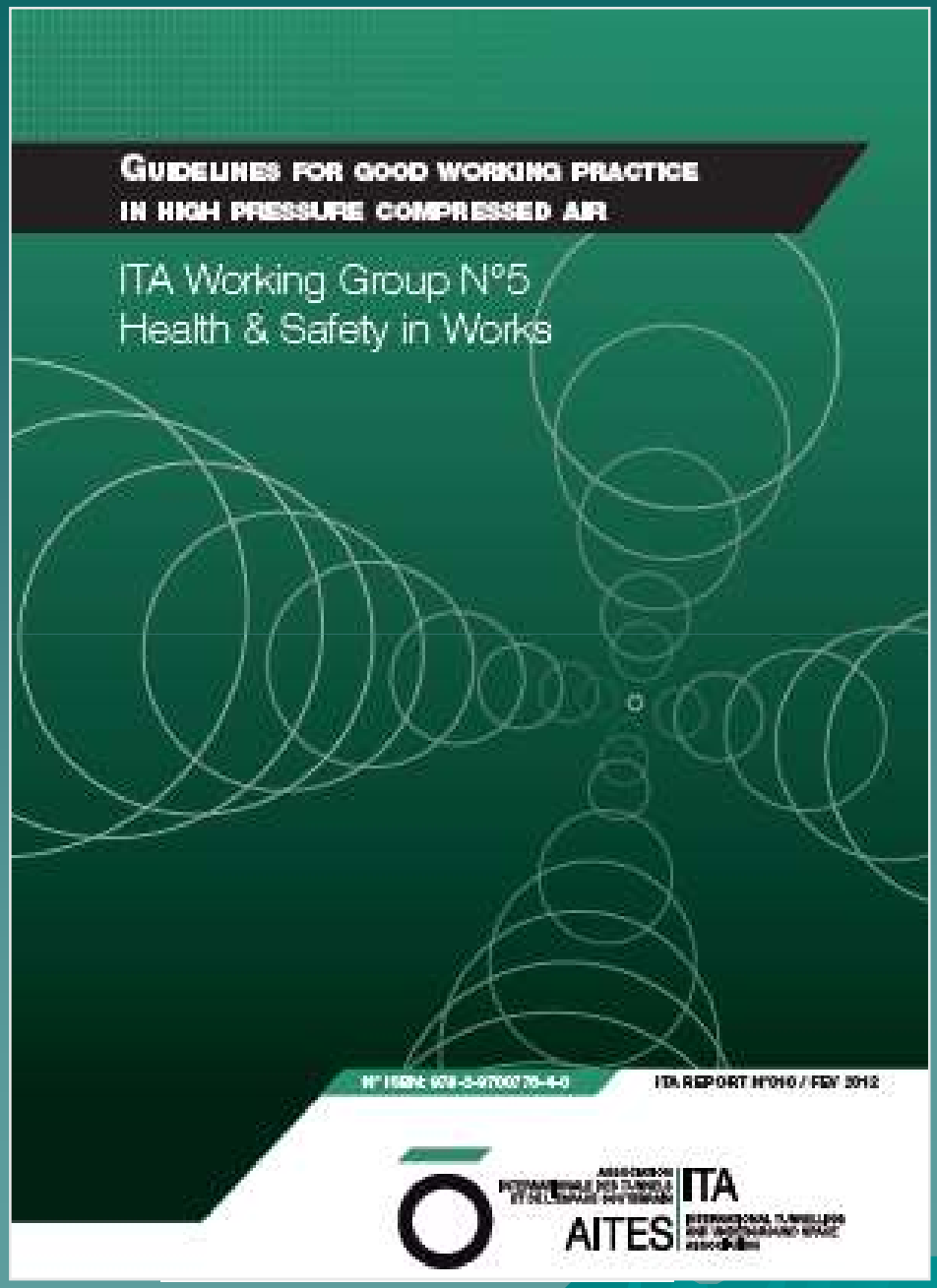

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What is HPCA?

- Definition
  - 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

Why ITA and BTS CAWG?

- The International Tunnelling Association is an organisation with around 65 member nations
  - Being an ITA report makes the "Guidelines" a recognised source of authoritative guidance in many countries around the world.

Why ITA and BTS CAWG?

- The British Tunnelling Society Compressed Air Working Group is a multi-disciplinary group of hyperbaric specialists – engineers, physiologists, and doctors from tunnelling and diving backgrounds
  - This gives the "Guidelines" considerable technical credibility

BTS CAWG

- In 1957 the UK Medical Research Council formed the Decompression Sickness Panel which consisted of some very eminent engineers and doctors, all with an interest in the problems associated with decompression sickness.
  - Bone necrosis was an early concern
- When the MRC withdrew funding, BTS took over responsibility and CAWG was formed

Why the ITA/BTS Guidelines?

- HPCA is relatively new and high risk technique
- It involves the transfer to the tunnelling industry of hyperbaric procedures more familiar in diving
- Probably only around 20 HPCA contracts worldwide have been completed to date
- There is currently no guidance on the technique

What is different about HPCA?

- The use of gases such as trimix in the working chamber
- The use of line-fed full-face masks for routine breathing in the working chamber
- Saturation exposures above 6 to 7 bar
- Hyperbaric living habitat on the surface
- Transfer under pressure in the tunnel

Is HPCA a new technique?

- The hyperbaric aspects of HPCA are not new
  - But they are new to tunnelling
- HPCA should be seen as an extension of existing compressed air tunnelling techniques to higher pressures than before.

Important principles

- Just as with traditional compressed air work, the pressurising medium is compressed air
- The number, pressure and duration of exposure should always be minimised whilst maintaining the overall safety of the work
- These guidelines do not recommend the use of HPCA – they apply once a decision to use HPCA has been made

Where is HPCA currently being used?

- HPCA is currently being used or considered for contracts from Hong Kong and China, through Singapore and London to Vancouver and Seattle
- Current pressures are 5 – 10 bar but in the next few years exposures at pressures of between 10 and 15 bar are likely to be attempted

At whom are the guidelines aimed?

- The guidelines are aimed at
  - regulatory authorities
  - clients,
  - designers,
  - contractors,
  - insurers
  - and others involved in HPCA work.

Changes in categorisation

	Low pressure - Exposures do not incur decompression stops	Intermediate pressure	High pressure - Exposures incur decompression stops
20th century	~<1 bar	-	1 – ~3.5 bar
21st century	~<1 bar	1 – ~3.5 bar	>3.5 bar

Content of the Document

- Not a stand –alone document
- Must be read in conjunction with
  - BTS Guidance on work in compressed air
  - EN 12110
  - BS 6164
  - Diving industry guidance
  - Other national standards

Explanation of terms

- Non-saturation exposure
  - A short duration exposure comprising a compression phase, a working period under pressure, followed by a decompression phase. It does not involve any storage time in a hyperbaric living habitat.

Explanation of terms

- Saturation exposure
  - A long duration exposure during which the person exposed lives under pressure, usually for a number of days, and may make transfers into the working chamber.
- Transfer under Pressure
  - The transfer of persons between pressurised environments whilst maintaining those persons under pressure.

Explanation of terms

- Breathing mixtures
  - mixtures of oxygen, nitrogen, and helium for breathing under pressure
- Nitrox
  - A mixture of nitrogen and oxygen other than natural air
- Heliox
  - A mixture of helium and oxygen
- Trimix
  - A mixture of oxygen, nitrogen and helium

Partial pressure – Dalton's Law

- When considering exposure limits it is the partial pressure of a gas which is important.
- Partial pressure of a gas in a mixture = absolute pressure x volume concentration of that gas in the mixture
- Air = 20% oxygen and 80% nitrogen
- We are currently breathing oxygen at a partial pressure (PO_2) of
  - 20% x 1 bar absolute = 0.2 bar

Gas physiology

- Oxygen
  - Essential for life
  - Toxic a high pressures
    - Oxygen convulsions – @>1.8 bar PO_2
    - Reversed by reducing exposure to oxygen such as by transferring to air breathing
  - Long term exposure leads to
    - Diminished lung function
    - Retinal damage

Oxygen dose

- The total dose of oxygen received during an exposure is important when considering adverse pulmonary health effects.
- Measured in Units of Pulmonary Toxicity Dose (UPTD)
  - PO_2 = 0.5 bar 0 UPTD/min of exposure
  - PO_2 = 1.0 bar 1 UPTD/min of exposure
  - PO_2 = 1.5 bar 1.78 UPTD/min of exposure

Gas physiology

- Nitrogen
  - Narcotic at high pressure
  - High gas density makes breathing increasingly difficult as pressure increases

Gas physiology

- Helium
  - Expensive
  - Light gas
  - Low breathing resistance
  - Voice distortion
  - High thermal conductivity
  - Causes High Pressure Nervous Syndrome at pressures of 15 – 20 bar and over

HPCA

- The main technical issues
  - Pressure
  - Gas mixtures
  - Saturation
  - Other factors

Exposure limits

- Oxygen - partial pressure of 0.2 to 1.6 bar
- Maximum oxygen dose - 400 UPTD per day and 2000 UPTD over 7 days
- Nitrogen – partial pressure not exceeding 3.6 bar
- These limits represent good practice and are considered appropriate for tunnel work.

Exposure limits

- Non-sat exposures
  - A maximum of 2 hours decompression time or
  - A maximum of 3 hours under pressure
- Sat exposures
  - 28 days for experienced saturation workers
  - 14 days for others

Sat v Non-sat

- Amount of work to be done and the working pressure dictate this
- Saturation exposures should be considered from 5 bar upwards and should be used from 7 bar upwards.
- Non-sat typically allows 45 minutes working time @ 6 bar

HPCA – technical issues

- Gas mixtures
  - The selection of appropriate breathing mixtures to remain within recommended limits
  - Ideally a single breathing mixture only for the exposure
  - Sourcing gas mixtures

Typical trimix

- 20/40/40 O_2/N_2/He (Air 20/80 O_2/N_2)
- At 5 bar (gauge) i.e. 6 bar absolute
- PO_2 = 1.2 bar < 1.6 bar limit (1.2 bar)
- PN_2 = 2.4 bar < 3.6 bar limit (4.8 bar)
- He used as diluent to reduce PN_2

HPCA – technical issues

- Pressure
  - The need to contain higher pressures within the working chamber and avoid blow-out
  - Risks associated with DCI
    - The incidence of DCI in commercial diving is 10 to 100 times lower than in tunnelling
    - Bone necrosis is no longer considered a significant risk in UK commercial diving!

HPCA – technical issues

- Saturation
  - The provision of saturation living complex on the surface
    - If underground can occupants be evacuated safely under pressure in all circumstances?
  - Transfer under pressure between living complex and tunnel/TBM airlock

HPCA – technical issues

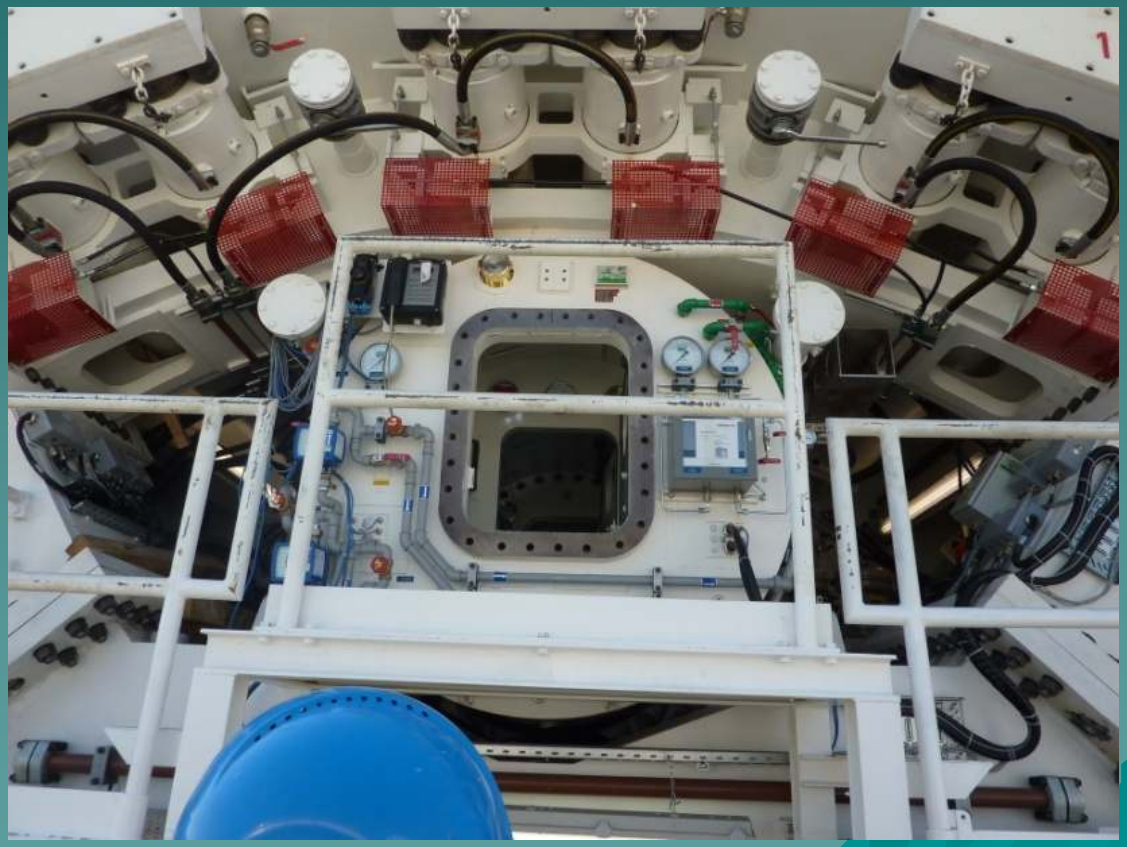
- Moving the TUP shuttle from habitat to working airlock
  - "Guidelines" suggest jacking and sliding in preference to lifting
  - Lifting may be only option in shaft

HPCA – technical issues

- Other factors
  - Provision of adequate working space and control panel on TBM around airlock
- Compare the TBM control cabin .....

HPCA – technical issues

- …….. with the lack of space around the airlock in which to undertake life-safety critical activities



HPCA – technical issues

- A typical medical hyperbaric chamber above ground

HPCA – technical issues

- Note the much greater working space around the airlock on this TBM

HPCA – technical issues

- The future for TBM design and use
  - Change culture to recognise that HPCA is not a hindrance to productivity but a life safety critical activity essential to production and which must be treated as such

HPCA – technical issues

- Human factors
  - Worker selection
  - Worker training standards
    - Divers require extensive training before being allowed to use mixed gas or saturation
    - What should be done in tunnelling?
      - Greater control over workers?

HPCA - Implications for regulators

- In most jurisdictions, HPCA work will probably need some form of exemption, approval, dispensation and/or variance to allow it to be done legally.
  - And a procedure within which exemptions, approvals etc can be granted

HPCA - Implications for clients

- Clients must recognise the costs of HPCA
- Contractor selection should be on competence and capability
  - Local diving contractors not necessarily the best option

Thank you for your attention