Regulations on occupational health and safety on construction sites	Work in Compressed Air (Application of the Compressed Air Regulations)	**RAB 25** Last updated: 12 November 2003

CONVENIENCE TRANSLATION – ONLY THE GERMAN VERSION IS AUTHORITATIVE

The German RAB regulations (regulations for occupational health and safety on construction sites, hereinafter referred to as RAB) provide safety and health guidelines for all work carried out on construction sites. These regulations are made by the Committee on Safety and Health on Construction Sites and they are updated regularly.
The German RAB is published by the Federal Ministry of Economics and Labour in the Federal Labour Gazette (BArbBI).

The RAB 25 regulations comprise recommendations further to the Regulations on Work in Compressed Air (DruckLV) and answers to frequently asked questions about the Work in Compressed Air regulations.

Contents

Section 1 Recommendations for granting exemption in accordance with § 12 Section 1 of the Work in Compressed Air Regulations (DruckLV)

Contents

Interpretation
In the following regulations, recommendations and appendices “Work in Compressed Air Regulations” or “Regulations” refers to the German “Druckluftverordnung” or “DruckLV”.

1 Preface

In accordance with § 12 Section 1 Clause 2 of the Regulations every compressed air contractor shall ensure that each of his employees who works in compressed air with a pressure in excess of 2.0 bar is under permanent medical surveillance by a doctor or employment medical adviser appointed in compliance with §12 of the Regulations and who is authorized to carry out such work under § 12 of the Regulations.

In exceptional cases the authorities responsible can exempt the compressed air contractor from the requirement to ensure the presence of an appointed doctor or medical adviser provided the compressed air contractor is able to demonstrate that effective first aid measures for divers suffering from decompression are available.

In the opinion of the Committee on Safety and Health on Construction Sites it is expedient to describe these measures, thus giving construction site managers and contractors a meaningful set of guidelines for planning, tendering and costing.

2 Application

This rule describes measures and requirements which must be complied with if a compressed air contractor wishes to be granted exemption from the regulations for construction projects during which employees will be working in a working chamber at pressures over 2.0 bar, but below 3.6 bar.

Recommended requirements for such cases in which an exemption has been granted will be made for all site staff entrusted with the care and treatment of employees suffering from decompression sickness; additionally, the contents of the exemption application and the records of exposure and deployment will be detailed.

Exemption shall only extend to the requirement to have an appointed doctor or medical adviser in permanent attendance in accordance with § 12 Section 1 Clause 2 of the Regulations. The compressed air contractor is responsible for ensuring that suitable and sufficient arrangements have been made for action in the event of an emergency. The compressed air contractor's full compliance with all other conditions and requirements in accordance with § 12 of the Regulations remains unaltered by the exemption.

3 Duties of the on-site staff

For the purposes of these regulations, on-site staff shall be deemed to comprise the following: the appointed doctor or medical adviser, the lock attendant, all supervisors/assistants and all doctors on call.

3.1 Appointed doctor or medical advisor

The compressed air contractor shall ensure that a doctor or medical advisor certified in accordance with § 13 of the Regulations is appointed in writing in accordance with § 12 of the Regulations.

3.1.1 Duties

In accordance with § 11 and 12 of the Regulations the appointed doctor or medical advisor is responsible for supervising all health aspects relevant to the work undertaken in compressed air conditions.

On-site emergency care shall be provided by the appropriate ambulance and emergency services; this is not the responsibility of the appointed doctor.

In specific cases (e.g. an accident in hyperbaric conditions in the working chamber where it is impossible to evacuate the employee under normal conditions) the areas of responsibility "emergency care" and "general compressed air care" may overlap. Procedures for dealing with such emergencies, e.g. a contingency plan, must be established.

While on duty, the doctor or medical advisor must always be available during the employees' working and standby times; the doctor must be able to reach the site of deployment in a reasonable amount of time.

Should it become necessary to treat more than one employee suffering from a compression-related condition then the compressed air contractor is responsible for ensuring that all the doctors on call have the necessary qualifications and are able to furnish certificates stating that they are fit for this type of work.

3.1.2 Qualifications

The appointed doctor must be qualified in accordance with § 13 of the Regulations. He/she must have specialised knowledge of the health issues associated with working under hyperbaric conditions, e.g. through regular attendance of appropriate training courses, and must be in a position to furnish evidence of this specialist training. The doctor is also required to provide a certificate of health stating that he/she is fit for this type of work.

3.2 Doctor or medical advisor on call

The duties and qualifications of doctors on call are not stipulated in the Regulations.

The appointed doctor can request a doctor on call to start treatment in accordance with § 12 of the Regulations of any person suffering from any acute condition arising from the work in compressed air should the appointed doctor not be able to be present at the site constantly.

The doctor on call is selected and assigned to this duty by the appointed doctor or medical advisor; however, the doctor on call does not need to be appointed in accordance with § 13 of the Regulations.

The doctor on call cannot stand in for the appointed doctor.

3.2.1 Duties

The doctor on call is responsible for starting treatment of persons suffering from any acute condition arising from the work in compressed air under the directions of the appointed doctor until the latter arrives at the site.

The doctor on call must be available at short notice, and must be in a position to arrive at the site within 30 minutes after the alarm is raised at the site.

3.2.2 Qualifications

The appointed doctor is responsible for ensuring that the doctor on call has all the necessary qualifications and is fit for such duties. The appointed doctor must also brief the doctor on call on how the examinations should be carried out, the type of treatment required for persons suffering from any acute condition arising from the work in compressed air, the local conditions and those specific to the compressed air contractor’s company, as well as explaining how the medical lock functions.

The appointed doctor will determine what instructions are given, how they are given and the duration of the instruction session.

3.3 Lock Attendant

The lock attendant is responsible for letting the workers into and out of the working chamber.

3.3.1 Duties

The duties of the lock attendant are detailed in Appendix 3 of the Regulations.

3.3.2 Qualifications

The qualifications for an lock attendant in accordance with § 18 Section 6 of the Regulations include knowledge of the physical processes that occur when working in compressed air, awareness of the implications of failing to observe correct procedures when airlocking workers and the ability to recognise signs of acute conditions arising from the work in compressed air.

The operator should also be trained and authorised to operate the medical lock.

The appointed doctor and an expert will determine what instructions are given, how they are given and the duration of the instruction session in accordance with § 18 Section 1 of the Regulations.

3.4 Experienced worker

The experienced worker shall be a person employed on the construction site; this person must be competent to provide first aid in the event of accidents and acute conditions arising from the work in compressed air.

3.4.1 Duties

In addition to providing first aid in the event of accidents in accordance with § 18 Section 1 clause 6, the experienced worker also has the following duties in the event of any acute condition arising from the work in compressed air:

- Assist the appointed doctor or the doctor on call to provide treatment for decompression illness
- Operate the medical lock
- Start recompression in the medical lock

The experienced worker shall perform these duties under the orders of the doctor in charge.

3.4.2 Qualifications

In addition to the qualifications required in accordance with § 18 Section 8 of the Regulations, the experienced worker must be competent to provide first aid for any person suffering from an acute condition arising from the work in compressed air, as well as being competent to operate the airlock.

The appointed doctor will determine what instructions are given, how they are given and the duration of the instruction session.

4 Details required for the application for exemption

The compressed air contractor can apply in writing for an exemption from the requirement to have the appointed doctor or medical advisor present in accordance with § 12 Section 1 Clause 2 of the Regulations. The application must give reasons for requiring the exemption and the following documents must be included to prove that first aid and emergency care is available to treat workers suffering from acute conditions arising from the work in compressed air:

1. Appointed doctor or medical advisor
1.1. Name and address
1.2. Certificate of appointment
1.3. Documentation of regular attendance of appropriate training courses
1.4. Certificate of health and fitness to provide health care to compressed air workers
1.5. Details of the exact amount of time required for the doctor to get to the site after being alerted (e.g. a diagram or map detail)

2. Details of doctors on call, if applicable
2.1. Names and addresses
2.2. Qualification certificates
2.3. Details of the exact amount of time required for the doctor to get to the site after being alerted (e.g. a diagram or map detail)

3. Assistants in accordance with § 18 Abs. 1 No. 6 of the Regulations
3.1. Names
3.2. Qualification certificates

5 Records of exposure and deployment

The airlock log required under Appendix 1 No. 1.14 of the Regulations must include the details required in accordance with Appendix A of RAB 25

Section 2 Issuing a certificate of competence in accordance with § 18 Section 2 of the Work in Compressed Air Regulations (DruckLV)

Contents

1 Preface

In accordance with § 18 Section 1 No. 1 of the Regulations the compressed air contractor must appoint an expert and a permanent deputy to supervise the compressed air work and monitor the operation of the working chamber at all times. The expert and his permanent deputy must be in possession of a certificate of competence issued by the relevant authorities in accordance with § 18 Section 2 of the Regulations.

The Committee on Safety and Health on Construction Sites has drawn up a list detailing the skills and practical experience in working with compressed air which any applicant should have in order to obtain a certificate of competence in accordance with § 18 Section 1 No. 1 of the Regulations. This list of required skills will act as a benchmark in issuing such certificates and is intended to make the management and supervision of work in compressed air safer.

2 Application

This paragraph outlines the skills and experience in working in compressed air required to obtain a certificate of competence as an expert in accordance with § 18 Section 1 No. 1 of the Regulations.

3 Duties of the Expert

The duties of the expert arise from the duties stipulated in the Regulations in addition to other responsibilities which may be transferred to him by the compressed air contractor, for instance:

- Supervise the compressed air work and monitor the operation of the working chamber at all times (§ 18 Section 1 No. 1 of the Regulations)
- Assist in preparing the notification of compressed air work for the authorities (§ 3 of the Regulations)
- Assist in preparing applications for exemption (§ 6 of the Regulations)
- Arrange for inspections by surveyors or technical assessors (§ 7 of the Regulations)
- Prevent unauthorised or untrained persons from undertaking compressed air work (§§ 9, 10, 11, 14 of the Regulations)
- Cooperate with the appointed doctor (§§ 11, 12, 14 of the Regulations)

- Administrate the health records (§ 16 of the Regulations)
- Help equip the medical lock, recovery rooms and sanitary facilities (§ 17 of the Regulations)
- Assist with the appointment of experts, lock attendants and experienced workers (§ 18 of the Regulations)
- Instruct the employees (§ 20 of the Regulations)
- Ensure that workers are correctly airlocked (§ 21 of the Regulations)

4 Application

Applications for a certificate of competence must be addressed to the responsible authorities in writing. Samples of the application form are attached to this document as Appendices B and C.

5 Requirements for obtaining a certificate of competence

The requirements for a certificate of competence are:

- A completed apprenticeship in a construction trade or equivalent qualifications
- Supervisory position
- Sufficient practical experience with work in compressed air (as a rule, the applicant should have completed at least 50 assignments in compressed air; this should be supported by photocopies from the record books as well as an authenticated list of these assignments signed by the supervising expert)
- Adequate knowledge of the potential hazards of working in compressed air and the precautions which should be taken to prevent these hazards occurring.

Proof of compliance with these requirements should be presented in an examination according to paragraph 6. The examination will be overseen by an examination committee in accordance with paragraph 7.

6 Examination

The applicant will sit an examination in which he must show sufficient knowledge of:

• **The health hazards of working in compressed air, e.g.:**
  - the specific effect of nitrogen and oxygen,
  - symptoms of conditions caused by working in compressed air,
  - illnesses caused by working in compressed air,
  - the danger of sudden decompression.

• **The technical features of a compressed air construction site, e.g.:**
  - the design and function of airlocks, working chambers and all the facilities and equipment needed to operate them, medical locks, recovery chambers, changing rooms, drying rooms and all sanitary facilities,
  - the hazards of working in compressed air and how to control these hazards, e.g. greater hazard of fire due to the higher air pressure, decompression with oxygen, the dangers of welding, cutting and burning, hazardous materials in compressed air.

• **The organisational requirements of carrying out assignments in compressed air, e.g.:**
  - clothing and personal protective equipment,
  - transfer procedures in airlocks, including how to deal with operational faults (e.g. malfunction of the oxygen equipment),
  - behaviour in the working chamber, behaviour before and during airlock transfer, what to do in the event of sudden loss of pressure,
  - instructions for lock attendants,

• **Knowledge of the regulations governing work in compressed air.**

7 The examining committee

The examining committee shall consist of at least the following:
- A representative of the of the responsible authorities as chairperson
- A representative of the statutory accident insurance company as assessor
- A doctor appointed under § 13 of the Regulations as assessor

8 Certificate of competence

The certificate of competence is valid for three years. It can be extended without an examination provided the applicant can prove that he has worked as an expert as defined in § 18 Section No. 1 of the Regulations within the space of three years of the certificate being issued.

Based on the pressure and duration of previous compressed air assignments, the certificate can be limited to specific pressures.

If most of the work which is offered as proof of the applicant’s work experience was undertaken at pressures of lower than 0.7 bar then the certificate shall be limited to pressures lower than 0.7 bar.

A sample of the certificate of competence can be found in Appendix D.

Section 3 **Airlocking with oxygen after working in compressed air in combination with § 21 Section 1 of the Work in Compressed Air Regulations (DruckLV) and Appendix 2 of the Regulations**

Contents

1 Preface

In accordance with § 21 Section 1 of the Regulations and Appendix 2 of the Regulations workers must be compressed or decompressed by passing through an airlock with oxygen. Appendix 2 to the Regulations gives details and tables with compression and decompression times.
A number of measures are required to ensure that workers are safely airlocked with oxygen.
It is the opinion of Committee on Safety and Health on Construction Sites that these measures should be detailed to allow compressed air contractors and workers to plan and carry out work in compressed air with the highest possible level of safety.

2 Application

This section describes measures and requirements for safe decompression with oxygen after work in compressed air in accordance with § 1 of the Regulations.

3 The principles of oxygen decompression

Depending on the pressure and time involved, human tissue undergoes additional nitrogen saturation if exposed to overpressure. This nitrogen surplus can be excreted again by the organism through the lungs within tight physiological limits during the transition to normal pressure.

During this process, certain pressure levels (retention levels) must be maintained for minimum times which are specified in tabular form and at which the decompression gas (air, oxygen or mixed gas) is inhaled. In the case of air as a decompression gas, only the low pressure gradient between the current tissue partial pressure and the nitrogen partial pressure of inhaled air is effective at the retention level as the pressure gradient for nitrogen elimination, whereby decompression then takes time.
Where 100% oxygen is used as a decompression gas however, the full pressure gradient between the tissue pressure and ambient pressure is effective and tissue is desaturated faster.

Inhalation of oxygen under overpressure also considerably increases the share of oxygen released physically into the blood, thus increasing the supply of oxygen to tissue. Possible micro-circulatory problems caused by nitrogen bubbles can therefore be prevented as they arise. A specific effect of oxygen is also the reduction of nitrogen bubbles as well as decreasing swelling by tissue.

Recent studies have proven that by applying oxygen decompression using the tables specified by the Regulations (DruckLV 1997), it was possible to significantly reduce the frequency of decompression sickness.

A prerequisite for such results is, however, safe handling of oxygen. An ongoing analysis of chamber air as a primary fire protection measure is equally necessary as adherence to the exposure limits for oxygen in terms of pressure and time. Oxygen may not be inhaled until the pressure in the airlock has been reduced to 1.0 bar. Inhalation of oxygen at higher pressure levels is only permitted if recommended by a doctor and within the framework of monitoring as a therapeutic measure. Oxygen is medication with the risk of dangerous overdose.

The inclusion of a qualified appointed doctor in monitoring exposure to compressed air ensures protection against acute or chronic oxygen poisoning in emergency cases where exposure levels are exceeded.

4 Measures prior to airlocking

In accordance with § 18, Section 1, No. 1 of the Regulations, the expert is responsible for ensuring availability of the volume of oxygen required for routine performance by the oxygen airlocks, whereby he must also ensure that this oxygen is suitable as inhaled air (please refer to the Appendix).
The expert must ensure that a personal oxygen mask is available for each worker regularly deployed in the overpressure environment.
Before each airlock process, the lock attendant must ensure that the oxygen volume indicated by the expert is actually available.
In the case of workers undergoing outward transfer of oxygen for the first time, trial airlocking must be performed in co-ordination with the appointed doctor, whereby such workers must be familiarised with inhalation using masks and the procedure in general as well as receiving instruction as to how they should conduct themselves inside the airlock.

5 Measures during airlocking

If a worker detects problems at his inhalation point, he must report them to the lock attendant without delay.
The oxygen airlocking process may not commence until the overpressure in the airlock has reached the pressure levels specified in Table 1, Appendix 2 of the Regulations (i.e. 1.0 bar or 0.5 bar).
The lock attendant may not instruct workers to don masks until the oxygen inhalation points have been supplied with the operating pressure.

The lock attendant must continually monitor the supply pressure for the oxygen inhalation system.

In the event of sudden interruptions, the oxygen airlocking process must be continued in accordance with the specifications of the appointed doctor.

In the event of failure of the oxygen inhalation system, the lock attendant must interrupt the oxygen supply and continue airlocking using compressed air in coordination with the appointed doctor and as specified by emergency tables 1 or 3 in Appendix 2 of the Regulations.

During the process of outward transfer of oxygen, the airlock must be flushed with sufficient supplies of compressed air.

The oxygen content in the airlock must be monitored by the lock attendant. In the event of the oxygen content rising, he must increase the flushing air volume immediately. The reasons for such an increase must be communicated without delay and suitable countermeasures introduced.

6 Measures following airlocking

The expert must ensure that the inhalation masks are cleaned immediately after use. Prior to re-use, they must be in an impeccable technical and hygienic state.
Deviations from the standard procedure of airlocking must be documented in the airlock log by the lock attendant as specified by Appendix A of the RAB 25.

7 Worker conduct

The oxygen masks may only be donned or removed following instruction to do so by the lock attendant.

If workers experience health problems, e.g. nausea or coughing, the lock attendant must be informed immediately. The airlocking process must be continued in accordance with the instructions of the appointed doctor. In such cases, the cause must be communicated. If necessary, the composition of oxygen used as well as the function of the oxygen inhalation system must be inspected.

Ignition sources may not be admitted to the airlock. Smoking, fire and naked lights are prohibited.

Workers inside the airlock must wear their masks at all times during the entire process of oxygen airlocking and must not be permitted to fall asleep.

8 Documentation of assignments

Airlocking procedures must be documented in the airlock log in correspondence with the sample in Appendix A of the RAB 25. This document must be submitted to the responsible industrial protection authorities following conclusion of construction work.

9 Operation of the oxygen inhalation system

The valves on lines conveying oxygen must be opened slowly.
All equipment conveying oxygen must be kept free of oil and grease.

10 Maintenance of the oxygen system via repairs, inspection and overhauling

Systems in operation must be subjected to regular inspections (e.g. every six months) by the manufacturer or supplier. Such inspections must be performed immediately in the event of faults.

Along with the inspections referred to in § 18, Section 1, No. 2 of the Regulations (i.e. inspection as per “DIN 31051 Grundlagen der Instandhaltung” (Basic principles of maintenance)), a technical functional inspection must also be performed on the oxygen system.

The oxygen system may only be overhauled following instruction by the expert.

11 Inspection of the oxygen system

The oxygen system is a component of the airlock system and must be included in inspections as per § 7 of the Regulations.

Appendix A (to Section 1 and Section 3 of the RAB 25)
Samples of records of exposure and deployment of divers working with compressed air

Logbook ____________ **Project:** ______________________ **TBM** ____________

NST-Hyperbaric Tunnel Construction and Diving*

Date	Compressed Air Personnel	Work pressure	Time under Pressure: Start compression	Time under Pressure: Start decompression	Total work time	Decompression time in minutes: time to 1. Step	time on Air (bar)		time on O_2 (bar)		End of decom-pression	Total time of decom-pression	Total time under pressure	Lock Attendant
	Surname / First name	in bar	time in h:min	time in h:min	in minutes		1,5	1,2	1,0	0,5	time in h:min	in minutes	in h:min	name / signature
1	2	3	4	5	6 = 5-4	7	8	9	10	11	12	13 = 12-5	14 = 6+13	15

during decompression. 05 min airbreak every 30 min.

Appendix B (to Section 2 of the RAB 25)
Sample application form for a certificate of competence in accordance with § 18 Section 2 of the Work in Compressed Air Regulations (DruckLV)

Application for a certificate of competence

in accordance with § 18 Section 2 of the Work in Compressed Air Regulations (DruckLV) permitting the holder to work as an expert as defined in § 18 Section 1 No. 1 of the Work in Compressed Air Regulations (DruckLV).

1. Personal details:

Last name: …….…….....

First name: …….....

Date of birth: …… Place of birth: .....

Profession: …….....

Address: …….....

Professional qualifications: …….....

2. Records of assignments/ work carried out in compressed air:

From..... to.....

Construction site: .....
(Assignment records in accordance with Appendix C of RAB 25 are enclosed)

2.1…….....

2.2.....

2.3.....

2.4.....

2.5.....

Please note:
This certificate is only valid in conjunction with a health certificate in accordance with § 10 of the Work in Compressed Air Regulations.

…….. ……
(Place and date) (Signature of the applicant)

Enc: Assignment records

Appendix C (to Section 2 of the RAB 25)
Sample of the application form for a certificate of competence in accordance with § 18 Section 2 of the Work in Compressed Air Regulations (DruckLV)

Proof of Assignment

Construction site:
(Stamp/letterhead).....

Mr / Mrs .....

was employed from ..... to .....

on the construction site .....

to carry out work in compressed air.

The working pressure was..... bar.

He/she carried out the following work:
.....

.....

.....

.....

.....

..... …….
Place / date (Signatures of the site manager and supervisor)

Appendix D (to Section 2 of the RAB 25)
Sample of a certificate of competence in accordance with § 18 Section 2 of the Work in Compressed Air Regulations (DruckLV)

Certificate of Competence
(in accordance with § 18 Section 2 of the Work in Compressed Air Regulations)
No. .....

1. Mr/Mrs.....

   born on ..... in .....

   address .....

   is authorised to operate as an expert as defined in § 18 Section 1 No. 1 of the Work in Compressed Air Regulations. He/she may supervise work in compressed air and monitor the operation of the airlock.

2. The certificate of competence is issued with the following conditions:
   - This certificate is only valid in connection with a certificate of health in accordance with § 10 of the Work in Compressed Air Regulations.

   - .....

   - .....

3. This certificate is revocable and is limited until.....

4. Comments:

.....

.....

Stamp
(Issuing authority)

(Signature)

Appendix to the RAB 25

Answers to frequently asked questions concerning the application of the Work in Compressed Air Regulations

In everyday working situations many questions may arise as to the application of the Regulations (DruckLV). The Committee on Safety and Health on Construction Sites, which is responsible for advising the Federal Ministry of Economics and Labour in all matters pertaining to general safety and health protection on construction sites, has compiled answers to some of the most frequently asked questions. The answers and recommendations given here represent a consensus of all authorities and parties involved in compressed air work. These answers are intended as guidelines to help plan, approve and implement work involving compressed air.

Contents

In the Work in Compressed Air Regulations pressure is measured and indicated in bar. To indicate quite clearly that the pressure to which the workers is exposed is the differential pressure which exceeds the normal atmospheric pressure, the symbol P_w is used throughout the Work in Compressed Air Regulations to represent the working pressure. The worker is exposed to a total pressure P_{abs}, which is the sum of the atmospheric pressure P_{atm} and the working pressure P_w.

The term “decompression illness” is used as a general term to cover all acute conditions caused by exposure to hyperbaric pressures.

1 Physiological principles when working with overpressure. What are the limits of exposure?

Inhaled air is a mixed gas whose essential components comprise oxygen (approx. 21%) and nitrogen (approx. 79%). Under normal atmospheric conditions of 1 bar, the human organism is saturated with nitrogen of approx. 0.79 bar in all bodily structures, whereby the same volume of nitrogen is inhaled with each breath and is then exhaled again as it does not have any function in terms of the body’s metabolism. Oxygen as a vital oxidation gas is metabolised by the body’s cells according to the current energy requirements of the organism. For this reason, the level of oxygen partial pressure remains unproblematic in the case of already critical nitrogen partial pressures (with the exception of inhalation of pure oxygen). In the event of increased ambient pressure, the partial pressure of the inhaled gas increases proportionately. At a new pressure level, all of the body tissue starts to become saturated with nitrogen, whereby there are considerable differences as regards the ability of various tissues to absorb nitrogen; e.g. fatty tissue dissolves five times more nitrogen than blood. The volume of nitrogen absorbed is essentially determined by pressure, time, individual biological metabolism and physical exertion. Only pressure and time enter into the calculation of decompression procedures as variables. Human tissue is capable of accepting a certain differential pressure between acquired, increased nitrogen tissue pressure and ambient pressure without displaying any symptoms (tolerated inert gas differential pressure during decompression); if this individual “internal limit value” is exceeded, there is an increasing change by the system’s status as regards nitrogen dissolved into the gas phase.

At all tissue structure levels, ranging from nerve tissue through tissue responsible for forming hormones and enzymes to the slowest metabolic tissue such as ligaments, cartilage and bones, organic problems start to arise which are grouped together under the clinical term decompression illness. Decompression illness can take a wide number of different forms and it causes varying degrees of damage necessitating swift specific medical treatment in the area of compressed air.

The limits for human exposure to overpressure are irrevocably specified via the exponential nitrogen saturation and desaturation processes taking complex biological processes (as described in simplified form above) into consideration. Variations as regards maximum diving depths or exposure to compressed air are primarily attributable to different marginal conditions of the respective exposure (temperature, climate, load, exertion, exposure medium etc.). Apart from the acute toxic effect of nitrogen (narcosis), which limits working pressures to a maximum of P_w = 3.6 bar for compressed air, the maximum working periods under overpressure are primarily determined by the long desaturation half-life values of “slow” tissue such as bones and cartilage. In particular long “basic times” in the case of repeated exposure which typically arises in the case of work performed under compressed air conditions, lead to gradual saturation on the basis of residual nitrogen from preceding exposure.

Even one-off exposure at high working pressures and a long basic time can also lead to nitrogen saturation in slow tissue which even tends towards saturation decompression in the case of decompression, i.e. necessitating overly long decompression periods with increased risks to health, including restricted mobility in the airlock.

This effect is exacerbated by the biological fact that slow tissue has significantly (exponential) swifter saturation features than desaturation features. Working pressures and working periods are therefore subject to biologically specified tight limits which may not be exceeded in the process of hyperbaric exposure using air as a gas for inhalation. These are the basic principles for the appropriate standards concerning safety and the protection of health.

2 Is it possible to generalise the experience gained in work carried out in compressed air at pressures of over 3.6 bar?

There is insufficient medical data available regarding work carried out in compressed air at pressures of over P_w = 3.6 bar. The majority of data on exposure to hyperbaric pressures in the region of P_w = 3.6 bar come from either commercial or military diving sources.

Exposure to these pressures is generally carried out with the aid of mixed gases and saturation techniques; special techniques and variable risk evaluations are employed in these projects.

Higher working pressures have been achieved in the past, and also in projects which involved a combination of diving and compressed air work. However, the experience gained in these projects is always strongly influenced by the local, technical and administrative conditions of each specific site.

All the data on working in higher pressures which have been collected to date are insufficient to provide significant insight into the technical, medical and hygienic implications of working at these pressures.

In principle, however, construction projects which comprise work at pressures in excess of P_w = 3.6 bar should be avoided. In specific cases the feasibility of these projects, and particularly the factors working safety and health protection, should be examined and verified in advance through expert reports and opinions. Due to the time and administrative input required to plan such projects, these expertises should be obtained at a very early stage in the planning process.

The authorities in charge of the project are responsible for providing a specific assessment and determining the boundary conditions, the methods which are to be used (e.g. mixed gas, saturation) and the exposure limits in projects of this type.

3 What organisational measures can be taken to reduce the physical impact of working in compressed air?

The following measures can be taken to ensure that the strain of working in compressed air remains as low as possible:
In all compressed air assignments the contractor must assure that the workers have a change of dry clothes with them to enable them to change out of damp/wet clothes before they enter the airlock. During work in compressed air and airlocking the workers must ensure that their intake of fluids is sufficiently high.

Duration of work under compressed air
The duration of work in compressed air should be significantly lower than normal if this is the worker's first deployment in compressed air, if it is the first assignment at higher pressures or if the worker has been absent from work for longer than 14 days. The exact duration shall be determined in consultation with the appointed doctor. This reduction shall apply to at least the first two assignments.

Factors which can cause additional decompression stress
A variety of factors can constitute additional decompression stress, e.g. air travel, travel over high passes, periods spent at high altitude, physical exertion and long drives. The appointed doctor shall give instructions with regard to additional measures that are required if a worker has been exposed to any of the above factors.
These measures can include: longer rest times, shorter working times and longer decompression times.

What to do in the event of decompression illness / Alert procedure for decompression illness
Before work commences in compressed air all compressed air workers must be instructed with regard to how to react in the event of decompression illness. A fixed procedure must be established. This procedure should include the following:

• Reporting system:
- Who must be alerted?
  Compressed air superintendent; fixed line number should be detailed on the compressed air badge

- What details are required?
  - Complaints and symptoms: what type, when did they start and what course have they taken?
  - When was the worker decompressed in the airlock, with or without oxygen?
  - What was the working pressure, type of job and number of preceding assignments in compressed air?
  - Where is the worker now and under which telephone number can he/she be reached?

• How will the worker be transported to the construction site (e.g. taxi, ambulance)?
• Who is responsible for alerting the appointed doctor?
• Who is responsible for alerting the operator of the medical lock?
• Who is responsible for ensuring that the medical lock is ready for operation?
• Who enters the medical lock with the patient (oxygen treatment)?
• Advance arrangements must be made with the rescue service to ensure that the worker is taken to the on-site medical lock and not to a hospital.

4 How can compliance with the ergonomic requirements of work in compressed air be ensured?

Personnel airlocks
The Work in Compressed Air Regulations specify the minimum dimensions and equipment required in airlocks used for people.

Ergonomic factors should play a role in the determining the dimensions of the airlock, the seating arrangements, the seating design and the lighting profile. The seats should be comfortable for people of different sizes and there should be sufficient leg and shoulder-room. Due to the specific physiological condition of the body during nitrogen desaturation, failure to observe basic ergonomic design factors can increase the risk of decompression-related illnesses. If local conditions do not permit the integration of an airlock designed according to ergonomic specifications in tunnel boring machines then the contractor shall ensure that an adequate number of ergonomically designed mobile personnel airlocks are available.

Transport chambers
If the personnel airlock cannot be designed to comply with ergonomic principles then transport chambers can be used to move the workers to a different airlock which fulfils ergonomic requirements, allowing them to continue decompression in this more favourable environment. This is particularly advisable if the workers have to undergo long decompression times.

Communication
Personnel airlocks and medical locks must be equipped with an acoustic monitoring system which must remained switched on at all times.
To prevent the interruption of the oxygen supply while the airlock is in operation the airlock should be equipped with breathing masks with integrated communication systems to enable the workers in the airlock to communicate with each other and the lock attendant. This will help to prevent the decompression process being terminated before it is complete.
Furthermore it is advisable to install audio systems in order to alleviate the mental strain of long decompression times.

Temperature regulation in airlocks and medical locks
The change of pressure in the airlock can cause considerable temperature fluctuations to occur. This can be avoided by ensuring that the transition from one pressure level to the next is as smooth as possible.
To protect the airlock and workers from exposure to the weather, the airlock should be encased to avoid overheating or overcooling.

The lock attendant's workplace
The lock attendant's workplace should be designed in accordance with ergonomic principles. The operator must be able to reach all the controls of the airlock or the medical lock with ease and must be able to take exact readings from all gauges as well as having visual and acoustic contact with the inside of the airlock at all times.
The operator's workplace must be equipped with a seat and it must have sufficient space to allow written documentation to be completed.

Transport of workers
After decompression workers must avoid all physical exertion, including climbing stairs (e.g. at the site) or long walks. A lift and/or suitable means of transport should be provided.

5 Why does every compressed air construction site need a medical lock?

The Work in Compressed Air Regulations stipulate that the compressed air contractor must provide a medical lock if the working pressure exceeds P_w = 0.7 bar (§ 17 Section 1 No. of the Regulations). Recompression must be provided to treat decompression-related conditions and illnesses. The provision of a medical lock at a construction site where work is being carried out

in compressed air ensures that immediate treatment can be provided in the event of decompression illness.

The availability of a medical lock at a construction site also means that it is more likely to be used by workers suffering from decompression-related symptoms, which in turn reduces the risk of complications caused by non-treatment or delayed treatment.

The medical examination of the workers shall include a compression/decompression test in the airlock in order to assess the possible health consequences of exposure to compressed air. The availability of a medical lock at the site means that tests can be performed at the required pressure without additional precautions having to be taken.

6 Why is it so important to ensure that the rest times are complied with?

Nitrogen desaturation is not completed when the worker leaves the airlock.
Complete desaturation is only attained after approx. 36 hours. As long as desaturation is incomplete there is always a risk of decompression illness occurring (caisson sickness). This risk diminishes as the nitrogen is gradually released, meaning that the risk of decompression illness occurring is greatest in the first few hours after coming out of the compressed air environment and airlock.

Recompression is necessary to treat symptoms of decompression illness. Recompression should be initiated as soon as possible at the construction site; every construction site where work is being carried out at pressures of over $P_w = 0.7$ bar must have a medical lock on site. It is essential that the workers remain at the site for the entire duration of the rest period. Failure to do this can mean the loss of valuable time should a worker suddenly display symptoms of decompression illness. Delayed treatment can cause irreversible physical harm and long-term physiological damage.

Additionally, a variety of factors outside the site can contribute to decompression illness or trigger symptoms, e.g. cramped position during long drives, air travel (because the ambient pressure is lowered), jolting while using vehicles or other means of transport (the “bubble” effect) and all forms of physical exertion. Decompression illness can also impair a patient’s ability to respond or act, e.g. driving skills.

7 What steps should be taken to prevent and fight fires in compressed air?

Fires are caused by sparks, combustible material and oxygen coming together. More oxygen means a lower ignition temperature and it increases the combustion speed. Compressed air contains a higher quantity of oxygen than air at atmospheric pressure.
The site manager must ensure that the quantity of combustible materials in the working chamber is always kept to a minimum. The site manager must establish procedures with regard to this and ensure full compliance with these procedures, e.g.:

- Regularly inspect potential fire sources, e.g. electrical systems, machines and conveyor systems, and check for any possible defects
- Ensure that the quantities of highly flammable, inflammable and combustible substances in the working chamber are kept to an absolute minimum as far as is practicable

- Ensure that easily combustible materials (e.g. wood wool) are stored in non-flammable containers
- Observe special safety warnings for cutting and welding work
- Remove all refuse immediately from the working chamber
- Establish an alert and rescue plan

As a rule, the compressed air workers will be responsible for controlling and extinguishing any incipient fires that occur in the working chamber.
In order to deal effectively with incipient fires the working chamber must be equipped with the following:

- A water supply with an adequate capacity and number of valves, fittings and hoses, to ensure that all areas of the working chamber can be reached
- Suitable fire extinguishers located wherever there is a higher risk of fire (e.g. foam or powder extinguishers approved for underground use)

Should the workers fail to extinguish the fire then the working chamber must be evacuated immediately. Complete evacuation of the working chamber has priority over all other measures. Only in very specific cases should external parties, e.g. the fire brigade, attempt to extinguish the blaze.

A fire protection plan must clearly outline rules and procedures to be followed in the event of a fire, e.g. duties and responsibilities, the alarm system, the number of people required to operate the airlock and emergency ventilation plans.

Workers must receive regular instruction and these instruction sessions should be documented. Regular emergency drills should be held.

8 What problems can occur when using “self-rescue” emergency escape self-contained breathing apparatus in compressed air?

“Self-rescue“ emergency escape self-contained breathing apparatus is personal protective equipment used to enable the wearer to exit an emergency zone as swiftly as possible.
This type of apparatus is not identical with the breathing apparatus used, for instance, by fire-fighters during rescue and fire-fighting missions. Due to the toxic nature of the gases that can occur during a fire and the reduction in the concentration of oxygen in the working chamber, it is essential that workers have access to a device which can function independently of the

surrounding atmosphere and which will isolate the wearer completely. Filter systems are not suitable for use in compressed air.

The following problems can occur if isolation devices (container devices or regeneration devices) are used:

- The breathing air throughput of emergency escape self-contained breathing apparatus increases in proportion to the working pressure. This means that the operating time of the device decreases compared to the time given for use at normal pressure. This reduces the usefulness of the device in environments with long escape routes.

- Standard oxygen self-contained breathing devices are customarily set so that the oxygen concentration in the wearer's breathing cycle reaches almost 100% shortly after the apparatus is donned.

The pressure of the breathing cycle is identical to the pressure in the working chamber P_{abs} (see preface). As oxygen can have a toxic effect at partial pressures of > 2.0 bar, such devices are not suitable for use in working pressures of P_w > 1.0 bar (equivalent to P_{abs} > 2.0 bar).

If due to the specific conditions at the site, e.g. working pressure, length of the escape route or the intensity of the blaze, an emergency self-contained breathing apparatus cannot be used then suitable "Breathing apparatus for work and escape" (as defined in Berufsgenossenschaftliche Regel 190 on the "Use of Breathing Apparatus" (German Employers' Liability Insurance Association Rules)) can also be used in an emergency. These devices can be operated with a breathing gas that has an adjusted concentration of oxygen, thus allowing the oxygen partial pressure to be reduced to a tolerable, non-toxic level.

To allow the device to be opened, all self-contained breathing apparatus used in compressed air should be equipped with an opening to enable pressure equalisation between the interior of the device and the surroundings. A device designed for use at normal pressure cannot be opened at higher pressures as the top is pressed on to the casing valve by the higher surrounding pressure.

Due to the problems outlined above it is not possible to make general recommendations.
The specific conditions of site should be taken into account when selecting self-rescue devices.

9 What procedures should be observed when using flame cutting and welding devices in compressed air?

The gases produced during flame cutting and welding can pose an even greater health hazard in compressed air than in normal atmospheric conditions. To date, no upper limits have been established for welding gases in compressed air.

To ensure the lowest possible exposure to these gases, the working chamber must be fully ventilated, as well as being equipped with a local exhaust extractor and a sufficient number of self-contained breathing devices.

The use of breath filters when carrying out such work is not recommended as breath resistance increases in higher pressures and the filter may not be designed to filter out as yet unidentified hazardous gases produced during welding and flame cutting.

The worker's personal protective gear must be made of materials that are non-flammable even in compressed air.

Note should also be taken of the regulations governing welding, e.g. in the German BGV D 1 (German Employers' Liability Insurance Association Regulations) and the TGB Data Sheet on welding.

10 What should be considered during diver deployments in compressed air projects?

During tunnel boring projects it may be necessary to employ divers as well as compressed air workers. A different set of safety regulations apply to diving work.

While the German Occupational Heath and Safety Administration is the authority responsible for issuing and overseeing compliance with the Work in Compressed Air Regulations, commercial diving operations in Germany are regulated by the relevant employer's liability insurance association, which is in charge of overseeing compliance with the accident prevention regulations for diving work (BGV C 23 (German Employers' Liability Insurance Association Regulations).

Divers employed to work, for example, in the working chamber of a tunnel boring project are regulated by the Work in Compressed Air Regulations. Additionally, the BGV C 23 regulations for divers apply for as long as the diver is immersed.

The Work in Compressed Air Regulations and the BGV C 23 regulations have different rules for the same pressure level, which can lead to conflicts.

If such work is scheduled to be carried out then it is advisable to contact the Occupational Heath and Safety Administration and the employer's liability insurance association as early as possible to ensure that an acceptable compromise can be reached with both authorities before construction work commences.

11 What duties does the compressed air contractor have with regard to the German Construction Site Health and Safety Regulations on work in compressed air?

Work in compressed air is particularly dangerous work as defined in § 2 Section 3 of the German Construction Site Health and Safety Regulations (BaustellV). As a rule, more than one compressed air worker is employed due to the nature and scope of work carried out on compressed air construction sites. If this is the case then a coordinator or supervisor must be appointed and the compressed air contractor must ensure that a Safety and Health Plan has been drawn up prior to the start of work. Additionally, full records of the assignments must be kept for future reference.

Employing a coordinator or supervisor at an early stage in the planning process for compressed air work means that suitable working methods and procedures can be selected which pose as minimal a hazard to the health of the employees as possible. It may also be

helpful to bring in external experts to assess the methods proposed. Preliminary assessment of the work to be carried out should take the following into consideration:

- Evaluation of alternative construction methods
- Collate information on potential compressed air construction methods (conventional tunnelling, caisson, machine tunnelling with slurry or compressed air, etc.) and the hazards associated with each method
- Identify and assess potential hazards at the compressed air site with regard to safety.

It is recommended that a separate module on “Compressed Air Safety” be included in the Safety and Health Plan for the site. This module should provide the companies and employees involved in the compressed air work with precise details of the measures and requirements arising from the work in compressed air.
Possible contents of the Safety and Health Plan are as follows:

• Precise definition of the compressed air work and documentation of the potential impact of this work on other areas of the construction work
• Inclusion of the medical care and emergency aid procedures for compressed air work in the overall emergency plan for the construction site
• Emergency response plan regulating all overlaps between “Emergency Medical Care” and “Compressed Air Medical Care” (e.g. an accident in compressed air in the working chamber where regular decompression in the airlock is not feasible)
• Roads and access routes which must be kept clear in the event of an emergency, including ambulance access routes
• Precedence plans for cranes and other means of transport during rescue measures
• Determination of communication and information paths
• Incorporate the requirements of the compressed air company / service provider in the site Safety Regulations
• Reference to applicable sections of the tender document.

12 What type of oxygen should be used when decompressing workers with oxygen?

Several different types of oxygen are available. In order to eliminate the health hazards posed by decontamination and traces of other gases, only medical oxygen should be used for the purposes of decompressing workers in an airlock.

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