

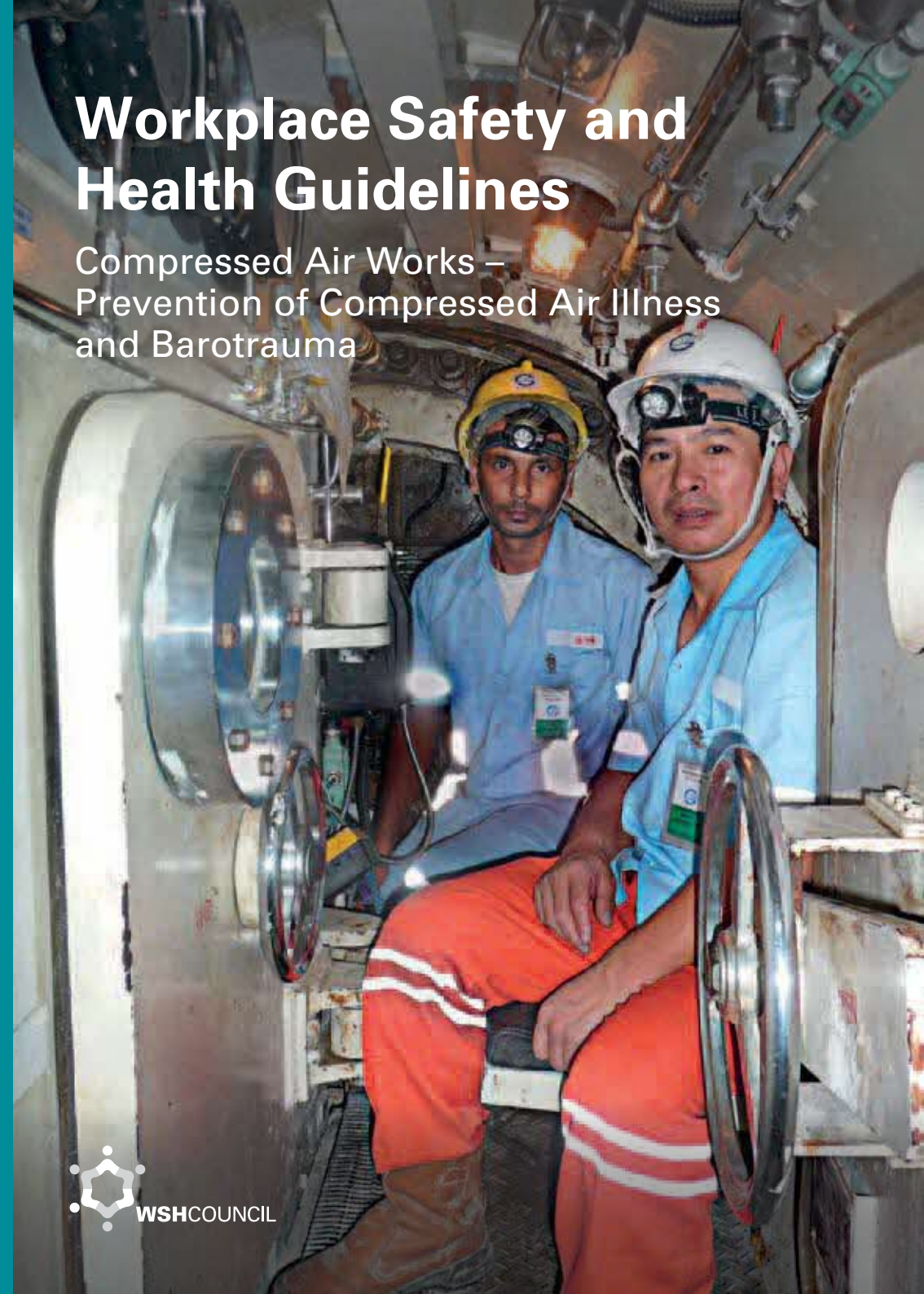
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Workplace Safety and Health Guidelines

Compressed Air Works – Prevention of Compressed Air Illness and Barotrauma



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1. Preface

This guideline provides information and guidance on the health hazards of tunnelling works in the compressed air environment. It aims to raise the awareness of personnel in the tunnelling industry to better understand potential hazards and good practices relating to control and prevention.

Users are advised to use this guideline in conjunction with other relevant materials where available.

2. Introduction

Compressed air work is not new in Singapore and has been used in the construction of the Mass Rapid Transit (MRT) system, Deep Tunnel Sewerage System and other tunnelling works. Examples of such works include inspection and replacement of tunnel boring machine (TBM) cutting tools. Workers who enter and/or carry out work in a compressed air environment are exposed to health hazards if compressed air work is not managed properly. Some associated health problems are decompression sickness and barotrauma.

This guideline was developed to assist project managers, supervisors, man- and medical- lock attendants in the tunnelling industry to better understand the health hazards associated with compressed air work, and how to manage and prevent related occupational diseases. Information provided in this guideline includes regulatory requirements, recommendations and good practices in the prevention of these diseases.

This guideline is not intended to be prescriptive in nature. It provides reasonable practicable guidance to ensure compressed air work can be carried out safely and without any risk to human health.

3. Health Hazards in Compressed Air Work

3.1 Working in Compressed Air Space

Compressed air is used in the construction of a tunnel to prevent entry of ground water into the tunnel. It may be used in the working space in front of the TBM to allow maintenance work to be carried out on the machine face or allow workers to manually remove obstructions, for example, boulders or old piles. Workers would be exposed to compressed air which can be intermittent in such cases. Compressed air may also be used in the tunnel itself where there are workers working and conventional TBM are being used. In this case, more workers would be exposed to the compressed air and its associated health risks.

Access to the compressed air portion of the tunnel is through a chamber called the 'man-lock'. Once inside the man-lock, the air pressure can be slowly increased to the desired pressure inside the compressed air portion of the tunnel (compression procedure). When the desired pressure is reached, workers can then enter the compressed air tunnel. When coming out of the compressed air tunnel, workers would be required to enter the man-lock again where the air pressure would be slowly reduced in stages to atmospheric pressure before they are allowed out of the man-lock (decompression procedure).

Working in a compressed air environment may result in diseases related to the changes in the air pressure.



Figure 1: Cutter head



Figure 2: Tunnel construction

3.2 Occupational Diseases Arising from Work in Compressed Air Space

3.2.1 Compressed Air Illness

This includes Type I and II decompression sickness and dysbaric osteonecrosis.

Type I Decompression Sickness

Pain in the joints, muscles or limbs (called 'bends') may develop soon after working in a hours or even later. The pain can be severe or mild. All such cases should be treated by a doctor who is trained in compressed air work and if needed, treated in a recompression chamber, for example, a medical-lock at the earliest possible.

Type II Decompression Sickness

Occasionally, workers may suffer from a more serious type of compressed air illness affecting the nervous system, lungs or the heart. Workers usually feel and appear ill. The onset can be during decompression, soon after (usually within 45 minutes) or up to 24 hours later. A worker may develop both Type I and Type II symptoms from the same decompression.

The symptoms are:

- Loss of consciousness;
- Collapse with shock;
- Giddiness, loss of balance;
- Visual symptoms, for example, flashes of light;
- Weakness, paralysis, numbness of limbs; and
- Breathing difficulties.

Such cases can be fatal or result in permanent disability, and should be treated as a medical emergency.

Treatment

For both types of decompression sickness, immediate recompression with oxygen breathing in a medical-lock is necessary. Air recompression therapy is not being used as far as possible due to increased nitrogen retention and prolonged decompression time needed to treat.

Dysbaric Osteonecrosis

It has been observed that some compressed air workers may develop bone necrosis (death of a portion of the bone) after many years of working in compressed air. In most cases, there are no visible symptoms as the affected bone does not involve the joints. Common areas involved are the lower end of the thigh bone and upper end of the shin bone. Where the joint surfaces such as the hip or shoulder joints are involved, about 22% have been reported to have been disabled. Some cases may require a joint replacement such as the hip. There is no specific treatment and the risk factors may include high pressures, long exposure duration and rapid decompression. The exact cause is still unknown. It can be detected by x-rays of the bones and joints which is a requirement to include x-rays in the pre-employment and annual medical examination of compressed air workers.

Causes of Compressed Air Illness

At normal atmospheric pressure (1 kg/cm²), the body tissues and blood are fully saturated with air. When the body is subjected to increased air pressure, more of the gases in the air (mainly nitrogen and oxygen) get dissolved into the blood and tissues. When the ambient air pressure is reduced too fast, these gases are released in the form of bubbles. The oxygen is readily utilised by the body, however, the nitrogen gas can accumulate within the body. Compressed air illness is a result of obstruction or effects due to gas bubbles formed in the blood stream giving rise to the symptoms of decompression sickness.

Risk Factors for Compressed Air Illness

The factors below may be associated with a higher risk of developing compressed air illness:

- Medical unfitness, for example, obese and older workers may be at higher risk
- High pressures exceeding one bar (greater risk with higher pressures)
- Long working hours in compressed air, for example, those working for more than four hours
- Failure to follow proper decompression procedure
- Multiple entries for supervisors and engineers
- Lack of acclimatisation for new workers
- Lack of adequate rest between shifts

3.2.2 Barotrauma

The eustachian tube connects the middle ear to the throat (where it is open to the atmosphere). During compression, it is essential that the pressure on either side of the ear drum be equalised by performing the Valsalva manoeuvre of blowing against the pinched nose and swallowing. If the eustachian tubes are too small or blocked as a result of infection such as flu or allergy, a person would be unable to clear during compression which may rupture the ear drum resulting in pain, discharge and deafness. This is called barotrauma where the tissue is damaged resulting from contraction or expansion of gas containing spaces within the body due to the changing pressures. Barotrauma may also affect the sinuses (air passages) or more seriously the lungs. It is commonly encountered during compression.

It is therefore important that workers who are at risk of barotrauma, for example, those who are not able to clear their ears or who have chronic diseases of the ear, air passages or lungs should be excluded from working in a compressed air environment.

The risk factors for barotrauma are:

- Medical unfitness especially for those with pre-existing medical conditions (as above);
- Sudden changes in pressure ;
- Failure to follow proper compression procedures;
- Smoking;
- Coughing;
- Breath-holding; and
- Upper respiratory tract infection.

3.2.3 Other associated health hazards

These are associated with underground tunnelling work:

- Noise induced deafness from prolonged exposure to excessive noise
- Heat-related disorders
- Industrial dermatitis from direct skin contact with chemicals
- Oxygen deficiency in a confined space (gases such as methane may displace oxygen)
- Poisoning by toxic gases (e.g. carbon monoxide, hydrogen sulphide) in a confined space
- Respiratory allergy or respiratory irritation from welding fumes and dust

4. Duties under the Legislative Framework

The Workplace Safety and Health (WSH) Act came into effect in March 2006. Under this Act, stakeholders are responsible for managing the risks they create at workplaces and taking reasonable practicable steps to ensure workers' safety and health.

The WSH (Construction) Regulations are legislated to ensure compliance with safety rules and procedures. Working in a compressed air environment requires discipline from all workers as well as the attendants.

4.1 Medical Examinations

Under the Factory (Medical Examinations) Regulations, pre-employment and periodic medical examinations are required for workers who are exposed to air at a pressure greater than normal atmospheric pressure. The examinations are to be carried out as follows:

All pre-employment examinations must be carried out within 30 days before employment.

Medical examination and tests required are:

- A clinical examination for compressed air illness and fitness for compressed air work (with particular emphasis on the ear, nose and throat (ENT), respiratory, cardiovascular, neurological and gastrointestinal systems);
- Height, weight and body fat estimation;
- Audiometry;
- Test in lock;
- Full-sized chest x-ray;
- Radiographic examination of shoulder, hip and knee joints;
- Electrocardiogram (for workers aged 35 and above); and
- Lung function tests (FEV1 and FVC).

A worker suffering from a cold, chest infection, sore throat or earache should not be allowed to work in a compressed air environment.

Compressed air workers will need to undergo periodic medical examinations as follows:

- Not less than once in every three months for working pressures below one bar; and
- Not less than once in every four weeks for working pressures at or exceeding one bar.

In addition, the worker will need to be re-examined if he has:

- Not been working in compressed air environment for more than 14 consecutive days;
- Suffered from a cold, chest infection, sore throat or earache; or
- Suffered from any illness or injury requiring absence from work for more than three consecutive days.

In these cases, the medical examinations should be carried out not more than three days prior to re-employment in compressed air work.

4.2 Notification to Carry Out Compressed Air Work

Companies should notify the Ministry of Manpower (MOM) if they intend to start work using compressed air and workers are required to work in a compressed air environment. This can be done using the form in **Annex A**. Essential details include pressures expected, number of workers and duration of compressed air usage.

4.3 Incident Reporting

Employers and occupiers are required to report accidents, dangerous occurrences and occupational diseases at workplaces to the MOM. See Chapter 6.2.

5. Risk Assessment

Under the Workplace Safety and Health (Risk Management) Regulations, risk assessments are to be conducted to address the safety and health risks posed to any person who may be affected by the activities in the workplace.

5.1 What is Risk Assessment?

It is the process of:

- Identifying and analysing safety and health hazards associated with work
- Assessing the risks involved
- Prioritising measures to control the hazards and reduce the risks

5.2 Why should we do Risk Assessment?

Risk assessment allows us to identify the hazards at workplaces and implement effective risk control measures before it escalate into accidents and injuries.

Under the Workplace Safety and Health (Risk Management) Regulations, every workplace including factories, should conduct risk assessments for all routine and non-routine work undertaken.

5.3 How is Risk Assessment done?

Prior to conducting risk assessment, adequate preparation must be done. A risk assessment team should be formed consisting of personnel from various levels of participation in the work activity.

Relevant information should also be collated to facilitate better understanding of the work process.

Having completed the preparation work, the workplace risks may then be assessed in three simple steps:

- Hazard Identification
- Risk Evaluation
- Risk Control

1Hazard Identification	2Risk Evaluation	3Risk Control
• Identify hazards. • Identify potential accidents or incidents.	• Estimate the risk levels of the workplace hazards identified. • Prioritise the hazards to be controlled.	• Formulate the control measures according to the Hierachy of Controls. • Analyse and evaluate residual risks.

Table 1: Steps for Risk Assessment.

STEP 1: Hazard Identification

Hazard identification involves identifying hazards associated with the activity of each process and type of potential accidents or incidents. During this phase, the aim is to spot hazards, brainstorm on all possible types of accidents and ill-health that can happen due to the hazard, and identify persons that can be victims of the accident or ill-health.

Aspects of the work to be considered when identifying hazards shall include, but not be limited to:

- *Environmental conditions*
Includes physical conditions at the operation’s site and along the route of the excavation that relate to hazards such as tunnel collapse, tunnel lining failure, loss of pressure or ingress of water and the effects of pressure on the surrounding environment.
- *Task-related aspects*
Includes the use of explosives, tools and equipment, and generation of noxious gases.
- *Hyperbaric/Physiological factors*
Includes the frequency, duration and magnitude of pressurisation, exertion required to conduct tasks, presence of excessive noise, decompression illness and heat stress.
- *Associated activity factors*
Includes accessing the site, other equipments and structures (including buried structures) at the site, and along the excavation route.
- *Emergency response factors*
Includes location and availability of appropriate emergency systems and emergency response procedures.

A simple way of identifying hazards for a particular work activity is to divide the work activity into major steps of carrying out the work and analyse the steps individually for the presence of hazards. It is also important to differentiate between hazards and accidents or ill-health, which are caused by inadequate control of hazards. The following chart illustrates the method of identifying hazards systematically and provides examples for hazards leading up to certain events.

Work Activity	Divided in Major Steps	Spot the Hazards	Accidents or Ill-health Arising from Hazards
E.g. Changing cutting tools at the cutter head chamber / excavation chamber	- Preparation of equipment - Compression of worker in man-lock prior entrance to plenum - Changing of cutting tools - Decompression of worker in man-lock after work completion	E.g. Falling hazards, heat, fumes, manual handling - Irregular air pressure in the man-lock E.g. Manual handling, falling hazards, flooding - Irregular air pressure in the man-lock	Falls - Decompression illnesses such as barotraumas Drowning - Decompression illnesses

Table 2: Examples and methods of identifying hazards.

STEP 2: Risk Evaluation

Risk evaluation is the process of estimating the risk levels for hazards and their acceptability. This is used as a foundation for prioritising actions to control the hazards and minimise safety and health risks.

Risk is made up of two parts:

- Predicting **SEVERITY** of the hazard; and
- LIKELIHOOD** occurrence of an accident, incident or ill-health taking into account the existing risk controls.

Factors to take into consideration are:

EXISTING RISK CONTROLS must be taken into account when assessing risks. By considering the effectiveness of these controls and the consequences of their failure, the risk of the activity can be better assessed.

SEVERITY is the degree or extent of injury or harm caused by the hazards, or as a result of an accident. The severity is classified into various categories – minor, moderate and major.

LIKELIHOOD occurrence of an accident, incident or ill-health is defined as a probability that a said incident will happen and is also classified into various categories, for example, remote, occasional or frequent. To minimise the subjectivity of estimating likelihood, and in addition to looking at existing risk controls, the following sources of information should be considered:

- Past incident and accident records;
- Industry practice and experience; and
- Relevant published literature.

RISK LEVEL may be determined once the severity and likelihood have been established. This may be achieved by using a matrix, the size of which may vary according to complexity of the work conditions.

The following chart illustrates how severity and likelihood come together to help determine risk level.

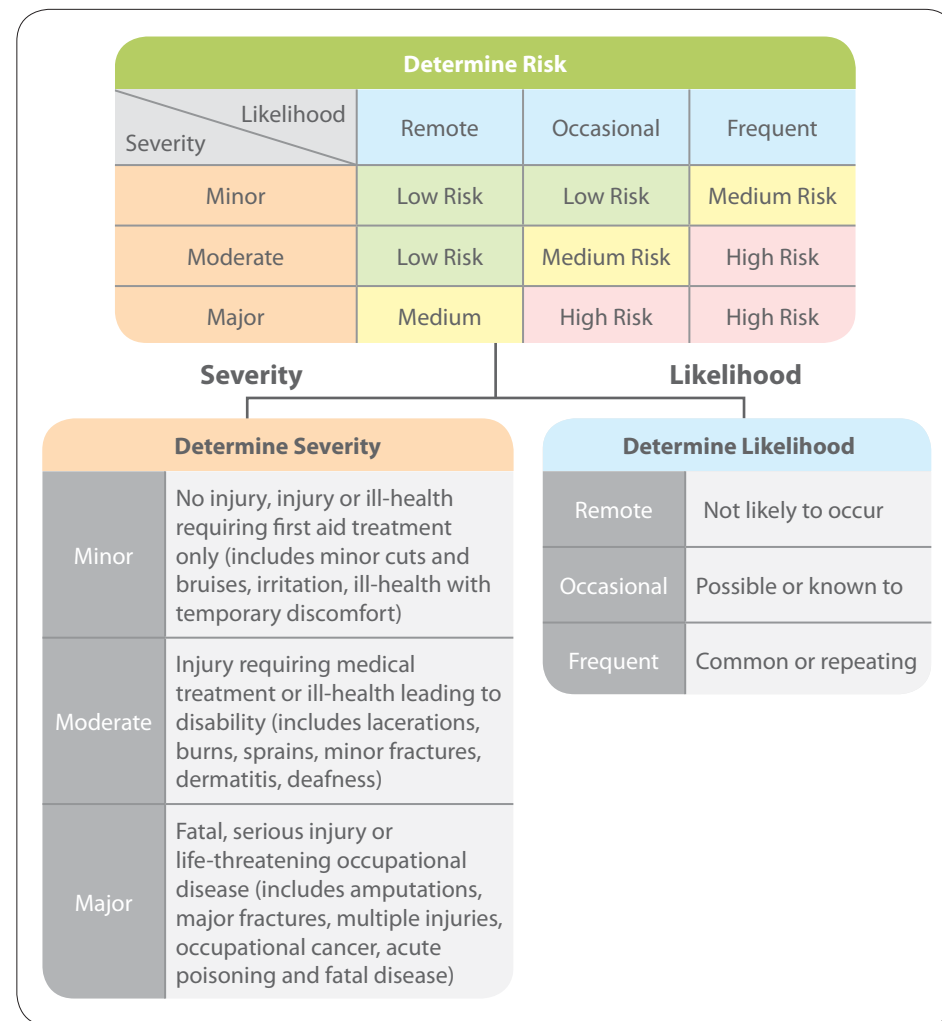


Table 3: Risk Evaluation Map.

Example:

If the consequence of a hazard is identified to have moderate severity and occasional likelihood, the risk level may be determined to be medium.

STEP 3: Risk Control

How to establish methods of eliminating or reducing the risks?

Based on the risk level determined in Step 2, risk controls should be selected to reduce or confine the risk level to an acceptable level. The following table suggests the acceptability of risk for different risk levels.

Risk Level	Acceptability Of Risk
Low	Acceptable
Medium	Moderately Acceptable
High	Not Acceptable

Table 4: Acceptability of risk for different levels.

In order to prioritise the risk controls adequately, the formulation of such risk controls may take into consideration the relative risk levels of different hazards, and the cost and benefit of the controls. The residual risk after the implementation of the controls should also be evaluated.

Reasonably practicable measures must be taken to maintain the risk level within the acceptable range. It is essential for risks to be eliminated or reduced 'at source'. If the risk level is high, work cannot commence until the risk level is reduced to the medium or low levels.

What risk control methods are there?

Methods to control risks may be analysed according to the Hierarchy of Controls: Elimination, Substitution, Engineering Controls, Administrative Controls and Personal Protective Equipment. Elimination of the hazard should take first priority while personal protective equipment should be the last line of defence.

- *Elimination*
Where the level of risk cannot be controlled to an acceptable level, no compressed air work shall take place.
- *Substitution*
Where the risk can be controlled by performing the task using alternative methods, consideration shall be given to using these alternative methods.
- *Engineering controls*
Plant and procedures shall be designed to minimise risk.
- *Administrative controls*
Every operational plan should seek to minimise the degree and duration of the worker's exposure to risk. Almost every aspect of planning falls into this administrative category.

Administrative controls include:

- Training, supervision, experience and selection of employees, including staffing levels;
 - Provision of an appropriate operations manual;
 - Organisation and planning before, during and after the operation;
 - Selection of appropriate plant; and
 - Selection of the appropriate form and level of communication.
- *Personal protective equipment*
Appropriately designed and sized personal protective equipment shall be provided, used and maintained. The limitations of all equipment used shall be identified as part of the risk assessment process.

The table below illustrates the possible control measures for a specific hazard and work activity.

Work Activity	Hazard	Possible Control Measure
For example, changing cutting tools at the cutter head chamber/ excavation chamber	Irregular air pressure in the man-lock	• The man-lock attendant must be a competent person who has undergone adequate training. • Lockout tagout to all the air valves to prevent unauthorised meddling. • Alternate air supply must be available. • Alternate power supply must be provided in case of power failure.

Table 5: Example of risk control methods.

5.4 Risk Assessment as a Component of Risk Management

Risk assessment when carried out appropriately will allow better understanding of the risks at the workplace and their control measures. It is a key component of Risk Management. A worked example is shown in **Annex B**.

Besides Risk Assessment (RA), Risk Management also consists of other components such as Communication, Record Keeping and Implementation and Review. Together, they form the Risk Management Process as illustrated in the diagram below. In the table below, column 6 refers to a review every three years. The review, however, should be more frequent when there is a change in the work process and/or accident or incident. A review of risk should be undertaken at the start of every tunnelling contract and after the first compressed air work intervention to evaluate and possibly improve procedures. The ground conditions must be reviewed at each location to assess the potential for air loss and blow out. In compressed air work case, a review after every period of interventions would be useful.

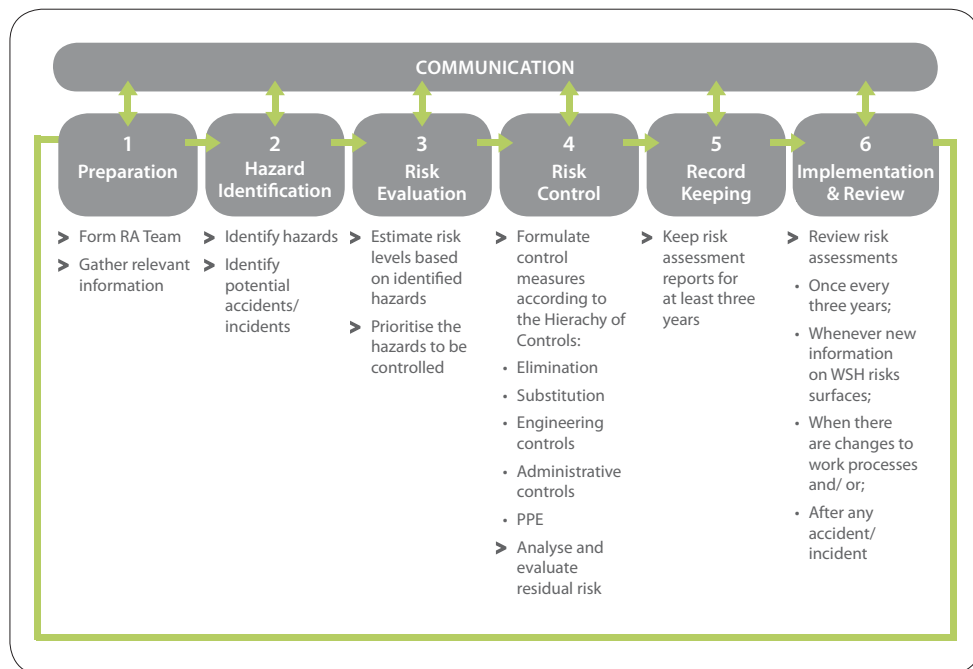


Figure 3: The Risk Management Process.

6. Managing Workplace Safety and Health in Compressed Air Work

6.1 Workplace Safety and Health (WSH) Policy

Leadership and commitment from management is essential for an effective WSH management system. The management should develop a clear safety and health policy to communicate the company's overall safety and health objectives and how it seeks to achieve its commitment.

The policy should:

- be endorsed by top management;
- be appropriate to the nature and scale of the facilities WSH risks;
- be understood by all staff;
- include a commitment to the protection of the safety and health of all members of the facility by preventing work-related accidents, ill-health and incidents, continual improvement and compliance with current applicable legislation;
- be effectively communicated to all employees with the intention that employees are aware of their WSH obligations;
- be available to interested parties; and
- be reviewed periodically to ensure its relevance to the company.

An achievement of effective WSH management system requires the active and positive involvement by all levels of management as well as the full support of all employees of the contractor and their sub contractors.

6.2 Safety and Health Management System (SHMS)

The SHMS is a systematic approach for managing WSH. SHMS sets out management commitment and approaches for WSH. It integrates WSH goals into business objectives, and accords them equal importance along with other aspects of the business.

6.2.1 Implementation and operation

Safe work procedures should be in place to provide a safe and healthy working environment. These procedures should be relevant and include but not limited to:

- Documentation of all incidents, accidents, dangerous occurrences, occupational diseases, risk assessments and training records;
- Investigation of any work-related incident, accident or disease;
- Periodic safety and health inspections to identify potential hazards, unsafe acts and conditions in the workplace;
- Implementation of written safety and health rules, and regulations for compliance by employees and contractors;

- Communication of pertinent WSH information to and from employees and other interested parties;
- Emergency response plans to include fire, airborne release of hazardous substances; and
- Regular review of the safety and health programme.

The roles and responsibilities of the employer and employees should be clearly defined, documented and communicated to ensure effective implementation.

Employers are responsible for:

- Developing and implementing an effective SHMS;
- Informing all employees of workplace hazards and ensuring all safety and health rules and procedures are followed;
- Providing proper equipment and personal protective devices; and
- Documenting the SHMS and keeping all necessary records.

Correspondingly, employees are responsible for:

- Following all safety and health rules and procedures;
- Attending relevant safety and health training;
- Using the equipment and personal protective devices properly;
- Reporting incidents, accidents, diseases and any workplace hazards to the supervisor or manager; and
- Providing suggestions and feedback to management on safety and health at the workplace.

6.2.2 Recording and reporting of occupational injuries and diseases

There should be a system to record and report all work related injuries and diseases. This is a requirement under the Workplace Safety and Health (Incident Reporting) Regulations, and it is the duty of the employer to do so.

When incidents outlined in the table below occur, the employer must submit the report within 10 days to the MOM through the electronic reporting system, iReport.

Reportable Incidents, Accidents and Occupational Diseases
An accident in the course of work that results in: • A fatality; • Hospitalisation for at least 24 hours; or • The injured being given more than three consecutive days of medical rest; or
A dangerous occurrence such as: • An explosion or fire; • Collapse of structures or equipment; • Machinery damage; and • Flooding.
See Annex C for List of Reportable Occupational Diseases in Singapore.

6.2.3 Audit and management review

Periodic audits should be conducted to determine the adequacy of the SHMS in ensuring the safety and health of all personnel in the workplace. The audit programme can include the audit scope; methodology, reporting and auditor competency.

The audit results would help management to focus on areas of concern during the management review. Top management should review the SHMS for its relevance, adequacy and effectiveness. The management shall determine the frequency of review and its duration as appropriate.

From the audit results, changing circumstances and need for continual improvement, the review should address potential changes to:

- WSH policy;
- Objectives; and/ or
- Elements of the SHMS.

6.2.4 Training

All workers deployed in compressed air work must undergo a safety and health orientation programme to acquaint them with all the associated hazards and the necessary precautions to be taken. They must be reminded regularly of reporting illnesses to the supervisors and to bring their log books whenever they visit the appointed doctors. Companies must ensure that training is conducted in the language the workers understand and documents are translated into the workers' languages.

Specific training for man-lock and medical-lock attendants should be conducted to ensure the safe delivery of duties. All workers must also be trained on the proper use of breathing apparatus, and be familiar with compression and decompression procedures. The appointed medical practitioner must be trained in rescue procedures, resuscitation, and the proper handling and usage of medical equipment. Refresher training on a routine basis should be provided to ensure workers are informed of safe work procedures and hazard information.

6.2.5 Permit to work system

A permit to work (PTW) system should be established before entry into the compressed air environment such as the work area within a tunnel or underground. The PTW system ensures that safe work procedures are implemented properly and serves as a means of communication among the site management, supervisors and workers.

Some features of the PTW system to consider include:

- Identifying who may authorise particular work and who is responsible for specifying the necessary precautions;
- Ensuring that compressed air workers are medically fit and that their log books and personnel ID tags are available. These persons must be monitored closely in the compressed air environment;
- Ensuring that the air lock chambers are MOM-approved models with valid Air Receiver Certificates and are in good physical condition;
- Ensuring that the man-lock attendants and medical-lock attendants (for pressures above 1.0 bar) are available;

- Testing of the worksite for possible presence of flammable or toxic gases, or oxygen deficiency;
- All telephone systems are working;
- Electrical appliances used in the chamber should be designed to minimise the risk of fire and production of toxic fumes and withstand pressure changes to the maximum working pressure of the airlock;
- Excavation chamber is isolated and the keys retained by job supervisor;
- Locomotive is on standby in tunnel for rescue or emergency purpose;
- Fire fighting equipment is available and kept in chamber;
- Reserve supply of compressed air for locks is available;
- Proper access and egress available to work areas;
- No hot works to be conducted outside the lock (only under special circumstances);
- No works on services (tracks, air supply, water supply lines, tracks and etc) whilst workers are in compressed air environment as this may cause disruption of air and water supply in the lock;
- Keeping the PTW form simple and user friendly, and applying a consistent method of differentiating different forms for different types of hazards; and
- Verifying and monitoring the PTW system to ensure it works as intended.

6.3 Monitoring of Hygiene Parameters

When work is carried out in a compressed air environment, certain parameters must be monitored to ensure that the environment is safe for occupancy and work. Some important parameters to be monitored are:

- Working pressure
- Oxygen
- Flammable gases
- Carbon dioxide
- Carbon monoxide
- Temperature
- Relative humidity
- Toxic gases or vapours that may be present

These parameters should be continuously monitored throughout the work shift in the compressed air environment. When these parameters reach certain levels, actions should be taken. Measurements should be recorded and made available when requested for during inspections. A sample of the record is shown in the table in **Annex D**.

Action Levels for Hygiene Parameters

Certain actions are to be carried out for the following and the atmosphere in the airlocks and cutter head chamber will be deemed **not fit to enter** when they contain:

- Less than 19.5%, or higher than 23.5% of Oxygen by volume (ideally 20.8% oxygen)
- More than 25ppm of Carbon Monoxide (CO)

- Above 5000ppm of Carbon Dioxide
- Above 10% of flammable gases
- Above 10ppm of Hydrogen Sulphide
- Above 25ppm of Nitric Oxide
- Above 3ppm of Nitrogen Dioxide
- Above 2ppm of Sulphur Dioxide
- Above 0.5mg/m³ of Oil Mist
- Toxic gases or vapours above PEL (short term)

Actions taken should reduce the contaminant level to meet the criteria before workers are allowed to enter the compressed air environment. Quality of compressed air in working chamber, man-lock and medical-lock should always be maintained at the levels below:

- *Carbon monoxide*
Not more than 25 parts per million (25ppm)
- *Carbon dioxide*
Not more than 5,000 parts per million (5,000 ppm) divided by the absolute pressure in bars of the compressed air environment when the air is tested at atmospheric pressure.
- *Oil mist*
Not more than 0.5 milligram per cubic meter of air at atmospheric pressure (0.5 mg/m³)
- *Odour and cleanliness*
As far as is practicable, the air shall be free from all odour and contamination by dust, fumes and other toxic substances.
- Less than 10% of the PEL (short-term) for any toxic substance

Temperature and humidity

The temperature in the working chamber, man- or medical-lock, should not exceed 29°C and the relative humidity should not exceed 85%. This can be done by air flushing and purging, and cooling the air with chillers before supplying it to the compressed air chamber.

7. Prevention of Compressed Air Diseases

7.1 Medical Fitness, Surveillance and Monitoring of Worker’s Health Status

7.1.1 Medical Fitness and Surveillance

Compressed air workers have to undergo medical surveillance for both compressed air and noise hazards. These examinations must be conducted by an appointed designated factory doctor.

Before any worker is allowed to work in compressed air environment, he must be certified medically fit by the appointed doctor. This is required under the Factories (Medical Examinations) Regulations. This is to exclude persons who are suffering from certain medical conditions which may put them at increased risk. These include persons suffering from certain chronic diseases of the ears, sinuses or lungs, heart diseases, uncontrolled high blood pressure or diabetes, epilepsy and hearing difficulties.

The examinations vary according to the working pressure (whether more than one bar). The pre-employment examination includes a clinical examination, chest x-ray, x-ray of the shoulder, hips and knees, lung function tests, hearing test, body fat estimation and a test in a lock.

Annual lung function and hearing tests are required. For workers who are exposed to more than one bar, annual x-rays of the shoulders, hips and knees are required. Older workers (more than 35 years of age) would require an electrocardiogram (ECG) at pre-employment and annually.

All workers are also required to undergo periodic medical examinations as follows:

- Not less than once in every three months for working pressures below one bar; and
- Not less than once in every four weeks for working pressures at or exceeding one bar.

In addition, workers will need to be re-examined if they:

- Have not been working in compressed air environment for more than 14 consecutive days;
- Suffered from a cold, chest infection, sore throat or earache; and
- Suffered from any illness or injury requiring absence from work for more than three consecutive days.

This is to ensure that they remain medically fit to continue work in compressed air environment. Workers with a cold, sore throat, earache or chest infection should not be permitted to enter or work in compressed air environment. They would be at a higher risk of developing barotrauma as they may have difficulty clearing their ears.

Workers who are sick for more than three days, must be examined by the appointed doctor and certified fit before going back to work in compressed air.

Records of medical fitness are updated in the personal logbook of each compressed air worker. The worker should show this to the man-lock attendant who would check to ensure that the worker has been certified fit to work in compressed air.

7.1.2 Monitoring of Workers’ Health Status

Companies should have a system to monitor the medicals of workers, their fitness to work in compressed air and manage the medical records (log books). Such information should be centralised and man-lock attendants must be aware of the workers’ fitness status. This should be under the charge of a competent person, for example, project manager and/ or WSH officer.

The workers’ conditions are monitored and supervisors and man-lock attendants are aware if workers are not to enter compressed air space. The company must ensure that every compressed air worker is informed about the maximum working time based on the ambient working pressure.

The company should make sure that all scheduled compressed air workers’ medical clearances are current and valid, i.e., check annual status, three-monthly status and 14-days status, and every worker must make a health declaration. Shift engineers and foremen should be informed at every stage of compression and decompression at the start and the end of every dive.

TBM “Dive Days” (131 for this period)	1	2	3
Actual Dive Number (from main log)	Dive 4 TBM Man-Lock & Cutterhead	Dive 5 TBM Man-Lock & Cutterhead	Dive 6 TBM Man-Lock & Cutterhead
TBM	TBM 2	TBM 3	TBM 3
Tunnel	East Inner	West Inner	West Inner
Date	xx / yy / zzzz	xx / yy / zzzz	xx / yy / zzzz
Number of men - Dived	3	6	12
Type of work	Inspection Dive	Inspection/ Work Dive	Working Dive
Pressure	1.30	1.30	0.90

Table 6: An example of a dive log
NB: Contractors can amend the table to suit their particular sites. However, it should give a summary of the compressed air works.

Work should not be carried out on the operating systems which will affect the supply/ exhaust or compressors. There must be good noise control measures in place so that clear communications can be established between the compressed air workers and man-lock attendants. The company must ensure that no unauthorised person is allowed to open or close valves to the man-lock from within or outside the man-lock.

7.2 Worker Records

Some workers have previous compressed air work experience and their new company may not have their records. It is a good practice to allow the worker at the end of a contract to be given their compressed air log books or their dive histories for their next employer. This would be useful as some workers are “suitable candidates for working” in compressed air operations and have minimal problems. The company should also keep individual records (medicals and exposure) for future employers use.

7.3 Identification Badges

Identification badges must be worn by all compressed air workers. If any worker collapses or becomes ill when he is on site, there is sufficient information to indicate that he is a compressed air worker and may need to be urgently recompressed (if he is suffering from decompression sickness). The location of the medical-lock and the contact number of the appointed medical doctor should be indicated.

7.4 Compression and Decompression Procedures, Health Declaration, Use of Post-Decompression Oxygen

7.4.1 Compression Procedures

New workers must be instructed on the precautions to take. During compression, the pressure in the man-lock is gradually increased by not more than 0.2 bar in the first minute. The pressure will be held at 0.2 and 0.5 bar to check if any worker is having discomfort. After which the pressure is raised by not more than 0.7 bar per minute. If any worker expresses discomfort, the pressure will be held to determine if the symptoms are relieved. If not, the man-lock attendant will gradually release the pressure until the discomfort has ceased. Otherwise, the man-lock attendant will reduce the pressure to atmospheric and the affected worker is required to report to the medical-lock attendant or appointed doctor.

A new compressed air worker would need to be accompanied by an experienced worker.

No person shall be required or permitted to be employed in a compressed air environment at a pressure more than 3.5 bar unless with prior written permission from the Commissioner for Workplace Safety and Health.

7.4.2 Decompression Procedures

The procedure for decompression after work in a compressed air environment is a staged decompression, breathing air. Decompression from pressures of one bar and over is required to be in accordance with the Blackpool tables. Equivalent table may be submitted to the MOM for consideration.

Decompression from pressures less than one bar should not be greater than 0.4 bar per minute.

Decompression is carried out by a trained and qualified man-lock attendant who would:

- Check the man-lock attendant register to confirm for this group of workers:
 - Total period exposed to compressed air (from start of compression to start of decompression in hours)
 - Maximum working pressure (bar)
- Determine the appropriate stage pressures and times at stage pressures from the decompression tables
- Decompression is carried out at a rate not faster than 0.4 bar/min, with halts at the stage pressures at the indicated times

For example:
Maximum working pressure is 1.3 bar
Total exposure time is 7 hr 20 min
Table to use: Table 2, Line 8

Table no.	Maximum working pressure (bar)		Exposure period (hr)		Total decompression period (min)		Line no.	
2	1.2 –1.35		4.0-9.25		44		8	
Time (min) at Stage pressure of:								
1.8	1.6	1.4	1.2	1.0	0.8	0.6	0.4	0.2
							5	35

7.4.3 Health Declaration for Compressed Air Workers

All persons engaged to work in compressed air are required to report to their supervisor, which may be their employer or compressed air contractor if they have a cold, chest infection, sore throat or ear ache. This would render them unfit to enter the compressed air environment as they would have an increased risk of developing barotraumas. For the purpose of ensuring that workers with such illness or symptoms do not enter the compressed air environment, the 'Health Declaration for Compressed Air Workers' form may be used (see **Annex E**). The form should be translated into all relevant languages and the lock attendant must specifically ask each worker if they felt unwell before entering the compressed air environment.



Figure 3: Man-lock

7.4.4 Use of Post-Decompression Oxygen

The factors influencing the onset of decompression sickness for most projects in Singapore are the long intervals of non-exposure followed by intensive compressed air work especially at pressures of more than 1.8 bar.

Post-decompression oxygen should be used depending on the pressure and duration of work in the compressed air environment. This is useful to reduce incidence of decompression sickness when working pressures are in excess of 1.5 bar gauge. For example, surface oxygen can be given for a period of 30 minutes. Contractors should liaise with their contract medical advisors on the use of post-decompression oxygen.

7.5 Restriction of Total Hours in Compressed Air, Limit on Consecutive Dives, Bends Watch

7.5.1 Restriction of Total Hours in Compressed Air and Limit on Consecutive Dives

Every person who is employed in compressed air environment shall spend not less than 12 consecutive hours at atmospheric pressure in any 24 hour period.

For example, after a six-hour or eight-hour shift, 12 hours of rest at sea level is required. The worker should not enter the compressed air environment before the 12 hours is up. Any shift change should be adjusted for more than 12 hours.

No person who has undergone three decompressions from a pressure more than one bar in any 24-hour period preceding the time he is to enter compressed air environment shall be permitted to work in compressed air except for rescue work.

However, a supervisor or one who is engaged in maintenance work can enter up to five occasions in any 24-hour period, provided that each occasion is less than half an hour, the interval is at least one and a half hours and the maximum pressure is not more than two bar.

Information on multiple entries is captured on the transfer record (or logbook) by the man-lock attendant and the worker is to present the record to the man-lock attendant, so that the appropriate decompression procedure can be determined. Do make sure that the workers have their logbooks and that the exposure and medical fitness records are updated.

A 24-hour rest break at sea level atmospheric pressure is recommended after every six days of consecutive compressed air exposure.

7.5.2 Bends Watch

The symptoms of decompression sickness may commence soon after decompression. It is important for the workers to remain on site for at least one hour after decompression when the working pressure is more than one bar.

Bends watch should be periods of proper rest, drinking lots of water and cooling off. Contractors should not deploy the workers for topside manual labour.

7.6 Acclimatisation

A new worker is liable to develop decompression sickness during his first week at work, particularly if the pressure is high as he may not be acclimatised to the compressed air environment. Should he continue working regularly, he may not have any problem. This acclimatisation may be lost after a short period of being continuously away from the compressed air environment. Acclimatisation to a certain pressure does not protect a person when working at a higher pressure.

A person who has not worked in compressed air environment for more than 14 consecutive days shall not be permitted to work in pressures of more than one bar for more than four hours in one day and shall not in any subsequent day be increased by more than one hour on each subsequent day.

7.7 Emergencies

Emergencies can occur in a compressed air environment and procedures to deal with emergencies and the evacuation of casualties must be in place before the start of such work.

7.7.1 Worker Collapses

When a person in a man-lock collapses or becomes ill during decompression, the man-lock attendant shall raise the pressure in the lock until it is equal to the maximum pressure to which the affected person was exposed. Report the incident immediately to the medical-lock attendant or the appointed doctor.

Closed-circuit television (CCTV) can be installed in the locks to monitor the workers in the compressed air environment.

7.7.2 Emergency Decanting

Decanting should only be carried out as a means of evacuating the tunnel during an emergency such as fire or flood. The workers would be decompressed rapidly in the man-lock and immediately transferred to the medical-lock and be recompressed to the working pressure,

be held at this pressure for 10 minutes and decompressed following an appropriate treatment table. The appointed doctor must be informed immediately.

7.7.3 Medical-Locks

At working pressures exceeding one bar, the likelihood of a case of decompression sickness occurring increases and there is a possibility of being a serious form of the illness. Where persons are employed in a working chamber of more than one bar pressure, a suitably constructed medical-lock shall be provided and maintained.

There should be at least a hyperbaric or chamber-trained first-aider (for example, medical-lock attendant) present and a medical-lock attendant during the treatment of decompression illness. This person would be able to enter the medical-lock to monitor and provide an appropriate medical care for the patient in the lock and assist in communication. This person could be the medical-lock attendant if another suitable person is available to operate the lock, for example, another medical-lock attendant.

The medical-lock is best selected by the compressed air contractor in conjunction with the contract medical advisor. It needs to be of an appropriate size and consist of an inner (treatment) and an outer (entrance) chamber. The size must be adequate to accommodate the injured and chamber medic. The medical-lock would normally be located near the top of the shaft giving access to the compressed air workings.

The medical-lock should be equipped with a facility for supplying food, drink and medical supplies to the persons undergoing therapeutic recompression treatment. There should be means for verbal communication between each compartment of the lock and the person operating the lock. The medical-lock needs to be fitted with equipment to allow the administration of oxygen by a built-in breathing systems (BIBS) for persons being treated in the lock and should have a suitable supply of oxygen. The medical-lock must be kept ready for immediate use while persons are in compressed air in excess of one bar and for 24 hours thereafter. Air banks should be configured for dual redundancy and oxygen and carbon dioxide monitoring of the chamber is required. A self-recording barograph is also required for chamber treatment. Facilities for firefighting should be specified.



Figure 4: Medical-lock

8. Personnel and Responsibilities

The supervisor, man- and medical-lock attendant have important roles to play in the prevention of compressed air illness and barotrauma.

8.1 The supervisor must:

- Provide a safe and healthy working environment by complying with all the health and safety requirements of compressed air work;
- Ensure that the compressed air workers understand the safety instructions and observe them;
- Ensure that only persons who are medically fit and have undergone the necessary training are allowed to enter or work in compressed air;
- Ensure that there are qualified and trained medical-lock attendants and appointed medical practitioners to provide immediate medical attention;
- Ensure that the proper procedures are carried out by trained man-lock attendants;
- Recognise any workers who have developed illnesses from compressed air work and arrange for them to seek medical attention immediately; and
- Be familiar with all emergency procedures.

8.2 The man-lock attendant is to:

- Ensure that only authorised persons enter into the compressed air working area. Check the logbooks of the workers to ensure that they are fit for compressed air work;
- Ask the workers if they have colds, sore throats, earaches or chest infections and not allow them to enter compressed air if they are sick. He can also ask if they are able to perform the Valsalva manoeuvre;
- Instruct new workers on the precautions to take in compressed air;
- Ensure that workers follow the acclimatisation schedule;
- Ensure that any worker who may develop problems in the man-lock is given immediate attention;
- Ensure that proper compression and decompression procedures are carried out;
- Ensure that the pressure gauges and other critical equipment are in good working order; and
- Keep proper records of all entries, decompressions (man-lock attendant register, charts, transfer records etc) and ensure proper hand-over.

8.3 The medical-lock attendant is to:

- Provide first aid and attend to all cases of decompression sickness or barotrauma immediately and liaise closely with the appointed medical doctor; and
- Keep good records and ensure that all equipment in the medical-lock are in good working order.

8.4 General Rules for the Compressed Air Worker

General rules

- Follow Lock Attendant's instructions.
- Always observe the safety rules and know the emergency procedures.
- Take extra outer clothing into the tunnel and wear it during decompression to avoid chilling.
- Do not smoke in compressed air environment.
- Do not carry any inflammable items like cigarettes, lighters or matches into compressed air area.
- Wear identification badge/tag at all times, whether or not at the worksite, so that in the event of an emergency, the correct medical assistance would be given.

Rest and compressed air work

- Sleep at least seven hours daily. Have adequate rest and sleep in between shifts.
- Spend not less than 12 continuous hours in free air in any 24-hour period.
- Do not enter a compressed air environment more than three times in any 24-hour period.
- Light exercise is permissible.

Food and drinks

- Eat moderately before going on shift.
- Drink plenty of water before and after shifts to prevent dehydration.
- Avoid excessive alcoholic beverages the night before or within eight hours of going on shift.
- Do not drink alcohol or fizzy drinks prior to or when working in a compressed air environment.

Medical conditions

- Do not work in compressed air if you are having a cold, sore throat, earache or chest infection. The 'Health Declaration for Compressed Air Workers' form serves as a reminder for this. If unable to perform the Valsalva manoeuvre, report to supervisor or the man-lock attendant.
- If not feeling well in a tunnel, report immediately to supervisor.

When to seek medical attention

- If feeling unwell and/or possibly suffering from compressed air illness, report to your work site and arrange to see the medical-lock attendant or doctor.
- Report to the appointed designated factory doctor if suspect suffering from 'air pains' or decompression illness.
- If 'niggles' or 'air pains' developed that persist longer than 30 minutes after decompression, seek medical attention immediately.
- Report at once to the appointed doctor if become ill away from the job site.
- Do not re-enter the man-lock if suffering from air pains or decompression illness.
- Do not give workers suffering from compressed air illness any intoxicating liquor.

Medical examinations

- Make sure to undergo the required medical examinations.
- Must be certified medically fit by the appointed doctor.
- If the working pressure is one bar and above, see the appointed doctor once in every four weeks.
- If the working pressure is below one bar, see the appointed doctor once in every three months.

Logbooks

- The individual health and exposure record (logbook) is every worker's property.
- The individual book records the results of medical examinations and exposures to compressed air.
- Bring the logbook when seeing the appointed doctor.
- Present the logbook to the man-lock attendant before entering compressed air.
- Read the rules carefully, understand and follow them.

9. Annexes

Annex A: Notification on the Use of Compressed Air

To: The Director
OSH Specialist Department
Occupational Safety and Health Division
Ministry of Manpower
Fax: 68765303

Name and address of contractor:

Site of work in compressed air:

Purpose of use of compressed air:

Expected date/time of commencement:

Expected date/time of completion:

Expected maximum pressure (bar):

Expected maximum exposure time of any worker (hrs):

Expected maximum number of workers inside working chamber at any one time:

Expected total number of workers working in compressed air:

Name, address and telephone number of appointed medical practitioner:

Location of medical-lock:

I certify that only workers who have been certified medically fit to work in compressed air and have undergone the necessary training would be deployed in the compressed air work.

Name

Designation

Telephone

Date

*The notification should be made at least 14 days before such work commences or as soon as is practicable after the necessity of such work becomes known to the contractor.

Annex B: Risk Assessment Worked Example

Scenario – Tunnels in compressed air environment

The activities involve compression and decompression of a compressed air worker in the man-lock when he works on the tunnel in a compressed air environment. The man-lock attendant must be competent to carry out the compression and decompression process. The tunnel engineer must also ensure that right pressure is maintained at the compressed air work area. The compressed air worker who enters the compressed air work area must ensure that he has sufficient surface interval rest and is feeling well before compression takes place.

Risk Assessment Form									
Company : ABC Company			Process/location : Tunnels in compressed air environment						
Conducted by : 1. Tunnel Manager 2. Safety Co-ordinator 3. Senior Engineer									
Approved by : Senior Tunnel Manager									
Last review late : aa/bb/cccc			Next review late : aa/bb/cccc						
Hazard Identification			Risk Evaluation				Risk control		
No	Work Activity	Hazards	Possible accident/ill health and persons-at-risk	Existing control measures	Severity	Likelihood	Risk level	Additional control measures	Action officer
1	Compression and decompression of persons	Accidental compression of personnel	Injury/fatal	1) To lock out / tag out all inlet valves inside and outside the air lock, to lock out / tag out all equalisation valve from the plenum and keys kept by the TBM operator. 2) Keys to be drawn out only by tunnel engineer or air lock attendant.	Major	Remote	Medium		Tunnel Super-intendent/ Tunnel Engineer / Man-lock Attendant

						3) To brief tunnel workers during tunnel safety induction and immediately before each intervention tool box talks about the dangers. 4) To enforce on site that no one enters the lock without the presence of the man-lock attendant under compressed air environment. 5) To enforce on site that no one enters the air lock even in free air unless instructed and supervised by the tunnel superintendent or engineer. 6) To install signages to warn remind workers not to enter the lock unnecessarily.	Moderate	Remote	Medium	Tunnel Engineer / Man-lock Attendant
						1) Compression and decompression carried out properly using approved tables. 2) Lock attendant in position at all times. 3) Only compressed air workers certified fit to work in compressed air. 4) Medical assistance provided. In accordance with the guidelines. 5) 1 hour "bends" watch to be enforced. 6) Compulsory 30 minutes of medical oxygen in atmospheric pressure to be inhaled after working in pressure exceeding 1.5 bars or as per compressed air medical doctor's recommendation.				
		DCS on site	Serious illness			1) Workers trained and aware of symptoms of DCI. 2) All CA workers to wear tags to identify them and state emergency numbers to contact if found unconscious or disorientated.	Moderate	Remote	Medium	Tunnel Engineer / Man-lock Attendant
		Barotrauma	Damage to ear drums and pressure sensitive areas of body			1) Compression carried out under the constant visual surveillance of the lock attendant. 2) Telephone communications between lock attendant and men inside caw inside the air lock. 3) Workers trained and aware of symptoms. 4) Only CA workers certified fit to work in CA.	Moderate	Remote	Medium	Tunnel Engineer / Man-lock Attendant.

						5) Vasalva manoeuvre to be done only during compression. Strictly no such manoeuvre to be carried out during decompression.					Tunnel Engineer / Man-lock Attendant
		Osteorecrosis	Long term illness			1) All workers fit and medically examined prior to commencement of CA works. 2) Decompression rules strictly enforced. 3) Ongoing medical examination during project.	Moderate	Remote	Medium		Tunnel Engineer / Man-lock Attendant
2	Decompression of working area	Air leakage	Reduction of support			1) Air losses calculated in advance and plant supplied to suit. 2) Air losses monitored during pressurisation, before a manned intervention. Should air loss prove too high, inspection will be abandoned.	Remote	Minor	Medium		Tunnel Manager / Man-lock Attendant
		Blow out	Serious injury			1) Pre-intervention air losses to be checked as above. 2) Inspections to be carried out where most suitable ground is encountered.	Major	Occasional	Medium	1) Close supervision by tunnel engineer and TBM operator. 2) Maintain proper communication between man-lock attendant and comp air workers and compressor station attendant.	Tunnel Manager
		Fire in chamber	Serious injury			1) Materials in chamber strictly controlled. 2) No hot work allowed unless special permission is granted and special requirements met. 3) Fire extinguishers provided. 4) Compressed air workers to be aware of sprinkler activation lever.	Moderate	Remote	Medium	1) All compressed air workers to be trained on use of fire extinguishers'	Tunnel Engineer / Man-lock Attendant

3	External effects	Loss of power on TBM	Loss of lights	1) Emergency lights in chamber and tunnel. 2) Workers will be brought into lock and if necessary decompressed.	Moderate	Remote	Medium	1) Emergency back up power to be provided which is capable of maintaining a safe decompression.	Tunnel Manager
		Loss of powers to compressors	- Loss of air pressure. - Loss of face support. - Uncontrolled decompression	1) Back up diesel compressors on standby. 2) Air receiver tanks of sufficient capacity on site.	Moderate	Remote	Medium	1) Tapping of air from dedicated compressed works air line strictly not allowed.	Tunnel Manager
		Fire in tunnel	Workers isolated in chamber or decanting necessary	1) No hot works in tunnel during compressed air working, sprinkler system and fire fighting equipment to be checked regularly and before each intervention session.	Moderate	Remote	Medium		Tunnel Manager
		Damage to CA supply pipes	- Loss of pressure - Loss of face support - Uncontrolled decompression	1) Two independent compressed air lines, mounted on the side of the tunnel. 2) Back up electrical compressor and air receiver on TBM provided.	Moderate	Remote	Medium	1) One line dedicated for compressed air works only. 2) Tapping of air from dedicated compressed works air line strictly not allowed. 3) Bypass valve arrangement to be suitably located to promptly switch	Tunnel Manager

								between each supply line. 4) All electrical compressors to preferably be auto start for a slight loss in air pressure. 5) All hoses to be over specified e.g. 20 bar.	Tunnel Manager
		Contamination of air	Serious illness/asphyxiation	1) Continuous monitoring of air within man-lock. 2) Air to be purified/ filtered before use. 3) Air purification system to be maintained regularly.	Moderate	Remote	Medium	1) Use only galvanised pipes. 2) Tapping of air from dedicated compressed works air line strictly not allowed. 3) Air filter system is fitted to each supply line.	Tunnel Manager
4	Changing cutters in the cutter head	Face collapse	Injury/fatal	1) Air pressures calculated in advance and confirmed by Tunnel Manager and Senior Tunnel Engineer and plant supplied to suit. 2) Air pressure monitored during pressurisation and throughout the work duration to prevent any face collapse.	Major	Remote	Medium	1) Continuous face monitoring by compressed air workers. 2) Maintain bentonite cake on face. 3) Routine face inspection and records maintained by a suitable qualified person. 4) Optimum selection of ground conditions for	Tunnel Engineer

									where possible. 5) One worker to remain in man-lock at all times.	Tunnel Engineer	
		Fire in cutter head/man-lock	Injury/fatal			1) No hot works in tunnel during compressed air working in general, no highly combustible materials allowed inside the compressed air, non-flammable grease to be used inside compressed air environment, workers to remove oily or greasy clothing before decompression and change to disposable clean overalls, oily rags and clothing to be removed from decompression chamber through the material lock before decompression start, sprinkler system and fire fighting equipment to check. Extinguisher (designed for use in pressure chamber) to be placed in each cell of man-lock.	Moderate	Remote	Medium	1) All compressed air workers to be trained on use of fire extinguishers. 2) Man-lock attendant and compressed air workers team leader to ensure compliance. 3) A high standard of man-lock and worker personal cleanliness must be maintained.	Tunnel Engineer
		Excessive water ingress	Face flooding. Serious injury or fatal due to drowning			1) Air pressures calculated in advance and confirmed by Tunnel Manager and Senior Tunnel Engineer and plant supplied to suit. Air pressure monitored during pressurisation and through out the work duration to prevent any water ingress. Man-lock chamber to be kept vacant at all time to facilitate escape uncontrollable water in flow.	Major	Remote	Medium	1) Abort works, enter man-lock and shut all doors.	Tunnel Engineer
		Heat stress/high temperature inside the cutter head	Injury			1) Chilled air to be supplied to working chamber to maintain workable temperature. 2) Drinking water to be provided to prevent dehydration. 3) Water available in the chamber at all times for hosing down. 4) Wet bulb thermometer to be provided cutter head to be kept to the required	Major	Occasional	Medium	1) Duration of works to be reduced. 2) Rehydrate compressed air workers with isotonic drinks.	Tunnel Engineer

					temperature of 29 °C or as low as practically possible.							
		Fumes in the cutter head during hot works	Injury		1) Where possible no hot works to be carried. 2) Fumes to be channel out the chamber through the exhaust vent. 3) Air to be regulated consistently by the Samson Unit or by the lock attendant.	Moderate	Occasional	Medium	1) Provide suitable respirators.		Tunnel Engineer / Man-lock Attendant	
		Falling of cutter during transporting into cutter head	Injury		1) All lifting gear to be checked at regular intervals, moving of cutters to be done slowly and all lifting eyes to be checked that they are connected well before lifting the cutter. 2) No person to work under suspended load.	Moderate	Occasional	Medium	1) Close supervision by compressed air workers team leader.		Tunnel Engineer	
		Falling from heights	Injury/fatal		1) Proper platform to be used. 2) Cutters to be changed at 4 o'clock to 8 o'clock positions.	Moderate	Occasional	Medium	1) Close supervision by compressed air workers team leader. 2) Anchor points welded to TBM for attaching a full body harness. 3) Foot and hand hold points installed.		Tunnel Engineer	
5	Operating the surface air compressor	Tripping, slipping, crushing, trapping, hitting	Various minor injuries		1) Good housekeeping. 2) Layout design for ease of access. 3) Pipe work kept to a minimum. 4) Condensation piped away. 5) Area well lit.	Moderate	Remote	Medium			Plant Manager/ Compressor Attendant	
		Electrocution	Serious injuries / fatal		1) Purpose made unit. 2) No exposed unprotected cables or parts. 3) Lock off system in use.	Major	Remote	Medium	1) Pre-checks to be carried out.		Plant Manager	
		Noise, smoke and pollution	Noise induced deafness, smoke inhalation		1) Use silenced units only. 2) Workmen issued with ear protection. 3) Diesel exhaust pointing up. 4) Air exhaust baffled. 5) Area well ventilated. 6) Scheduled maintenance.	Moderate	Remote	Medium	1) Rotation of personnel daily.		Plant Manager	

6	Operation of diesel air compressor	Oil spillage/ fire	Burns, injury	1) Fuelling up to be organised to avoid spillage. 2) Drip tray installed. 3) Oil dry granules available to clear spillage. 4) Regular servicing to avoid compressor becoming a fire hazard (a) Stop engine leaks, (b) Exhaust system kept tight. 5) Dry powder fire extinguishers 9(2no) provided. 6) Overshoot protection on compressor.	Moderate	Remote	Medium	Plant Manager
7	Operation of electrical compressor	Overheating, fire, electrocution	Burns, injury	1) Regular servicing to avoid compressor becoming fire hazard. (a) Stop blocked cooling vents (b) Water ingress to panels. 2) All cabling protected and earth trips in place. 3) Compressors shut down on over heat.	Major	Remote	Medium	1) Electrician to conduct pre-check. Plant Manager
8	Overpressure in compressed air system	- Ruptured air hose or vessel - Loss of air pressure	Various injuries	1) Safety Valves fitted on: (A) Compressors, (B) Coolers, (C) Air Vessels. 2) Air regulator valves located on TBM. All electrical compressors on auto start & load for slight drop in pressure. 3) Flexible hoses fitted with claw clamps (outside hoses). Inside hoses fitted with double saddle clamps (in container). 4) All hoses materials well over specified (20 Bar). 40 Bar steam hose outside for 'Hot' air off compressor. 5) Leaks/blow cut on each compressor circuit can be isolated by closing valves. 6) Surface plant always attended while personnel in working pressure.	Moderate	Remote	Medium	Plant Manager
9	Working in the plenum/ excavation chamber	Ground / water inundation	Fatal/ major injuries	1) Compress air attendant must immediately inform personnel in pressurised working. 2) Personnel in pressurised working should immediately enter airlocks.	Major	Remote	Medium	1) Close monitoring by TBM operator in control cabin. Tunnel Engineer

				3) Non-return valves located in each air line. (Trailer3). 4) 35m of twin air pipes at high pressure.	Moderate	Occasional	Medium	1) Close supervision by compressed air workers team leader in the excavation chamber. Tunnel Engineer
		Tripping, slipping, falling	Various injuries	1) Open mesh platforms at mid and upper levels. 2) Hand holds provided. 3) Lifting lugs provided for attaching harness. 4) Alternative access points through cutter head bulkhead. 5) Provide sufficient lighting for adequate illumination in the cutter head.	Major	Remote	Medium	1) Close supervision by compressed air workers team leader in the excavation chamber. Tunnel Engineer
		Crushing, trapping, collision	Fatal/ various injuries	1) Local isolation button in man-lock to prevent cutting wheel & slurry system operation. 2) Direct communication with TBM operator. 3) Keys retain by job supervisor in excavation chamber so cutter head cannot free wheel.	Major	Remote	Medium	1) Stop works immediately and evacuate to airlock if face condition worsens or deteriorates. Tunnel Engineer
		Face collapse, entrapment	Fatal/ major injuries	1) Cutter head can be extended & retracted to improve working space. 2) Emptying of excavation chamber to be carried out by TBM operator and only when no one is working inside excavation or plenum chamber.	Major	Remote	Medium	1) All electrical equipment to be checked and issued by electrician only. 2) All electrical hand tools to be checked by LEW. Plant Manager
		Electrocution	Serious injuries/ fatal	1) Provide low voltage lighting for illumination. 2) Equipment to be checked prior to use. 3) Use only double insulated neoprene cable and watertight plugs. 4) Use low voltage tools only. 5) Use pneumatic tools whenever possible.	Major	Remote	Medium	

Likelihood Severity	Rare	Remote	Occasional	Frequent	Almost Certain
Catastrophic	Medium	Medium	Medium	High	High
Major	Medium	Medium	Medium	High	High
Moderate	Low	Medium	Medium	Medium	Medium
Minor	Low	Medium	Medium	Medium	Medium
Negligible	Low	Low	Low	Medium	Medium

Disclaimer: This RA is for illustration purposes and the employer must identify, evaluate and control the hazards and risks at the workplace.

Annex C:

List of Reportable Occupational Diseases in Singapore	
1. Aniline poisoning	16. Hydrogen Sulphide poisoning
2. Anthrax	17. Occupational skin diseases
3. Arsenical poisoning	18. Lead poisoning
4. Asbestosis	19. Liver angiosarcoma
5. Barotrauma	20. Manganese poisoning
6. Beryllium poisoning	21. Mercurial poisoning
7. Byssinosis	22. Mesothelioma
8. Cadmium poisoning	23. Noise-induced deafness
9. Carbamate poisoning	24. Occupational asthma
10. Carbon Bisulphide poisoning	25. Organophosphate poisoning
11. Chrome ulceration	26. Phosphorous poisoning
12. Chronic benzene poisoning	27. Poisoning from halogen derivatives of hydrocarbon compounds
13. Compressed air illness	28. Repetitive strain disorder of the upper limb
14. Cyanide poisoning	29. Silicosis
15. Epitheliomatous ulceration (due to tar, pitch, bitumen, mineral oil or paraffin or any compound, product or residue of any such substance)	30. Toxic anaemia
	31. Toxic hepatitis

10. Useful References

Ministry of Manpower (MOM), Occupational Safety and Health Division

The following legislations and guides are available on the MOM website at www.mom.gov.sg

- Workplace Safety and Health Act
- Workplace Safety and Health Subsidiary Legislations
- Guide to Workplace Safety and Health Act 2006
- Guide to Workplace Safety and Health (Risk Management) Regulations
- Risk Assessment Guidelines

Workplace Safety and Health (WSH) Council

The following guidelines are available on WSH Council website at www.wshc.sg

- Guide to Workplace Safety and Health Laws
- Prevention of Compressed Air Illness and Barotrauma in Tunnel Construction

Contact

- For enquiries, please email the Workplace Safety and Health Council, contact@wshc.sg
- To report unsafe practices at workplaces, please call the MOM hotline at 6317 1111.
- To report accidents, dangerous occurrences and occupational diseases, visit: www.mom.gov.sg/ireport

11. Acknowledgements

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